The Impact of Load on Dynamic Versus Static Situational Knowledge While Driving

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Situation awareness (SA) was examined while driving in a driving simulator under load or no load conditions. Participants drove through two simulated maps and were periodically interrupted, the driving paused, and were asked questions regarding dynamic (i.e., moving) and static (i.e., non-moving) aspects of the environment. Participants in the load condition also had to count backwards by sevens during the drive. Results indicate that driving under load conditions leads to an overall drop in performance in processing of the dynamic elements of the scene, but no such decrement was observed for the static elements. Implications for current theories of SA and applied attention, as well as the potential relevance to understanding impaired driving performance from cell phone use, are discussed.

INTRODUCTION

When driving a car, one must monitor several factors: speed, direction, and the other drivers around us. Keeping track of this information helps us to avoid accidents and other undesirable events such as getting a speeding ticket. The process involved in monitoring our surroundings to better aid decisions in dynamic, changing environments is called situation awareness (SA). This paper will focus on the dynamic aspects of SA, particularly how dynamic knowledge of our surroundings is impacted by an attentionally demanding load.

Situation Awareness and Driving

Generally, SA is the understanding of the dynamic events happening in the environment. More specifically, Endsley (1995; Endsley, 2000; Endsley, Bolté, & Jones, 2003) has defined SA as having three levels (though see Sarter & Woods, 1991 for a different view on SA as well as criticisms of the concept). These levels are “Level 1: perception of the elements in the environment; Level 2: comprehension of the current situation; and Level 3: projection of future status” (Endsley et al., 2003, p. 14).

While SA is not synonymous with performance (Parasuraman, Sheridan, & Wickens, 2008), it does have a large impact on performance. A breakdown at any of the three levels of SA can lead to poor and sometimes catastrophic decisions. For example, studies looking at aviation and air traffic control databases have indicated that the loss of SA is one of the most common reasons for performance failure and can have fatal consequences (Durso, Truitt, Hackworth, Crutchfield, & Manning, 1998; Jones & Endsley, 1996). Jones and Endsley showed that the majority of SA errors are Level 1 errors, such that people do not perceive, or misperceive, a problem in the environment. These studies suggest that SA plays an important role in human error and that these errors can be tied to failures of attention (i.e., Level 1 errors) and, to a lesser extent, failures of memory (i.e., Levels 2 or 3 errors).

Research on SA has primarily focused on SA for dynamic information. The domain with the most research examining SA is aviation (for an overview see Wickens, 2002a). However, SA has also been examined in a variety of domains with dynamic (i.e., changing) environments such as air traffic control (e.g., Gronlund, Ohrt, Dougherty, Perry, & Manning, 1998; Mogford, 1997; Shorrock, 2005), medicine (e.g., Drews & Westenskow, 2006; Gaba, Howard, & Small, 1995), and military operations (e.g., Artman, 1999, 2000).

One domain that has received less attention in the SA literature is driving. Driving is also a dynamic task in which the driver must constantly update the surroundings and where variables change over time (Ma & Kaber, 2005). While theories of SA in driving do exist (Gugerty & Tirre, 2000), there is little empirical evidence to support those theories and an operational definition of SA in the context of driving has not been established (Ma & Kaber, 2005). Much of the current literature on SA and driving focuses on the implementation of automated systems, such as adaptive cruise control, and how they affect performance (Ma & Kaber, 2005; but see Gugerty, 1997; Gugerty, 1998; Gugerty & Tirre, 2000 for some exceptions).

In this paper we propose that one useful way to explore SA while driving is by focusing on the role of dynamic (i.e., moving) versus static (i.e., non-moving) elements of the environment.

Load and Driving

There is substantial evidence showing that conversing on a cell phone while driving (i.e., driving with a load) significantly impairs driving ability (e.g., Caird, Willness, Steel, & Scialfa, 2008; Drews, Pasupathi, & Strayer, 2008; Horrey & Wickens, 2006; Rakauskas, Gugerty, & Ward, 2004; Redelmeier & Tibshirani, 1997; Strayer & Drews, 2007; Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001). However, as Drews and colleagues (2008) point out, much of the prior work on the impact of cell phone use while driving has focused on assessing the level of impairment and not on the cognitive mechanisms underlying the impairment, though recent research has started to examine these mechanisms.

