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THE EFFECTS OF CONVERSATION ON WORKING MEMORY AND SITUATION
AWARENESS IN SIMULATED DRIVING

by
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A thesis submitted to
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in partial fulfillment of the requirements for the degree of

Master of Arts

in

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ABSTRACT

Although there is empirical evidence that conversation impairs driving performance, the cognitive mechanisms that mediate this relationship remain underspecified. One possibility is that conversation impairs driving by reducing a driver's situation awareness (SA). Johannsdottir and Herdman (2010) reported that a phonological working memory task decreased driver SA for vehicles located behind them while a visuospatial task impaired SA for vehicles ahead. It was hypothesized here that because conversation taxes the phonological loop, SA would be reduced for cars behind the driver. Participants completed 20 trials in a medium-fidelity driving simulator. The screens were blanked 40 – 60 s into each trial and participants estimated the positions of other vehicles. The driving impairments caused by conversation (e.g., SA for location of other vehicles) were greater for vehicles located behind the driver than for those in front. These findings suggest that conversation impairs drivers' SA by taxing working memory's phonological loop.

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The Effects of Conversation on Working Memory and Situation Awareness in Simulated Driving

Recent proliferation in the use of cell phones has inspired a substantial amount of research on how cell phone conversation affects driving performance. Not surprisingly, cell phone conversations have been shown to impair driving performance and increase the likelihood of having a collision compared to when not conversing (e.g., Horrey & Wickens, 2006; Kass, Cole, & Stanny, 2007). Various legal measures across North America have attempted to address this problem by prohibiting drivers from using cell phones but these restrictions tend to target only handheld devices. As such, these laws imply that cell phone-induced driving impairment is primarily caused by the physical manipulation of a cell phone rather than by the cognitive effects of engaging in conversation. Research shows that this is not the case.

Most attempts at explaining how conversation causes driving impairment have focused on attentional processing (Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001). Comparatively, situation awareness (SA) has received relatively little attention in the driving literature and may provide valuable insight into the nature of conversation-induced driving impairment. SA is frequently defined as the understanding of what is going on around oneself (Endsley, 1995a, 1995b, 2000) and conversation has been found to reduce drivers' SA (Gugerty, Rakauskas, & Brooks, 2004; Kass et al., 2007; Ma & Kaber, 2005). Furthermore, poor SA has been correlated with poor driving performance (Gugerty, 1997; Kass et al., 2007). These findings suggest that the impairments in driving performance caused by conversations may be related to reductions in drivers' SA.

One possibility for how conversation impairs SA is through conversation's effects on working memory. Johannsdottir and Herdman (2010) provided initial support for this theory by showing that taxing working memory's subsystems (i.e., the phonological loop and the visuospatial sketchpad) impacts drivers' SA in a predictable manner. Based on their results, Johannsdottir and Herdman concluded that a relationship exists between SA and working memory. With this finding in mind, the specific goal of this thesis is to examine how working memory mediates conversation-induced SA impairment in drivers.

Situation Awareness (SA)

Research on SA first gained prominence in the field of aviation psychology where creating user interfaces that foster good SA is considered an essential component of an aircraft's design (Endsley, Bolté, & Jones, 2003). In fact, many aviation errors and accidents have been attributed to pilots having poor SA of their flying environment, such as the status and location of their own aircraft, the location of other aircraft in their environment, and current weather conditions (Endsley, 1995a).

SA is conceptualized as having three distinct levels: perception (level 1), comprehension (level 2), and projection (level 3); and each of these levels utilizes different mental resources (Endsley, 2000; Endsley et al., 2003). With respect to driving, SA is formed by first perceiving visual and auditory information acquired from the surrounding driving environment (level 1) and then comprehending this sensory input in such a way that the driver can form accurate and cohesive mental representations of their surroundings (level 2). With an adequate mental representation, the driver can then anticipate how events in their surroundings will likely unfold (e.g., where cars will be in the future) and can alter their current driving behaviour based on these projections (level

3). For these reasons, effective SA is critical for many driving behaviours, including monitoring and updating the positions of other vehicles, navigating busy roadways, monitoring road conditions, and maintaining proper speed.

This emphasis on the awareness of past, present, and future factors has also been stressed by Durso, Hackworth, Truitt, Crutchfield, Nikolic, and Manning (1997). They argued that SA is the understanding of dynamic environments and is affected by one's own goals and motivations. Also, like Endsley, Durso et al. differentiated between SA of present and future states and emphasized the importance of predicting events based on current SA. Because SA is dynamic and complex, Durso et al. argued that it might be more useful to define SA in terms of operational definitions using validated SA measures. For example, Durso et al. asked air traffic controllers to perform a simulated air traffic controller task and found that SA measures of both the present and the future were predictive of their performance. Furthermore, better SA of the present was associated with decreased SA of the future and vice versa, suggesting that focusing on one level of SA had a deleterious effect on the other. However, although these SA measures appear to correlate with performance, Durso et al. admitted that it is difficult to ascertain whether these measures are truly indexing SA or some other cognitive resource required to perform the task.

According to Adams, Tenney, and Pew (1995), SA is the constantly updating awareness of one's own environment. This awareness allows one to predict future events based on current environmental cues and guides behaviour based on this knowledge. Drawing from the work of Neisser (1976), Adams et al. (1995) suggested that situations activate specific schemas that alter the way we perceive the environment. SA is therefore

shaped by one's interpretation of the information they acquire, but is also shaped by their expectations. Smith and Hancock (1995) also emphasized that SA is tempered by one's goals in an environment. Smith and Hancock defined SA as an externally guided consciousness, which they described as an interface between one's consciousness and the external environment. Dekker, Hummerdal and Smith (2010) similarly equated SA with consciousness, but have criticized current SA research for overlooking the ontological questions of SA. According to Dekker et al., SA researchers are too focused on operationalizing SA with query and recall methods and, by doing so, overlook the dynamics and complexity of SA.

Though there is no universally accepted definition, Durso and Sethumadhavan (2008) argued that current research on SA could be divided into two streams: process and product. Research in the process stream is most concerned with the underlying cognitive processes involved in forming SA. Alternatively, the product stream focuses on the finished product of SA, that is, the awareness that emerges from the interaction between all necessary cognitive processes. Adams et al. (1995) have also made this distinction by arguing that SA can be envisioned as both a product of several sub-processes and as a process that is being constantly updated. The present thesis is important as it combines aspects from both these streams by examining both drivers' SA (as a finished product) and the processes (i.e., working memory) through which SA is formed.

Working Memory & SA: Top-down vs. Bottom-up Processes

Working memory is a short-term information storage system that is commonly described in terms of a multi-component model that includes a central executive, phonological loop, and visuospatial sketchpad (Baddeley & Hitch, 1974), as well as an

episodic buffer (Baddeley, 2000). The phonological loop and visuospatial sketchpad act as separate storage subsystems for information that can be accessed by the central executive. The phonological loop acts as a temporary storage area for verbal information (whether articulated internally or aloud) and the visuospatial sketchpad serves as a cache for visual information derived either from the external environment via the senses or from imagery stored in long-term memory. The central executive actively exerts control over other cognitive processes (e.g., motor processes) by allocating attentional resources and initiating behaviour. The most recent addition to Baddeley's working memory model, the episodic buffer, acts as a short-term storage system that holds information from the visuospatial sketchpad and phonological loop where it can then be combined into one unified representation (Baddeley, 2000).

