CHARACTERIZING THE EFFECTS OF VIDEOPHONE CONVERSATIONS ON YOUNGER AND OLDER DRIVER PERFORMANCE

BY

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DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2014

Urbana, Illinois

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ABSTRACT

Driver distraction is a widespread and growing issue. Previous studies have shown that passenger conversations can be less distracting than cell phone conversations because of an increase in shared situational awareness when the conversation partner can see the driver and driving scene. Recently, Gaspar and colleagues (in press) found that providing remote conversation partners views of the driver and driving scene via a videophone could mitigate driver distraction relative to cell phone conversations. The goal of the present project was to extend these results by examining the efficacy of videophone conversations in reducing cell phone distraction during freeway and intersection driving for younger and older drivers. Pairs of younger and older adult drivers completed highway and intersection driving assessments in each of four conditions: driving alone without distraction, conversing with an in-car passenger, conversing with a remote cell phone partner and conversing with a remote partner via a videophone. Although all conversations disrupted driving performance relative to driving alone, the results suggest that passenger and videophone conditions reduced distraction relative to the cell phone. Conversational analyses suggest that the benefit for passenger and videophone conversations was due to an increase in partner situational awareness, even when the partner could only see a subset of the critical information in the driving scene. Importantly, younger and older adults showed similar benefits from videophones over cell phones. These results provide evidence for the efficacy of videophone conversations in reducing, but not eliminating, cell phone distraction across different driving tasks and for different groups of drivers.

ACKNOWLEDGEMENTS

This project would not have been possible without the support of many people. I would like to thank my adviser, Arthur Kramer, for his support throughout the project and the duration of my graduate studies. I would also like to thank my committee members, Daniel Simons, Alejandro Lleras, Daniel Morrow, and Frances Wang, for their insightful suggestions and support. I would also like to thank the staff at the Illinois Simulator Lab for their assistance, and Chun Kim and Anya Knecht for their work in scheduling and subject running. Finally, I would like to thank my family for their continued support throughout my graduate studies.

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CHAPTER 1: INTRODUCTION

Distracted driving is still a growing problem. At any moment, approximately 5% of drivers (roughly 660,000) are performing some other task while driving (Pickrell & Ye, 2013), despite abundant epidemiological, experimental, and observational evidence linking distraction (such as talking on a phone or texting) with driver impairment (Horrey & Wickens, 2006; Caird et al., 2008). Secondary tasks increase brake response time (e.g. Strayer et al., 2003), narrow the visual inspection window (Recarte & Nunes, 2000; 2003), increase mental workload (Alm & Nilsson, 1995; Cantin et al., 2009) and reduce attention to visual inputs (Strayer, Drews and Johnston, 2003).

Interestingly, recent evidence suggests that not all conversations affect driving performance in the same way. That is, conversing with an in-car passenger is less distracting (under certain conditions) than conversing on a cell phone with a remote partner (Reuda-Domingo et al., 2004). A potentially critical difference between the driver conversing on a cell phone and with a passenger centers on the partner's increased understanding of the driving context. In-car passengers can monitor the driving scene and adjust their conversations accordingly (Drews & Strayer, 2008). For instance, if they notice that traffic is getting busy, they may stop conversing to allow the driver to focus on the driving task. They may also help keep the driver focused on the task of driving by making frequent references to traffic. Finally, they may alert the driver to stimuli in the driving environment, such as a road sign for a specific exit.

Based on these results, a recent study attempted to reduce driver distraction by showing remote partners views of the driver and driving scene via a *videophone*, where the conversation partner could see the driver and driving scene as the driver drove through a busy freeway environment (Figure 1A). Compared with cell phones, videophone conversations resulted in better driving performance (i.e., fewer collisions), as did conversations with in-car passengers. Conversation partners in the passenger and videophone conditions also showed evidence of enhanced situational awareness, an understanding of the components of an environment and their likely future states (Endsley, 1995), compared to when they talked on a traditional cell phone.