For example, Strayer and Drews (2007) argue that cell-phone use while driving leads to inattentional blindness (the failure to notice something in the environment; Wickens & McCarley, 2008). In their research, they have shown that even though drivers look at various objects in a driving environment (as measured by eye movements), they often do not recognize them on later recognition memory tests. Thus, drivers fail to construct an accurate mental model of the driving environment, leading to poor SA. They suggest that this inattentional blindness is due to poor allocation of attention while dual-tasking. Additionally, this interference between driving and cell-phone use may be due to limited general resources, or a central attentional bottleneck (Strayer & Drews, 2007).

Current Experiment

Previous research has shown that driving performance is impaired under dual task conditions and has suggested that impoverished SA may be implicated. Thus far, research has not yet demonstrated the exact nature of this deficit. Some remaining questions then are what cognitive mechanisms underlie driving performance and SA, can they be broken down into more specific sub-levels, and are they equally affected by load? Additionally, further examining different types of situational knowledge may help to dissociate specific SA deficits in knowledge from more generic memory deficits.

The current experiment addressed these remaining questions by examining memory for dynamic versus static elements of a driving scene under load and no load conditions to further examine the relationship between attention and SA, as well as if all types of situational knowledge are impacted by an attentionally demanding secondary task. While it can be difficult to distinguish between dynamic and static elements in a complex driving environment, it was expected that driving under load conditions would differentially impact dynamic versus static knowledge.

METHOD

Participants and Design

Thirty-three Colorado State University undergraduate students (mean age = 19; 20 males, 13 females) with driving licenses participated for partial course credit in an introductory psychology course. Participants were randomly assigned to the load (n = 16) and no load conditions (n = 17). Five participants did not complete the experiment due to motion sickness or technical difficulties, leaving a total of 28 participants (16 in no load, 12 in load).

Load while driving and question type were manipulated in a mixed design. Load was manipulated between-subjects and question type was manipulated within-subjects. In the load condition, participants were asked to count backwards by sevens, whereas no counting was required in the no load condition.

Two types of questions were asked, dynamic and static questions. Dynamic questions related to aspects of the driving environment that could move within the driving environment, such as location of surrounding cars (e.g., "Is there a car behind you?") or movements of other cars (e.g., "What vehicles have passed you since your last turn?"). Static questions related to aspects of the environment that could not move (i.e., items with fixed allocentric coordinates), such as most recent posted speed limit, landmarks passed (e.g., "What was the first building you passed on the right?").

Apparatus

A fixed platform driving simulator (DS-600c) was used in this experiment, providing a 180° simulated field of view from the front half of a Ford Focus. The simulator also included side and rear view mirrors, force-feedback steering, and an immersive audio environment.

Two environments simulating approximately 20 minutes of driving in sunny conditions with dry pavement and intermittent oncoming traffic were generated. At intersections, directions indicating which way to turn appeared in green letters in the frontal field of view, overlaying but not obstructing the driving environment. No randomly generated traffic or random events of any nature were utilized.

Procedure

Participants completed two driving sessions. The first session lasted approximately 15 minutes the day prior to the experimental drive and was intended to acclimate participants to the driving simulator and to screen participants for motion sickness. During this time, participants drove two short routes. The first route was a straight drive, and the second route included left and right turns.

During the experimental session, participants drove two separate routes, the order of which was counterbalanced. Participants were instructed to follow onscreen directions at intersections indicating whether a turn was necessary and/or which direction to turn. The instructions and the route for each map were identical across conditions.

In the load condition, a three-digit number was presented on the center of the center screen approximately every 30 s. The number was presented in green and overlaid the driving scene. Instructions were given to count backward by sevens aloud until a new three-digit number was presented and then to start the process again with the new number. An experimenter was present during the drive to enforce the counting as well as to ensure that participants followed the directions.

In both conditions, three pauses were presented in each route in which the experimenter orally asked questions about the current driving situation. During these pauses, the environment was obscured with solid blue for two minutes. The experimenter asked three questions per pause (for a total of nine questions per route) about the current driving environment with the question types (i.e., dynamic vs. static) in a fixed random order and an equal number of questions for each type. The participants responded with one to two word short answers and the experimenter recorded those answers while the participant remained in the simulator. For example, the experimenter would ask "What was the most recent sign you passed?" with the participant responding "Deer Crossing."

Participants were advised of the pauses and questions before beginning the drive and told to answer the questions to the best of their ability. The final pause in each route was positioned at the end of the drive.

RESULTS

All analyses were significant at the .05 level unless otherwise noted. Questions from the SA questionnaire were divided into dynamic and static questions, scored for accuracy, and then averaged across both maps.