SA involves the input of perceptual information from the external environment (bottom-up processing) and the corresponding activation of associated representations in long-term memory (top-down processing) being integrated and unified within working memory (Adams et al., 1995; Endsley et al., 2003). This interaction between top-down and bottom-up processes in working memory has been investigated in many neuroimaging studies. For instance, Friedman and Goldman-Rakic (1994) imaged the brains of monkeys while they performed working memory tasks and reported that both hippocampal and prefrontal areas were activated during these tasks. They also reported that parietal regions responsible for transmitting visuospatial information to the dorsolateral prefrontal cortex (DLPFC) were activated while these tasks were being performed. Similarly, Chafee and Goldman-Rakic (2000) found evidence for both prefrontal and parietal activation in monkeys when they performed working memory

tasks. Based on their results, Chafee and Goldman-Rakic argued that connections between frontal and parietal areas of the brain are necessary to produce the sustained firing of neurons required to maintain information in working memory.

Evidence implicating frontal and parietal activation during working memory tasks has also been established in humans. Olesen, Westerberg, and Klingberg (2004) trained participants on a variety of working memory tasks over a five-week period. When comparing fMRI data collected prior to training with data obtained after, they found increased activation in the middle frontal gyrus of the frontal lobe as well as the superior and inferior parietal cortices following training. Similarly, Townsend, Bookheimer, Foland-Ross, Sugar, & Altshuler, (2010) analyzed patients with bipolar disorder (who are known to have working memory impairments even while euthymic) with fMRI and found they displayed significantly less activation in the DLPFC and in posterior parietal areas while performing an N-back test than healthy controls. Decreased connectivity between these two brain areas has also been found in dyslexics, who are known to have deficits in verbal working memory (Wolf, Sambataro, Lohr, Steinbrink, Martin, & Vasic, 2010)

According to Kastner and Ungerleider (2000), working memory and visuospatial attention processes require this interaction between parietal and prefrontal areas, and consequently this interaction creates the visual representation we form of the external world. This representation of reality that emerges from the connectivity between top-down and bottom-up processes in working memory may be SA.

The Episodic Buffer & SA

If Baddeley's (2000) theory of an episodic buffer is correct, then the information processed by the visuospatial and phonological pathways must be integrated at some

point. In their review of the literature, Buckner, Logan, Donaldson, and Wheeler (2000) contended that episodic memory encoding is dependent upon communication between frontal and medial temporal areas of the brain. They argued that the binding of information takes place in temporal regions and that frontal areas exert top-down influence over this process. In fact, Buckner et al. suggested that activation of left frontal areas is related to whether or not a memory is successfully encoded (i.e., greater activation) or dooming the memory to be forgotten (i.e., less activation). This interaction between top-down executive control and automatic informational binding might be analogous to the function of the episodic buffer, as described by Baddeley (2000).

Berlingeri et al. (2008), for instance, used fMRI to image the brains of patients with Alzheimer's disease (AD) while having them complete both immediate and delayed recall tasks (designed to require the episodic buffer), as well as tasks designed to assess executive function. Berlingeri et al. hypothesized that patients with AD would exhibit impaired recall due to episodic buffer impairment. They reported that although those with AD demonstrated impaired performance on both recall tasks, their performance on executive functioning tasks did not differ from that of healthy controls. Furthermore, the fMRI data they obtained showed no difference between controls and participants with AD in terms of frontal lobe activation but participants with AD did show significant deactivation in the left anterior hippocampus. Based on their results, Berlingeri et al. theorized that the episodic buffer may be separate from executive functioning and that the left anterior hippocampus may serve as the neural substrate for the episodic buffer.

As the episodic buffer is responsible for integrating disparate pieces of information into a cohesive whole, it may be analogous to SA in that SA represents the product of this

integration. Working memory and SA have been shown to be intimately linked (Endsley, 2001; Gugerty, 1997; Johannsdottir & Herdman, 2010), thus Baddeley's (2000) inclusion of a multi-modal buffer may yield a cognitive model with a richer theoretical base than those offered to date (i.e., Adams et al., 1995; Endsley, 1995a). For instance, executive control is required to maintain information within the episodic buffer (Baddeley, 2000) and so taxing executive functioning may also affect SA. Baumann, Petzold, Groenewoud, Hogema, and Krems (2008) had participants drive in a driving simulator while performing executive functioning tasks (i.e., an auditory monitoring task or a running memory task) and found that these tasks impaired driving performance in terms of collision avoidance. Baumann et al. contended that this impaired collision avoidance was due to SA impairments (specifically predicting future events) caused by a reduction in available executive functioning resources. If SA can indeed be equated with the output of the episodic buffer, taxing executive functioning could be therefore one potential explanation for decreased in SA.

SA, Working Memory, & Driving

Even brief lapses in SA while operating an automobile can have potentially serious consequences given the rate at which information can change in a driving environment. Compared to its popularity in aviation psychology though, SA has received relatively little attention in the driving literature. This is especially surprising given that the limited research on this topic suggests that SA is highly correlated with driving performance (Gugerty, 1997; Kass et al., 2007). In complex tasks such as driving, decreases in all levels of SA are generally observed when cognitive demands become overwhelming (Adams et al., 1995; Endsley, 2000; Endsley et al., 2003).

In one of the few studies on SA and driving, Jackson, Chapman, and Crundall (2009) reported that experienced drivers typically have better SA while driving (i.e., better detection and identification of driving hazards) than novice drivers. The authors concluded that experience might improve the processing efficiency of driving-related information, thus freeing up cognitive resources that can be allocated to the formation and maintenance of SA. Similarly, Walker, Stanton, Kazi, Salmon, and Jenkins (2009) reported that advanced driver training increased both SA and positive driving behaviours (e.g., speed and lane maintenance), possibly through the development of behavioural and cognitive heuristics that allowed more information to be processed in working memory. Gugerty (1997) examined the link between SA and driving performance by having participants engage in simulated driving and then answer a variety of SA probes. Gugerty reported that participants who had higher SA scores were better at avoiding crashes and concluded that greater SA may be linked with better driving performance.

It is possible that cognitive processes like working memory mediate the driving impairment caused by reduced SA. According to Endsley (2001), working memory capacity posits a major ‘bottleneck’ for SA because there are a finite amount of cognitive resources that can be allocated to forming and sustaining SA. Gugerty (1997) provided empirical evidence supporting Endsley’s claim by showing that drivers’ SA for other vehicles decreased with increased working memory load. Other researchers have found that simulated driving impairs performance on working memory tasks (Radeborg, Briem, & Hedman, 1999) and that working memory tasks impair driving performance (Briem & Hedman, 1995; Oron-Gilad, Ronen, & Shinar, 2008).

Oron-Gilad et al. (2008) reported that when participants were asked to complete a working memory task while driving in a simulator, their average driving speed decreased. They concluded that this reduction in speed might have been compensatory in nature since less cognitive resources were available to allocate to driving. Similarly, Strayer and Drews (2007) reported that certain brain activity elicited by visual probes (thought to index working memory processing) was attenuated in drivers who were talking on the phone compared to when they were not. They also found that this brain activity was negatively correlated with driving performance. Furthermore, Guerrier, Manivannan, and Nair (1999) found that working memory capacity was the strongest predictor of elderly women's performance on a simulated left-turn task (i.e., turning left through oncoming traffic at an intersection) and Gugerty and Tirre (2000) reported that working memory capacity (measured using a cognitive test battery) was a strong predictor of response times to visual probes while concurrently engaged in driving. These results all support the claim that safe driving requires working memory and that taxing working memory impairs driving performance by drawing resources away from driving.