Figure 1. Depiction of what videophone partners saw during the highway task (A) from Gaspar et al. (in press) vs. the intersection task (B) from the present study, and a diagram of a left turn scenario.

The goal of the present study was to extend these results in two critical ways. The first goal was to understand the effects of videophone conversations on intersection driving performance. Whereas in the freeway task videophone partners could see a majority of critical information happening in the driving scene (e.g., cars braking or merging in front of the driver), videophone partners could not see approaching vehicles in the intersection task, and thus it was hypothesized that the benefit of increased situational awareness and reduced distraction relative to cell phone conversations might be reduced or eliminated.

A second pressing issue is the general aging of the U.S. population, which will represent a rapid increase in the number and percentage of older drivers who represent an increased crash risk per vehicle mile traveled (VMT) compared with younger experienced drivers (IIHS, 2012). Importantly, crashes involving older drivers tend to occur during turns at intersections and when driving in heavy traffic (Lyman et al., 2002; Li, Braver & Chen, 2003; Stutts, Martell & Staplin, 2009; Braitman et al., 2007; Chandraratna & Stamatinaidis, 2006), and older driver crashes are theorized to represent a confluence of factors, including physical, cognitive and strategic age-related changes (Romoser & Fisher, 2009). Research further suggests that older drivers are more susceptible to secondary task interference than are younger drivers (Horberry et al., 2006; Lam, 2002; McPhee et al., 2004; McKnight & McKnight, 1993; Reed & Green, 1999; Schreiner et al., 2004; Shinar et al., 2005; but see Strayer et al., 2004). However, older drivers might also be able to draw on years of driving expertise to offset deficits in physical and cognitive abilities (Kramer & Morrow, in press).

The extent to which passenger and videophone conversations might ameliorate older driver distraction is an unexplored issue. This is an important question because as the driver population ages and older generations become more fluent with and reliant upon technology, older adults will increasingly interact with non-driving devices while driving. Furthermore, continued driving is a critical component to maintaining independence with age.

CHAPTER 2: LITERATURE REVIEW

2.1 Driver Distraction

Driver distraction is commonly defined as performing any secondary non-driving task that reduces attention to the driving task. Such tasks include selecting a song from a CD menu, making a phone call and entering information into a navigation system. The number of distracted drivers is increasing. At any given time, approximately 5% of U.S. drivers (660,000) are performing a non-driving task, such as talking on a cell phone or texting, while driving (Pickrell & Ye, 2013) and driver inattention accounts for 10-25% of crashes (IIHS, 2012). The following review will focus on the impact of cell phone conversations on driving performance.

Extensive research using simulator and on-road methods has provided evidence that cell phone distraction has a negative impact on driving performance and safety (see Horrey & Wickens, 2006; Caird et al., 2005; Caird et al., 2008). Cell phone conversations increase brake response time (e.g. Strayer et al., 2003), impair scanning and narrow the visual inspection window (Recarte & Nunes, 2000; 2003), increase subjective and mental workload (Alm & Nilsson, 1995; Cantin et al., 2009) and reduce attention to visual information, which can lead to inattentional blindness (Strayer, Drews and Johnston, 2003). Cognitive distraction also impairs scanning behavior at intersections. In an on-road assessment, Harbluk and colleagues (2007) had young adults drive through several intersections with no cognitive task, an easy task (simple math problems) and a difficult task (complex math problems). Drivers made significantly fewer glances toward critical areas in the difficult condition compared to the no distraction condition.

An important point here is that cell phone distraction derives primarily from cognitive interference. In a now classic simulator study, Strayer and Drews (2003) compared the effects of hands-free and handheld cell phone conversations on performance in a lead vehicle following task, where participants followed a lead car that braked intermittently and had to respond quickly to avoid a collision. Hands-free and handheld cell phone conversations resulted in equivalent costs to driving performance, suggesting that cell phone distraction is primarily cognitive in nature.