Mean accuracy on the SA questionnaire was analyzed in a 2 (load condition: load vs. no load) x 2 (question type: dynamic vs. static) mixed analysis of variance (ANOVA). A significant main effect of load was found [$F(1, 26) = 9.42$, $MSE = .02$, $\eta^2 = .27$], with the no load condition [$M = .67$, $SD = .10$] being significantly more accurate than the load [$M = .55$, $SD = .10$] condition. The main effect of question type also reached significance [$F(1, 26) = 14.22$, $MSE = .01$, $\eta^2 = .35$], with the static questions [$M = .67$, $SD = .13$] being significantly more accurate than the dynamic questions [$M = .57$, $SD = .16$]. There was a significant Load x Question Type interaction [$F(1, 26) = 9.05$, $MSE = .01$, $\eta^2 = .26$]. Refer to Figure 1 for a graph of these effects.

To further examine the load x question type interaction, independent samples t-tests were conducted between load and no load conditions for the two question type conditions. There was a significant difference between load and no load conditions for dynamic questions [$t(26) = 4.55$] but not for the static questions [$t(26) = .46$, $p > .05$] showing memory for dynamic items declined as load increased.

To ensure that these effects are not due simply to greater difficulty of the dynamic questions, a paired-samples t-test was conducted in the no load condition between dynamic and static questions. The difference was not significant [$t(15) = -.64$, $p > .05$], suggesting that dynamic questions were not inherently more difficult than the static questions.

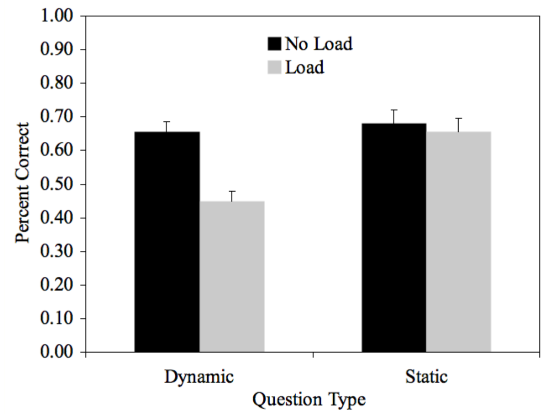

Figure 1. Percent correct on SA questionnaire as a function of question type and load condition. Error bars represent one standard error.

DISCUSSION

This experiment examined the nature of SA while driving, as well as how SA is impacted by an attentionally demanding load. The present results demonstrate degraded SA in driving when under attentionally demanding load. However, they also suggest making distinctions between different types of situational knowledge (specifically, dynamic versus non-dynamic elements of the scene). When general attention resources are used up, significant impairment is observed for the dynamic, but not static, aspects of the environment.

These data have implications for current theories of SA, and particularly offer some potential discriminant validity between basic memory phenomena and SA. As highlighted in the Introduction, theories of SA typically focus on the evolving representation of dynamic elements within a situation. The current experiment supports the link between dynamic knowledge and SA by showing evidence for selective impairment of the dynamic elements coupled with preserved memory for the non-dynamic elements. We note that the operational definition of "dynamic" employed here is limited to only one possible sense of that term – items in motion themselves. It remains a question for future research whether unique decrements in performance are present for these items, or whether other types of SA relevant information are similarly impacted. Additionally, the distinction between dynamic and static may relate to a third variable not examined in the current experiment, such as differences in bandwidth.

This research is also in line with current theories on the mechanisms underlying cell phone related driving impairments. Strayer and Drews (2007) suggest that one possible theoretical explanation for the impairment in driving while conversing on a cell phone could be due to a central attentional bottleneck (or limited general attentional resources;

e.g., Wickens, 2002b) in which performing two complex tasks, despite being in different modalities, can lead to performance decrements in one or both of the tasks. These data are compatible with this view; when participants were given a demanding attentional load, their awareness of dynamic events in the environment was reduced. However, these data offer an important caveat to the idea, implying that not all information suffers equivalent impairment.

One final implication of these findings relates to drivers' own awareness of decrements occurring from cell phone use. The current experiment suggests that drivers may be misled when attempting to monitor their performance. Unchanging portions of their environment might seem to offer an external, reliable standard for drivers to index their memory against at any time, and hence infer whether their cell phone usage is impairing their driving. In contrast, dynamic elements, critical for SA and linked to many types of catastrophic errors, are by their very nature temporary states of the environment. Their fleeting nature means that drivers have few opportunities to subsequently recognize what they have failed to register, yet it appears to be on this type of information for which significant decrements in performance occur.

Further research in this area can help to distinguish between different cognitive mechanisms that underlie complex performance and determine how they are impacted by various types of distractions or loads.

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