Effects of Conversation on Driving

Researchers have repeatedly found that both hands-free and handheld phone conversations impair driving performance (Consiglio, Driscoll, Witte, & Berg, 2003; Harbluk, Noy, Trbovich, & Eizenman, 2007; Horrey & Wickens, 2006; Ishigami & Klein, 2009; Kass et al., 2007; Rakauskas, Gugerty, & Ward, 2004; Strayer et al., 2003; Strayer & Johnston, 2001). Kass et al. (2007), for example, had participants engage in simulated driving while either talking on a hands-free cell phone or not talking. They found that participants who were talking were more likely to collide with vehicles and

pedestrians, were more likely to drive through stop signs, and had greater difficulty maintaining speed than those not talking. Furthermore, these cell phone-induced impairments were not contingent upon participants' level of driving experience.

Rakauskas et al. (2004) also reported that participants had greater difficulty maintaining a constant speed in a driving simulator when conversing over a hands-free cell phone. They noted that participants drove more slowly while conversing regardless of the difficulty level of the conversation.

An important debate that has emerged in the driving literature is the distinction between cell phone conversations and conversations with passengers. Some researchers have argued that cell phone conversations have a larger negative impact on driving performance than passenger conversations, whereas others have found no difference. One of the most common arguments in favour of passenger conversations being safer than cell phone conversations is that passengers modulate their conversations in accordance with the external driving environment (McKnight & McKnight, 1993). For example, passengers may slow down the pace of the conversation when driving becomes more difficult or make references to the external environment for the benefit of the driver. Empirical support of this was provided by Drews, Pasupathi, and Strayer (2008) who had participants drive in a high-fidelity simulator while conversing with either a passenger or with a confederate over a cell phone. Conversations between passengers and drivers were found to involve more references to the driving environment than when drivers were conversing with someone over a cell phone. Cell phone conversations were also associated with increased following distances and poorer lane maintenance and

navigation, suggesting that cell phone conversations impair driving performance on certain tasks more than passenger conversations.

In contrast, Gugerty et al. (2004) found that passengers did not refer to the external environment significantly more than people speaking with the driver over a cell phone; nor did passenger conversations differ from cell phone conversations in terms of crash avoidance. Furthermore, Amado and Ulupinar (2005) reported no difference between participants who conversed with passengers and those who conversed over a hands-free cell phone with respect to performance on a peripheral detection task. In their meta-analyses of the driving literature, Horrey and Wickens (2006) reported that passenger and cell phone conversations did not differ with respect to the associated driving impairments. Because of the conflicting findings in this area of the driving literature, it remains unclear whether passenger and cell phone conversations impair driving to the same extent. However, there appears to be consensus that both types of conversation impair driving performance.

One explanation for how conversation may cause driving impairments is that conversing affects visual scanning patterns. McCarley, Vais, Pringle, Kramer, Irwin, and Strayer (2004) found that conversation impaired the ability to detect changes in the driving environment and reduced the length of time that drivers fixated on targets in a driving scene. They also reported that conversation impaired concurrent change detection of these targets. Recarte and Nunes (2003) found that driving performance in an on-road experiment was more impaired when drivers performed generative mental tasks that were similar to the task demands of conversation (e.g., verbal production tasks where participants tell a story in their own words) than when they performed acquisition-type

mental tasks (e.g., attending to verbal stimuli). Specifically, they found that participants were less likely to glance down at their speedometer or at their rear-view mirrors, detected significantly fewer visual probes, relied more on their peripheral vision to detect targets, and displayed less variability in their visual search patterns when performing generative mental tasks.

More recently, Harbluk et al. (2007) tested participants in an on-road experiment in which they drove a prescribed route under three different task conditions: easy math task, difficult math task, and no task. The two math task conditions were performed verbally with a researcher in a remote location by conversing over a hands-free phone. Harbluk et al. reported that drivers spent more time fixating centrally and less time fixating on peripheral locations (e.g., instrumentation, mirrors, upcoming traffic signals, and areas around intersections) in the difficult math task condition than in the other conditions.

Reaction times to external events are also adversely affected by conversation. Harbluk et al. (2007), for instance, reported that the participants in an on-road experiment were significantly more likely to brake heavily when performing a difficult math task than when not performing a task. They argued that the heavier attentional demands of the difficult math task caused delayed braking onset by reallocating attentional resources away from the driving task. In accordance with this finding, Horrey and Wickens (2006) reported that one of the most profound driving impairments associated with cell phone conversations was slowed reaction times to potentially critical traffic events.

Further evidence that conversation delays responses to traffic events was demonstrated by Strayer and Johnston (2001) who had participants perform a pursuit-tracking task while speaking with a confederate over either a hands-free or handheld

phone. Participants conversed with confederates using a natural conversation technique where the participant was asked to discuss a preselected topic. They reported that reaction times to traffic signals were delayed and that the probability of missing them altogether more than doubled when participants were conversing over a phone compared to a control group that listened to the radio. This finding suggests that the passive encoding of verbal stimuli alone is not enough to produce the same degree of impairments caused by conversation. Strayer and Johnston also reported no difference between the hands-free or handheld phone groups with respect to reaction times and the probability of missing traffic signals, indicating that cell phone-induced impairments were not simply due to physically holding the phone.

To address the fact that some participants in the radio control group had not been actively listening to the radio, Strayer and Johnston (2001) conducted a subsequent experiment in which participants in the control condition listened to an audio book rather than the radio. Only those who passed a subsequent comprehension test on the contents of the audio book were included in final analyses. Again, Strayer and Johnston found that the control group was not impaired in terms of driving performance (i.e., either reaction time or probability of missing traffic signals) compared to participants who were conversing. Interestingly, they also found that participants required significantly more time to respond to traffic signals when they were speaking during the conversation task compared to when they were listening. This finding suggests that acquisition-type tasks impair performance on tasks related to driving more than generative-type tasks. This has been supported by McCarley et al. (2004) who found that being actively engaged in

conversation impaired change detection performance, whereas simply listening to a conversation did not.

Another theory of how conversation causes driving impairments is that conversation diverts attention away from processing information (even if it is at fovea) in a process called *inattention blindness* (see Mack & Rock, 1998). For instance, Strayer et al. (2003) had participants engage in simulated driving either while conversing with a confederate over a hands-free phone using natural conversation (dual-task condition) or while not conversing (single-task condition). Participants were given a surprise recall task at the end of the experiment regarding the billboards that had been present in the driving environment. Strayer et al. found that fewer billboards were recalled in the dual-task condition than in the single-task condition. In a separate experiment, the possibility that participants had simply not spent as much time looking at the billboards in the dual-task condition compared to the single-task condition was addressed. Strayer et al. tracked participants' eye movements as they drove through the same simulated driving environment and found that participants in the dual-task condition still recalled fewer billboards even though they did not differ from those in the single-task condition in terms of the number of billboards they fixated on. Furthermore, a supplementary analysis was performed to assess recall probability for only the billboards that were fixated on. Even when fixated on, fewer billboards were recalled in the dual-task condition than in the single-task condition. That is, conversation caused participants to be 'inattentionally blind' to some of the billboards. These results suggest that the attentional system may be taxed by conversation, leaving fewer resources to be allocated to processing visual information.