2.1.1 Passenger vs. Cell Phone Conversations

An important resulting question has been whether all types of conversations, including passenger conversations, are equally disruptive of driving performance. Compared to remote conversation partners, in-car passengers have access to additional information, including views of the driver and driving scene, which can promote enhanced situational awareness.

From an epidemiological standpoint, there is an advantage to having a passenger in the vehicle. Reuda-Domingo and colleagues calculated odds ratios for different activities, such as talking with a passenger, commonly performed while driving. Passenger odds ratios were below 1, indicating that passengers actually have a protective effect on crash risk. An important caveat here is that the benefit of passengers exists only for experienced adult drivers. Crash risk rises significantly for young novice drivers with one or more passengers.

Importantly, certain conditions must exist to engender a benefit of passenger conversations over cell phone conversations. When passengers and drivers are free to converse naturally and passengers are engaged in the drive, data support a benefit for passenger conversations over cell phone conversations (Drews et al., 2008; Gaspar et al., in press; see also Charlton, 2009). However, when passengers are distracted and not actively monitoring the driving task, there is typically no benefit for passenger conversations over cell phone conversations (Strayer et al., 2013; Becic et al., 2010; Amado et al., 2005; Gugerty et al., 2004).

In a driving simulator experiment, Drews and colleagues (2008) compared the effects of passenger and cell phone conversations on younger driver performance in a simulated freeway drive. Drivers conversing on a cell phone with a remote partner (who could not see the driving scene) were more likely to miss a highway exit and showed poorer vehicular control (i.e., lateral lane keeping) than drivers conversing with an in-car passenger (see also Charlton, 2009). The critical difference between the cell phone and passenger conversations appears to be how aware the conversation partner is of the driving situation. In-car passengers can see what is happening in the driving scene and how the driver is responding and can provide assistance by alerting the driver (e.g., "Here comes your exit"). Passengers may also restrict or alter their conversation during times where the driving task requires the driver's full attention. Drews and colleagues (2008) analyzed the content and structure of conversations to infer changes in situation awareness. Pairs in the passenger condition were more likely to reference the surrounding driving scene compared to pairs conversing on a cell phone. Passengers also supported the driver by moderating the pace of the conversation (i.e., fewer syllables per minute), which may have allowed drivers to focus more on the driving task during periods of high workload (i.e., busy traffic). The importance of situational awareness for passengers is further highlighted by recent research from Strayer and colleagues (2013), who compared the distraction potential of several secondary tasks, including hands-free cell phone and passenger conversations, in both a simulator and instrumented on-road vehicle. Importantly, conversations were scripted and passengers were unable to reference the driving scene, which resulted is similar levels of distraction as the cell phone conversations. Thus, it appears that a necessary benefit in order to observe a passenger benefit is that the conversation partner is engaged in the task (and can converse freely) and is undistracted (see also Becic et al., 2010).

2.1.2 Videophone Conversations

Given the substantial risk of cell phone conversations and drivers' seeming inability to recognize or acknowledge their own multitasking limitations, a critical question is what might be done to reduce driver distraction from cell phone conversations. Simply restricting cell phone use while driving has done relatively little to reduce the frequency of distracted driving (Foss et al., 2009), as indicated by the continued increase in distracted driving despite an increase in public awareness campaigns. As noted, drivers tend to overestimate their ability to multitask in general (Sanbonmatsu et al., 2013) and underestimate the costs of distraction to driving performance (Horrey et al., 2009).

Based on the work comparing passenger and cell phone conversations, one potential strategy to mitigate cell phone distraction may be to make the remote partner more aware of the driving situation, as they would be as an in-car passenger. In a recent study, Gaspar and colleagues (in press) found that providing remote partners views of the driver and driving scene via a *videophone* reduced driver distraction. The videophone interface consisted of two monitors, which displayed real-time video of the driver's face and a subset of the driving scene (i.e., the front channel of the driving simulator; Figure 1). We compared this condition with an in-car passenger conversation and remote cell phone conversation, as well as a drive-alone distraction-free condition (Figure 2).