Conversation & SA

While many researchers have sought to explain conversation-induced driving impairments in terms of attentional processing (e.g., Strayer et al., 2003; Strayer & Johnston, 2001), relatively few have investigated how conversation impacts SA. As Ma and Kaber (2005) point out though, driving impairments caused by conversing might occur because conversation impairs SA. To test this, Ma and Kaber had participants drive in a medium-fidelity simulator where they were asked to follow a lead car while either talking on a handheld cell phone or not conversing. The conversation task involved answering a series of arithmetic questions asked by a researcher over the phone. The simulation was paused randomly throughout the experiment, at which point the participants were asked a series of SA queries. Ma and Kaber reported that those in the cell phone condition responded correctly to significantly fewer SA queries than those who did not converse, hence indicating that conversation reduces SA. Interestingly, these results applied only to levels 2 and 3 of SA. Thus, conversation may only interfere with SA that requires higher-order cognitive processing (i.e., comprehension and projection).

Kass et al. (2007) performed a similar experiment where experienced and inexperienced drivers either conversed using a hands-free phone or did not converse while engaging in simulated driving. The simulation was randomly paused to administer SA questions. Experienced drivers had more correct responses to SA queries than inexperienced drivers. Conversation was also found to impair SA, as conversing drivers responded to significantly fewer SA queries than drivers who were not conversing. Kass et al. noted that the magnitude of this conversation-induced impairment did not differ as a

function of driving experience (i.e., no interaction between conversation condition and level of experience).

Gugerty et al. (2004) also investigated the effect of conversation on SA. Conversation was operationalized using a last-letter task where drivers were required to generate a word that began with the last letter of a word provided by another participant (a task that the researchers admit may be much simpler than real conversation). Gugerty et al. randomly paused the simulation and queried participants about their SA of the driving environment and found that participants in the conversation condition recalled fewer cars and answered fewer SA probes successfully compared to those in the no conversation condition. In a second experiment, Gugerty et al. increased the difficulty of the verbal conversation task by increasing the rate at which the driver had to perform the task. Again, they found that participants in the conversation condition answered fewer SA probes successfully than those in the no conversation condition and that conversation was also related to reduced crash avoidance. These results indicate that, even with a relatively simple verbal task, conversation impairs a driver's SA.

Conversation, SA, & Working Memory Subsystems

Research in the field of aviation psychology has indicated that the visuospatial sketchpad and the phonological loop contribute differentially to a pilot's SA (see Aretz, 1991). This has been supported by a recent experiment from the driving literature. Johannsdottir and Herdman (2010) found that both the visuospatial sketchpad and the phonological loop are required to maintain SA for the locations of other vehicles. These authors had participants engage in simulated driving while concurrently performing either a phonological loop-loading task (consonant-vowel-consonant rhyming) or a visuospatial

sketchpad-loading task (finger tapping in a pattern) and found that the phonological loop-loading task selectively decreased drivers' SA for vehicles behind them while the visuospatial sketchpad-loading task selectively decreased SA for vehicles in front of them. The authors concluded that, without a constant visual representation of cars behind the driver beyond that obtained by occasionally checking rear-view mirrors, SA for vehicles behind the driver might be stored in phonological, verbal-based memory. SA for vehicles ahead of the driver, on the other hand, might be better conceptualized as being stored in visuospatial memory because drivers have a constant representation of these vehicles available through their front windshield. Given that conversation presumably taxes the phonological loop, the effects of conversation on working memory may provide a theoretical mechanism for how conversation impairs SA.

Defining SA

One of the problems with studying SA is that it is difficult to develop a valid and reliable measure because SA is inherently an internal representation. For example, asking participants to provide a subjective rating of their own SA is vulnerable to memory errors and subjectivity (Jones & Endsley, 2004). A more objective alternative is the Situation Awareness Global Assessment Technique (SAGAT), which involves 'freezing' a simulation, blanking all displays, and then querying the participant about information in the scenario (Endsley, 1995b). Participants' responses can then be compared to the actual information that was available when the simulation was suspended (i.e., reality). The degree of similarity between a participant's perception of the situation and reality serves as a measure of their SA. Assessments of SA such as the SAGAT serve well in simulation-based research but fare much poorer in real-time situations where scenarios

cannot be ‘frozen’ to query participants. Although SA measures have not received a great deal of attention to date in the driving literature compared to more objective measures such as speed and lane maintenance (see Horrey & Wickens, 2006), the availability of driving simulators make assessing SA using the SAGAT both feasible and efficient. Indeed, researchers have had success using the SAGAT to assess SA in simulated driving research (Gugerty et al., 2004; Johannsdottir & Herdman, 2010; Kass et al., 2007; Ma & Kaber, 2005). This thesis, therefore, employed the SAGAT method as well.

Even when technologically feasible though, using direct SA probes such as the SAGAT may have disadvantages. For instance, Adams et al. (1995) contended that the experimental paradigm being used would greatly influence what participants attend to. In the present thesis, for example, the participants’ task was to report the positions of other vehicles in the simulated driving scenario. Such task demands may fundamentally change how a participant drives, as they will be intently attending to the positions of other vehicles. While this may be a serious drawback of this measurement technique, the applied nature of the current thesis circumscribes it. That is, if participants are actively attending to the positions of other vehicles (more so than they typically would in a real-life scenario), then any decreased ability in estimating the positions of vehicles around them while conversing carries more weight.

Defining Conversation

While there appears to be some consensus on how to measure SA, conversation is often studied without any standard evaluation protocol. Not surprisingly, this makes interpreting the literature on conversation and driving quite difficult. Although there is a theoretical need for controlling conversation in laboratory experiments, this control often

inhibits ‘real’ conversation. In driving studies, ‘conversation’ tasks typically consist of either information-processing tasks (e.g., mental arithmetic) or conversation tasks [e.g., structured interviews; see Horrey and Wickens (2006) for more on this distinction]. In their meta-analysis of the literature on cell phone conversations and driving, Horrey and Wickens (2006) found that conversation tasks were more detrimental to driving performance than information processing tasks, possibly because conversation tasks are more engaging than information processing tasks. Although they offer less experimental control than information-processing tasks, conversational tasks are a better proxy for the cognitive demands of real-life conversation.

With this in mind, a ‘20-questions’ conversation task was developed and applied to allow for experimental control and to mimic natural conversation (Robert, Leblanc, Brown, & Herdman, unpublished manuscript). In the 20-questions conversation task, participants are required to guess a word (i.e., person, place, thing, animal, or food) by asking a series of yes/no questions. As such, participants must constantly load their working memory with new candidates while eliminating those that have been ruled out based on previous answers. The 20-questions task is both interactive (because it requires the participant to ask questions and listen to the experimenter’s responses) and continuous (because questions are asked serially and are contingent upon answers to previous questions). Furthermore, the inherent dependence on prior information means that the participant must store their previous questions (and the experimenter’s answers) in working memory and retain this information until they either guess correctly or run out of questions. The 20-questions task is therefore an effective alternative to typical conversation tasks used in the literature because it approximates the cognitive task load

and demands associated with real conversation. For these reasons, this thesis used the 20-questions conversation task.