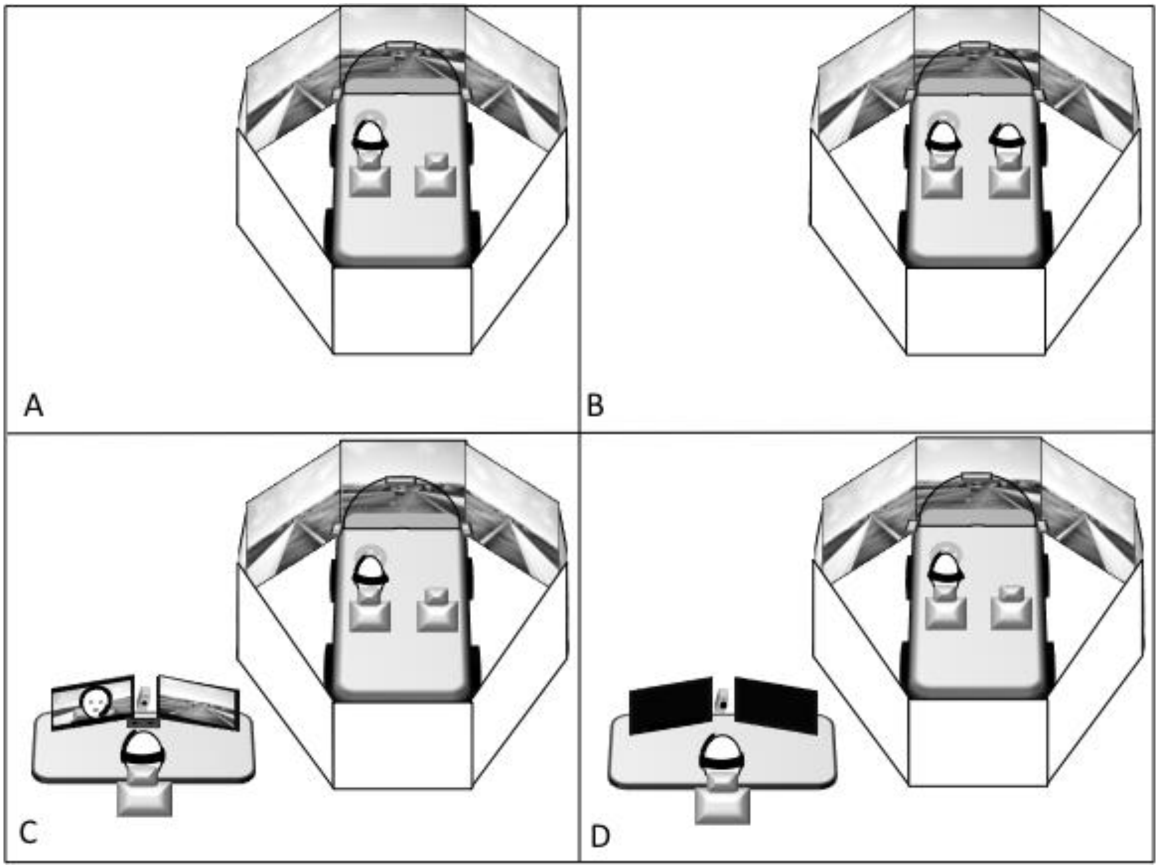


Figure 2. The experimental conditions from Gaspar et al. (in press) and the present study.

Drivers took four 15-minute drives along a busy highway where they had to respond to unexpected events that included lead vehicle braking and adjacent vehicles merging suddenly in front of them. Though there was a cost to conversing overall, passenger and videophone conversations reduced distraction relative to cell phone conversations. Drivers were involved in fewer (approximately half as many) collisions with merging vehicles when conversing via the videophone than when engaged in cell phone conversations. Importantly, this benefit was equivalent to having a passenger in the car.

Importantly, the reduction in crashes in the videophone condition appears to have been largely attributable to enhanced partner situational awareness, defined by the frequency of references to traffic. Conversation partners were more likely to initiate a reference to traffic when they could see, either as an in-car passenger or remotely via the videophone, the driver and driving scene, compared to the cell phone condition (Figure 3). Partners in the passenger and videophone conditions also modulated their speech by making shorter utterances.

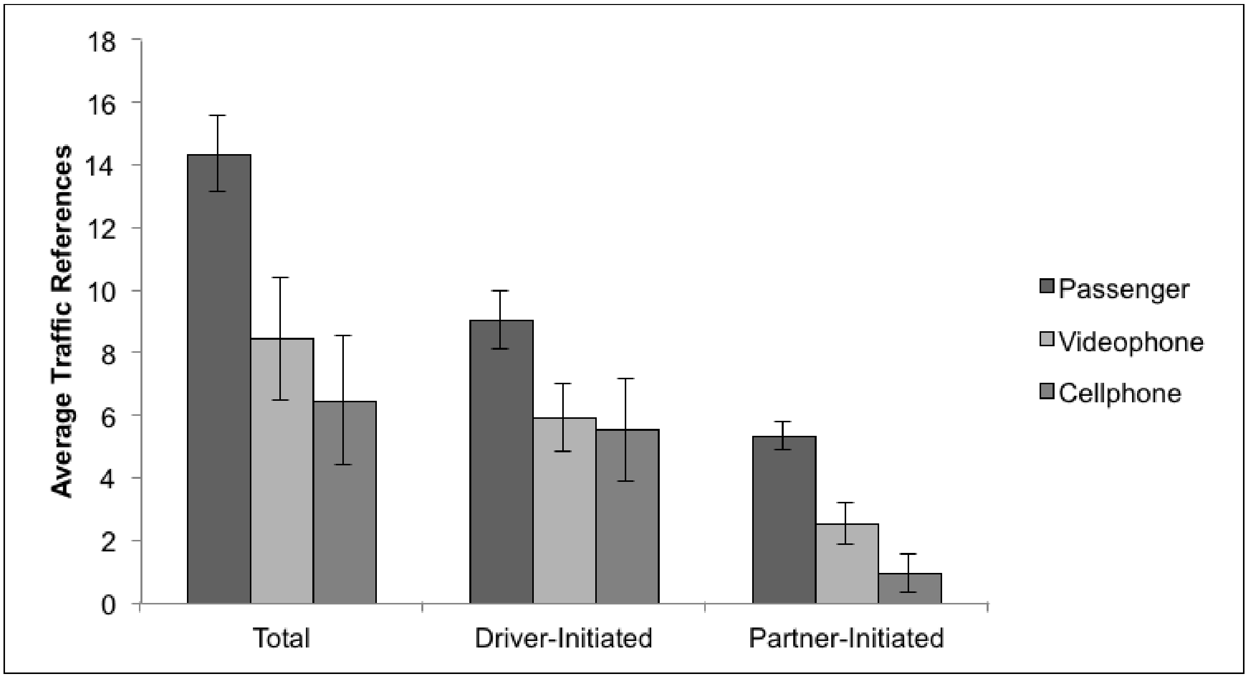


Figure 3. Traffic references from Gaspar et al. (in press). Error bars represent 95% confidence intervals using within-subjects standard error (Franz & Loftus, 2012).

A critical remaining question is the generalizability of the benefit of videophone conversations, both for other driving tasks and other age groups. The goal of this study was to examine the efficacy of the videophone interface for reducing younger and older driver distraction during both highway and intersection driving. A review of aging and driving literature details the motivation for these extensions.