Purpose & Hypotheses

Cell phone conversations impair driving beyond what can be accounted for by simply holding or dialing a phone (Strayer et al., 2003), suggesting that at least some of the driving impairments caused by conversation require a cognitive explanation. The purpose of this thesis was to examine the nature of conversation-induced driving impairments. This study used a repeated measures design with two conversation conditions: a ‘conversation’ condition in which participants were asked to engage in simulated driving while asking the experimenter a series of questions (i.e., the 20-questions task) and a ‘no conversation’ condition in which participants only drove. SA was measured using the SAGAT method, whereby the simulation was frozen (and displays blanked) 40 – 60 s after the onset of each trial. During the simulation pause, participants were asked to report the positions of the other cars in the scenario. Three independent variables were used in this experiment: traffic density (high vs. low), vehicle position (ahead vs. behind) and conversation (conversation vs. no conversation); as well as six dependent variables related to SA (distance estimation, number of vehicles reported in the wrong lane, number of extra vehicles reported, number of missed vehicles, speed maintenance, and lane maintenance).

The *strong hypothesis* of this study was that conversation would cause impairments in both SA and driving performance. Since conversation has been reliably found to impair SA (Gugerty et al., 2004; Kass et al., 2007; Ma & Kaber, 2005), it was predicted that conversation would impair SA measures in this experiment as well. Furthermore, it has

been reported that drivers have greater difficulty monitoring their speed when conversing, possibly as a compensatory behaviour aimed at freeing up cognitive resources to handle conversation-induced workload (Gugerty et al., 2004; Kass et al., 2007). For this reason, it was predicted that participants would have greater difficulty maintaining their speed when conversing than when not conversing.

Conversely, conversation typically does not impair lane maintenance, possibly because lane maintenance is an automatic task that requires few cognitive resources (Baumann et al., 2008; Horrey & Wickens, 2006; Ishigami & Klein, 2009; Kass et al., 2007). As such, it was hypothesized that conversation would not impair lane position maintenance. Also, given Strayer et al.'s (2003) finding that conversation caused greater driving impairments in high-traffic density than in low-traffic density; it was hypothesized that, relative to the no conversation condition, conversation would induce greater SA impairments in the 5-car condition (high traffic density) than in the 3-car condition (low traffic density). That is, it was hypothesized that conversation and traffic density would interact.

The second *experimental hypothesis* for this thesis was that conversation would have differential effects on SA for vehicles ahead of the driver than behind them. This experimental hypothesis was based on the results of Johannsdottir and Herdman (2010), who found that taxing the visuospatial sketchpad or the phonological loop had different effects on SA for the locations of other vehicles. Given this finding, it was hypothesized that conversation would impair SA for vehicles behind the driver to a greater extent than it would for vehicles ahead of the driver because the phonological loop (which is engaged during conversation) is primarily used for maintaining SA for vehicles behind the driver

and not in front. Therefore, it was hypothesized that conversation and vehicle position would interact.

Methods

Participants

Participants ($n = 28$; 14 females, 14 males) were undergraduate students from Carleton University with an age range of 19 to 34 years ($M_{\text{age}} = 22.93$ years, $SD_{\text{age}} = 3.89$). All participants held a valid driver's license and had a minimum of two years driving experience; driving, on average, 7.34 hours per week ($SD = 7.43$). All participants received course credit (1%) and had normal or corrected-to-normal visual acuity.

Design & Statistical Analyses

In a prior study using the 20-questions task (Robert et al., unpublished manuscript), participants were tested under three conditions ('no conversation', 'driver asks questions', and 'passenger asks questions'). The largest driving performance decrements were observed when drivers were required to ask questions. Based on these results, the conversation condition in the present thesis used only the 'driver asks questions' condition.

Six dependent variables were used in this thesis, including four SA measures, as well as lane position and speed maintenance. The four SA measures included distance estimation (i.e., the difference between participants' estimates of vehicle positions and actual vehicle positions), the number of vehicles reported in the wrong lane, the number of missed vehicles, and the number of extra vehicles reported.

The four SA measures were analyzed using a 2 (Conversation: conversation vs. no conversation) x 2 (Traffic Density: low vs. high) x 2 (Vehicle Position: ahead vs. behind)

repeated measures ANOVA. Lane position and speed maintenance were analyzed using a 2 (Conversation: conversation vs. no conversation) x 2 (Traffic Density: low vs. high) repeated measures ANOVA. The two levels of the conversation task were counter-balanced across participants such that half the participants received the no conversation condition followed by the conversation condition and the other half received the reverse order. Each conversation condition contained ten (40 – 60 s) trials. Of the ten trials in each condition, half had three other vehicles present (low traffic density) and half had five other vehicles present (high traffic density). Simulated traffic behaved pseudo-randomly (i.e., other vehicles' speeds were yoked to participants' speeds to prevent collisions).

Materials and Stimuli

Participants drove a fully configured, medium-fidelity, Drive Safety 500c simulator. The cabin consisted of a modified Saturn vehicle mounted on a fixed-base platform with full seat, steering wheel, gas and brake pedals, and instrumentation. The visual display system consisted of three rear projection displays subtending a visual angle of 21.8° vertically and 90° horizontally. All data (i.e., gas/brake pedal pressure, lane position, speed, and steering wheel position) was recorded at 20 Hz.

The same driving scenario was used across all experimental conditions and was constructed using Tool Command Language (TCL) on a PC-based Linux platform. The scenario consisted of a four-lane highway (although only the two right lanes were used) passing through an urban area with the participant's vehicle located in the right-most lane. The other vehicles traveled in the same direction as the participant's vehicle, were permitted to change lanes, and accelerated and decelerated pseudo-randomly with the

constraint that no vehicles were permitted to collide with the participant's vehicle. Speed and lane position of the participant's vehicle was also recorded, as well as the position of the other vehicles (relative to the participant's vehicle).

The conversation task was based on Robert et al.'s (unpublished manuscript) 20-questions task. Each of the participant's questions was required to be phrased such that the experimenter could respond with either a 'yes' or a 'no'. The participant and the experimenter conversed using headsets attached to portable phones. The same 25 items used by Robert et al. were used in this study (see Appendix A).

Procedure

Upon arriving, participants were asked to complete an informed consent form (Appendix B) and a driver experience questionnaire (Appendix C). The researcher then verbally relayed the instructions to the participant, with the emphasis being on following the speed limit (35 mph), maintaining proper lane position (i.e., staying in the centre of the lane), and monitoring the position of the other cars in the scenario. Participants familiarized themselves with the simulator by completing two practice trials similar to those used in the experimental conditions. The participant was instructed that the 20-questions items in the conversation condition were from one of five categories: a person, place, thing, food, or animal. Participants were instructed to ask only 'yes' or 'no' questions. The researcher informed participants when they only have five remaining questions. At the end of each trial, participants were asked to indicate the other vehicles' positions by drawing them on a grid pattern (with each cell in the grid representing one car length) with their own vehicle's position displayed (Appendix D). Participants were debriefed at the end of each testing session (Appendix E).

Results

1. Situation Awareness (SA) Measures

1.1. Distance Estimation

All distance estimates are given in terms of the absolute difference (in number of car lengths) between estimated and actual car locations. Distance estimates were analyzed using a 2 (Conversation: conversation vs. no conversation) x 2 (Traffic Density: low vs. high) x 2 (Vehicle Position: ahead vs. behind) repeated measures ANOVA. There was a significant main effect of conversation, $F(1, 27) = 4.43$, $MSE = 0.31$, $p = .045$, partial $\eta^2 = .14$, with larger estimation errors (poorer SA) in the conversation condition ($M = 2.14$, $SE = 0.10$) than in the no conversation condition ($M = 1.98$, $SE = 0.10$). The main effect of traffic density was also significant, $F(1, 27) = 14.22$, $MSE = 0.30$, $p = .001$, partial $\eta^2 = .34$, with larger estimation errors (poorer SA) on higher traffic density trials (i.e., 5 other vehicles; $M = 2.20$, $SE = 0.09$) than on lower traffic density trials (i.e., 3 other vehicles; $M = 1.92$, $SE = 0.11$). The main effect of car position was also significant, $F(1, 27) = 81.82$, $MSE = 1.68$, $p < .001$, partial $\eta^2 = .75$, with larger estimation errors (poorer SA) for cars ahead ($M = 2.84$, $SE = 0.16$) than for cars behind ($M = 1.28$, $SE = 0.09$).

Critically, the interaction between conversation and vehicle position was significant, $F(1, 27) = 5.55$, $MSE = 0.36$, $p = .026$, partial $\eta^2 = .17$. Conversation impaired distance estimation for vehicles behind the driver ($M = 1.45$, $SE = 0.12$) compared to when not conversing ($M = 1.10$, $SE = 0.08$, $p = .003$). Distance estimation was not impaired by conversation for vehicles ahead of the driver ($M = 2.85$, $SE = 0.16$) compared to when not conversing ($M = 2.83$, $SE = 0.18$, *ns*). In sum, conversation had no effect on SA for

vehicles ahead of the driver but significantly ($p < .05$) impaired SA for vehicles behind the driver (see Figure 1). No other interactions were significant.

1.2. Wrong Lane

Wrong lane data are measured as the number of vehicles reported in the wrong lane. The wrong lane data were analyzed using the same ANOVA used for the distance estimation data. There was a significant main effect of conversation, $F(1, 27) = 32.68$, $MSE = 0.29$, $p < .001$, partial $\eta^2 = .55$, with more vehicles being reported in the wrong lane when conversing ($M = 0.49$, $SE = 0.09$) than when not conversing ($M = 0.08$, $SE = 0.04$). The main effect of traffic density was also significant, $F(1, 27) = 4.40$, $MSE = 0.41$, $p = .045$, partial $\eta^2 = .14$, with more vehicles being reported in the wrong lane on higher traffic density trials (i.e., 5 other vehicles; $M = 0.38$, $SE = 0.09$) than on lower traffic density trials (i.e., 3 other vehicles; $M = 0.20$, $SE = 0.05$). The main effect of vehicle position was also significant, $F(1, 27) = 4.70$, $MSE = 0.31$, $p = .039$, partial $\eta^2 = .15$, with more vehicles being reported in the wrong lane for vehicles ahead ($M = 0.37$, $SE = 0.08$) than for vehicles behind ($M = 0.20$, $SE = 0.06$). No interactions were significant.

1.3. Missed Vehicles

Missed vehicle data were recorded as the number of vehicles that participants failed to report. Missed vehicle data were analyzed using the same ANOVA as above. There was a significant main effect of conversation, $F(1, 27) = 13.64$, $MSE = 0.63$, $p = .001$, partial $\eta^2 = .34$, with participants missing more vehicles in the 20-questions condition ($M = 0.64$, $SE = 0.12$) than in the no conversation condition ($M = 0.25$, $SE = 0.09$). The main effect of traffic density was also significant, $F(1, 27) = 19.24$, $MSE = 1.27$, $p < .001$, partial $\eta^2 = .42$, with participants missing more vehicles on high traffic density trials (i.e.,

5 other vehicles; $M = 0.78$, $SE = 0.16$) than on low traffic density trials (i.e., 3 other vehicles; $M = 0.12$, $SE = 0.06$). The main effect of vehicle position was not significant ($F < 1$).

The conversation by traffic density interaction was significant, $F(1, 27) = 16.11$, $MSE = 0.40$, $p < .001$, partial $\eta^2 = .37$. Participants missed more vehicles when conversing ($M = 1.14$, $SE = 0.22$) than when not conversing ($M = 0.41$, $SE = 0.14$, $p < .001$) on higher traffic density trials. The number of missed vehicles did not differ significantly when conversing ($M = 0.14$, $SE = 0.07$) and when not conversing ($M = 0.09$, $SE = 0.07$, *ns*) on lower traffic density trials. Thus, conversation had a larger effect in the high traffic density condition than in the low traffic density condition (see Figure 2). No other interactions were significant ($F < 1$).

1.4. Extra Vehicles

Extra vehicle data were recorded as the number of vehicles participants reported that were not actually present. Extra vehicle data were analyzed using the same ANOVA as above. The main effect of conversation was not significant, $F(1, 27) = 3.00$, $MSE = 0.29$, $p = .095$, partial $\eta^2 = .10$, nor was the main effect of vehicle position, $F(1, 27) = 1.45$, $MSE = 0.31$, $p = .239$, partial $\eta^2 = .05$. The main effect of traffic density was significant, $F(1, 27) = 4.67$, $MSE = 0.24$, $p = .040$, partial $\eta^2 = .15$, with more extra vehicles being reported on low traffic density trials ($M = 0.21$, $SE = 0.06$) than on high traffic density trials ($M = 0.07$, $SE = 0.03$). No interactions were significant.

2. Vehicle Data

2.1. Speed Maintenance

Speed maintenance data were calculated as the root mean squared error (RMSE) between the participant's speed and the speed limit (i.e., 35 mph). Larger RMSE values represent larger deviations and therefore worse speed maintenance. Speed maintenance data were analyzed using a 2 (Conversation: conversation vs. no conversation) x 2 (Traffic Density: low vs. high) repeated measures ANOVA. There was a significant main effect of conversation, $F(1, 27) = 23.74$, $MSE = 1.01$, $p < .001$, partial $\eta^2 = .47$, with larger RMSEs when conversing ($M = 5.63$ mph, $SE = 0.60$) than when not conversing ($M = 3.55$ mph, $SE = 0.36$). The main effect of traffic density was also significant, $F(1, 27) = 4.55$, $MSE = 0.23$, $p = .042$, partial $\eta^2 = .14$, with larger RMSEs on higher traffic density trials ($M = 4.81$ mph, $SE = 0.51$) than on lower traffic density trials ($M = 4.38$ mph, $SE = 0.40$). The conversation by traffic density interaction was not significant, $F < 1$.

2.2. Lane Position Maintenance

Lane position maintenance data were calculated as the RMSE of vehicle position relative to the centre of the lane. Lane maintenance data were analyzed using the same ANOVA used for the speed maintenance data. Neither the main effect of conversation, $F(1, 27) = 3.48$, $MSE < 0.01$, $p = .073$, partial $\eta^2 = .11$, the main effect of traffic density, $F < 1$, nor the conversation by traffic density interaction, $F < 1$, were significant.

3. Questionnaire Data

Correlations between the SA data and data obtained via the driver's experience questionnaire (Appendix C) were assessed. Only significant correlations that were pertinent to the hypotheses of this thesis were reported here.

The number of years participants reported driving were negatively correlated with distance estimation for vehicles behind the driver in the low traffic density condition while not conversing, $r(26) = -.39, p = .041$. This indicates that participants with more driving experience were better at estimating distances for vehicles behind them. The percentage of time participants reported driving in the city were negatively correlated with distance estimates for vehicles ahead of the driver in low traffic density while not conversing, $r(26) = -.41, p = .029$. This indicates that participants who drove more often in the city were better at estimating distance for vehicles ahead of them under these conditions. Conversely, those who reported driving more often on the highway had worse distance estimations under these same conditions, $r(26) = .40, p = .033$.

Participants who agreed more strongly with the statement ‘I can talk on the phone when I drive without it affecting my driving’ had better distance estimation for vehicles behind the driver in the high traffic condition when not conversing, $r(23) = -.41, p = .041$. These same participants were also more likely to miss vehicles behind them in high traffic density conditions when conversing, $r(23) = .50, p = .012$.

Discussion

The data clearly support that conversation impairs multiple measures of SA and performance on a simulated driving task. More importantly, the interaction between conversation and vehicle position shows that conversation selectively impairs SA for vehicles located behind the driver (see Figure 1). This finding is consistent with the hypothesis proposed herein that working memory is implicated in establishing and maintaining SA. The contention of this thesis is that SA for vehicles behind the driver is supported by the phonological loop and that SA for these vehicles was impaired in this

thesis because conversation taxed the phonological loop. Our data supports the theory that SA for vehicles behind the driver is stored using verbal coding within the phonological loop and that this process is impaired when resources from this system are taxed by conversation. In further support of this theory, overall SA (in terms of distance estimation) in this thesis was actually worse for vehicles located ahead of the driver than behind. Thus, conversation is not simply magnifying the effect of vehicle position on SA. Rather, conversation actually selectively impairs drivers' SA for vehicles located behind them.

Furthermore, our results do not support the argument that driver SA for vehicles behind the driver was impaired by changes in visual scanning patterns (e.g., Harbluk et al., 2007). If participants focusing centrally ahead of them caused the SA impairment observed in this thesis, one would still expect to see reductions in SA for vehicles ahead of the driver. This, however, was not the case in the present thesis. Rather, SA was preferentially impaired for only vehicles behind the driver. This suggests that the decreased driver SA observed in the present thesis was caused by the taxation of the phonological loop, and not more centrally focused visual scanning patterns.

Although the 20-questions conversation task was not employed here to exclusively tax the phonological loop, these results are consistent with Johannsdottir and Herdman's (2010) finding that tasks that engage the phonological loop selectively impair SA for vehicles behind the driver. In concert, the results of these two studies show that conversation taxes the phonological loop and that working memory mediates the effects of conversation on SA in simulated driving.

Consistent with the literature on conversation and driving (e.g., Gugerty et al., 2004; Kass et al., 2007; Ma & Kaber, 2005), conversation impaired driving performance. The 20-questions conversation task also impaired performance on several other SA measures, including failing to report the presence of other vehicles and reporting vehicles in the wrong lane. These results support the claim that conversation impairs SA in simulated driving (Gugerty et al., 2004; Kass et al., 2007; Ma & Kaber, 2005) and also provides evidence that Robert et al.'s (unpublished manuscript) 20-questions task is an effective approach to inducing conversation load in simulated driving studies.

Traffic density was included in this thesis as a secondary approach to manipulating working memory load (with conversation being the primary). The results indicate that traffic density did indeed impact measures of SA and driving performance, and is therefore consistent with literature showing increased working memory load impairs SA (e.g., Gugerty, 1997). Higher traffic density was associated with reduced SA, including greater distance estimation errors, more vehicles reported in the wrong lane, and more missed vehicles. Participants also had greater difficulty maintaining their speed on high traffic density trials, which is consistent with Gugerty et al.'s (2004) and Kass et al.'s (2007) claim that increased workload impairs speed maintenance. Furthermore, the significant interaction between traffic density and conversation for the number of missed vehicles is consistent with Strayer et al. (2003), who found that conversation impaired driving performance on a variety of measures and that higher traffic density exacerbated these impairments. One interpretation of the conversation by density interaction is that the additional demands on working memory load caused by conversation overloaded a working memory system that was already heavily taxed by high traffic density. In

contrast, in low traffic density, working memory was not taxed to the point that additional conversational demands could cause significant impairment.

Also as hypothesized, conversation significantly impaired participants' ability to maintain their speed. This finding supports Gugerty et al. (2004) and Kass et al. (2007), who argued that poor speed maintenance may reflect a compensatory behaviour aimed at freeing up cognitive resources to handle conversation-induced workload. Lane maintenance, however, was not affected by conversation or by traffic density, which is consistent with the view that lane position maintenance is an automatic process that requires few cognitive resources (Baumann et al., 2008; Horrey & Wickens, 2006; Ishigami & Klein, 2009; Kass et al., 2007). Thus, lane position maintenance is preserved under high workload conditions.

The correlational analyses revealed that when not engaged in conversation, participants with more driving experience had better SA for vehicles behind them than participants with less driving experience. These results support previous evidence that more experienced drivers have better SA while driving (Jackson et al., 2009; Kass et al., 2007). There was also evidence that participants with more city-driving experience had better SA for vehicles ahead of them in low traffic density while not conversing than those who drove more often on the highway. One possibility for this may be that city drivers have better developed SA for vehicles ahead of them given the more experience they have with vehicles in close proximity.

Also, participants who agreed more strongly with the statement 'I can talk on the phone when I drive without it affecting my driving' had worse SA (more missed vehicles) when conversing than when not conversing. This finding shows that drivers

may underestimate the effects that conversation has on their own driving performance, a characteristic that makes promoting awareness of the effects of (cell phone) conversation on driving even more important.

The finding that conversation may impair driving performance by reducing drivers' SA has the potential to be applied to automobile legislation. For example, our results show that conversation-induced driving impairment is associated with the cognitive effects of conversing. Legislative restrictions that target the physical aspects of cell phone use may therefore be immoderate. The results of this thesis suggest that conversation's effects on working memory cause driving impairment. For this reason, the results of this study support the argument that the use of both hand-held and hands-free phones should be prohibited while driving.

Increasing SA is also a major consideration in the design of airplane cockpits, as evidenced by the fact that these systems are constantly evolving to better allow pilots to achieve and maintain SA (Endsley et al., 2003). Knowledge of what does and does not improve SA can also be applied to the safe operation of a motor vehicle, despite the fact that SA is not as popular in the driving literature as it is in aviation. Even so, there is nothing preventing the automotive industry from designing vehicles and vehicle systems that promote good SA and therefore make driving safer.

In sum, these results suggest that conversation-induced driving impairments are mediated by working memory processes. This addresses a gap in the literature between the effects of conversation on driving performance and the cognitive mechanisms that are responsible for the observed impairments.

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Appendix A

20 Questions Experiment - Participant Question Tracking Sheet

Participant #: _____ Experimenter: _____

Word	Category	Game Questions	“Meta” Questions	Counts
Russia	Place	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
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Turtle	Animal	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
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Computer	Thing	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
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Frank Sinatra	Person	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
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Los Angeles	Place	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
Television	Thing	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
French Fries	Food	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
China	Place	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
Stephen Harper	Person	□□□□□ □□□□□ □□□□□ □□□□□	□□□□□ □□□□□	
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Appendix B

Informed Consent Form

Study: **The Role of Working Memory in Driver's Situation Awareness**

Faculty Sponsor: Dr. Chris Herdman, Department of Psychology
Carleton University, tel. 613-520-2600 x8122

The purpose of this informed consent form is to ensure that you understand both the purpose of the study and the nature of your participation. The informed consent must provide you with enough information so that you have the opportunity to determine whether you wish to participate in the study. Please ask the researcher to clarify any concerns that you may have after reading this form.

Research Personnel:

In addition to the Faculty Sponsor named above, the following people are involved in this research and may be contacted at any time should you require further information about this study:

Principal Investigators: Adam Heenan and Dr. Kamilla Johannsdottir (613-520-2600, x2487)

Should you have any ethical concerns regarding this study then please contact: Dr. Monique Sénéchal, (Chair, Carleton University Research Ethics Committee for Psychological Research, 520-2600, ext. 1155).

Should you have any other concerns about this study then please contact: Dr. Janet Mantler (Chair, Dept. of Psychology, 520-2600, ext. 4173).

Purpose:

The purpose of this study is to examine how working memory affects situation awareness in simulated driving. We are examining how conversation affects people's ability to monitor surrounding traffic.

Task:

In this study, you will be asked to drive in a series of trials (40 - 60 s) using a driving simulator. Your task is to stay in the right lane and maintain a steady speed (i.e., 35 mph). While driving, your task is also to monitor surrounding traffic and, at the end of each trial, you will be asked to report where you think the other cars were relative to your car. For half of the trials, you will be asked to converse (i.e., play 20-questions) while driving. Twenty-questions requires you to ask the researcher a series of 'yes or no' questions in order to determine what item they are thinking of.

Duration & Locale:

The experiment will take one hour. Testing will take place in Room 1114 of the VSIM Building at Carleton University.

Potential Risks/Discomfort:

People who are susceptible to motion sickness in vehicles may experience those symptoms in our simulator. There are no potential physical or psychological risks associated with participation in this experiment. Please note that your performance on the task in this experiment does not provide an indication of your suitability for university studies. However, if you feel anxious and/or uncomfortable about your performance in this experiment, please bring your concerns to the Researcher's attention immediately. Should this happen the experiment will be stopped and you will be given the option to withdraw without losing your credit or to take a break and continue with the experiment.

Anonymity/Confidentiality:

All data collected in this experiment will be kept strictly confidential through the assignment of a coded number. The information provided will be useful for research purposes only and you will not be identified by name in any reports produced from this study. Further, the information is made available only to the researchers associated with this experiment.

Right to Withdraw/Omit:

Your participation in this experiment is completely voluntary. You have the right to withdraw from this experiment at any time without academic penalty. However, you will still receive full credit for your participation.

I have read the above description of the study examining the effects of conversation on driving performance; I understand the conditions of my participation.

Name: _____ Date: _____

Signature: _____ Witness: _____

Appendix C

Driving Experience Questionnaire

The purpose of this questionnaire is to assess your driving experience and get some information about how you feel about driving.

Today's Date: _____ Participant Code: _____

Please complete each question by responding in the space provided.

Sex: Male Female

1. Year that you were born: _____

2. Do you have a valid driver's license? Yes No

3. What year did you obtain your driver's license? _____ (Year)

4. What country did you obtain your license from: _____

5. Did you attend driving school? Yes No

6. Do you own a car? Yes No

 If yes, for how long? _____ (Years)

7. Do you use glasses (or contact lenses) for distance? Yes No

8. Do you use glasses (or contact lenses) for reading? Yes No

9. Approximately how many hours do you drive per week? _____ (Hours/per week)

10. Approximately what % of your driving (per year) is

 In the city _____ %

 On the highway _____ %

11. How many accidents as a driver (including fender benders) have you had since you began driving that?

 a. Were considered your fault? _____

 b. Were considered the other driver's fault? _____

c. No fault was assigned: _____

12. Do you usually drive: Automatic Standard

13. Have you had previous experience playing driving games on a computer?

Yes No

If yes, how many hours per week do you play _____ (hours)

14. Have you had previous experience driving in?

Any driving simulator Yes No

This driving simulator Yes No

15. Do you own a cell phone? Yes No

16. Please indicate how **frequently** you perform each of the following activities **while**

driving:

	Never	Rarely	Sometimes	Often	Almost Always
While driving, I...					
a. Talk on a cell phone	1	2	3	4	5
b. Listen to the radio or CD	1	2	3	4	5
c. Talk with a passenger	1	2	3	4	5
d. Drink (e.g., coffee, tea, pop)	1	2	3	4	5
e. Daydream	1	2	3	4	5
f. Send a text message	1	2	3	4	5
g. Read a text message	1	2	3	4	5
h. Use a navigation system	1	2	3	4	5
i. Eat (e.g., sandwich, apple, cookies)	1	2	3	4	5
Other activities (please specify)					

j.	1	2	3	4	5
k.	1	2	3	4	5
l.	1	2	3	4	5

17. Indicate the extent to which you agree or disagree with the statement by circling the appropriate number.

	Disagree strongly	Disagree	Neither agree or disagree	Agree	Agree strongly
a. I am a confident driver in good weather with moderate traffic	1	2	3	4	5
b. I prefer to drive rather than to be a passenger	1	2	3	4	5
c. I can talk on the phone when I drive without it affecting my driving	1	2	3	4	5
d. Some traffic situations upset me	1	2	3	4	5
e. I get distracted easily while driving	1	2	3	4	5
f. I find driving relaxing most of the time	1	2	3	4	5
g. Listening to the radio while I drive distracts me	1	2	3	4	5
h. I am anxious while driving in heavy traffic	1	2	3	4	5
i. I am anxious while driving in bad weather (e.g., rain, ice)	1	2	3	4	5

j.	I stay calm even when I am driving in heavy traffic	1	2	3	4	5
k.	I can hold a conversation when I drive	1	2	3	4	5
l.	I am anxious while driving on the highway	1	2	3	4	5
m.	I almost always feel nervous when I am driving	1	2	3	4	5
n.	I usually drive faster than the speed limit	1	2	3	4	5
o.	Overall, I am a safe driver	1	2	3	4	5

Appendix D

03

Appendix E

Debriefing Form

The Role of Working Memory in Driver's Situation Awareness

In this study, we examined the role of verbal working memory (conversation) in establishing and maintaining situation awareness for the spatial location of surrounding vehicles. Some studies have manipulated verbal working memory using information processing tasks (e.g., counting backwards). Information processing tasks, however, may not be as interactive or as cognitively demanding as real conversation. The 20-questions task used in this experiment may provide a useful alternative to these methods as it more closely approximates real conversation. Our interest here is to determine how the cognitive demands of our realistic conversation task may interfere with a driver's awareness of surrounding traffic.

We would like to thank you for your participation in this research. Your time and effort are greatly appreciated!

Should you have any ethical concerns regarding this study then please contact Dr. Monique Sénéchal (Chair, Carleton University Research Ethics Committee for Psychological Research, 613-520-2600, ext. 1155). Should you have any other concerns about this study then please contact Dr. Janet Mantler (Chair, Dept. of Psychology, 520-2600, ext. 4173), or Adam Heenan (Principal Researcher, 613-520-2600 x2487), or Dr. Chris Herdman (Faculty Advisor, 613-520-2600 x8122).

Figure Captions

Figure 1. Distance estimation error (in car lengths) as a function of vehicle position and conversation condition.

Figure 2. Mean number of missed vehicles as a function of traffic density and conversation condition.