2.2 Aging Drivers

The U.S. population is aging. The percentage of adults aged 65 and over is predicted to increase by approximately 8% by 2030 and the number of active older drivers is consequently growing (IIHS, 2011). In 2010, there were 34 million licensed drivers aged 65 and older, representing a 22% increase from 2001. Comparatively, the total number of licensed drivers increased only 10% over that period (NHTSA, 2012). The following section will briefly review the aging and driving literatures, beginning with an overview of crash risk for older drivers.

2.2.1 Older Driver Crash Risk

The increase in older drivers is concerning because older drivers account for a disproportionate number of crashes, particularly fatal crashes, per vehicle mile traveled (VMT). When crash rates per VMT are plotted as a function of age, a U-shaped function emerges, with young novice drivers and older adults representing significantly higher crash rates than young-middle aged experienced drivers (Figure 4; IIHS, 2011). In 2010, for example, 17% of fatal crashes involved a driver aged 65 or over, which represents a 3% increase in fatal crashes among older adults from 2009 and a 1% increase in total crash involvement (NHTSA, 2012).

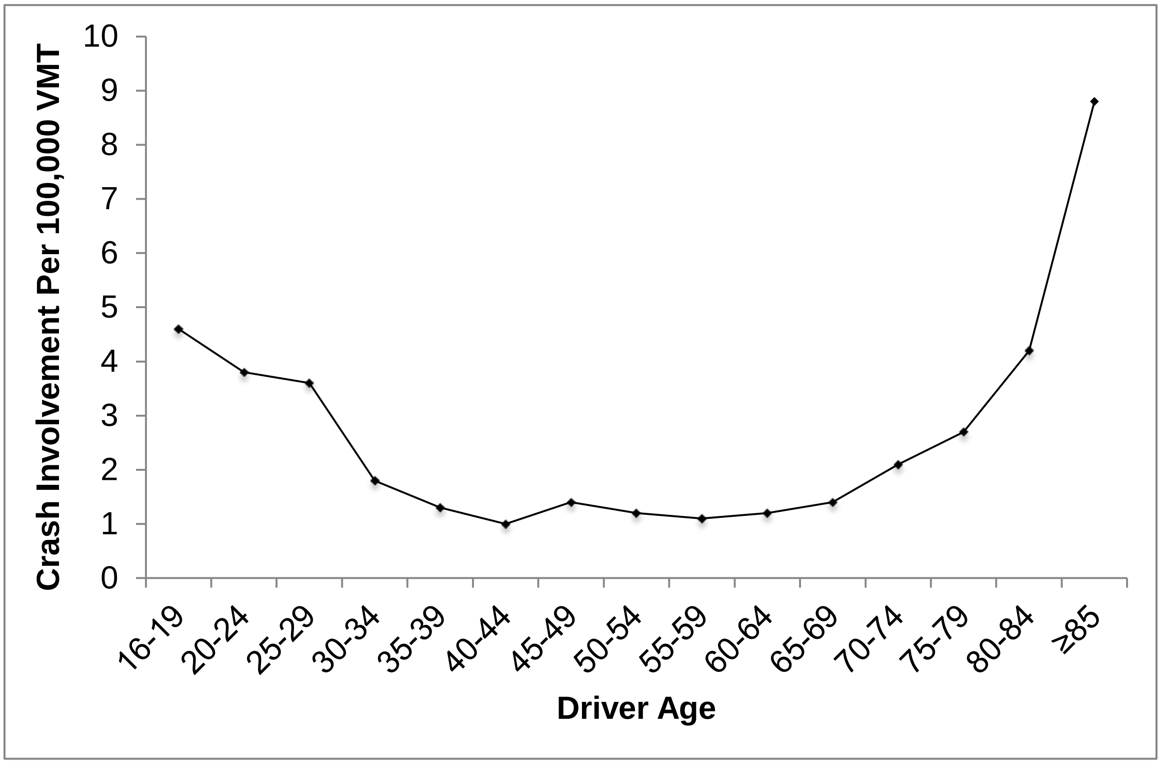


Figure 4. Data from IIHS, 2011. Crash involvement per 100,000 vehicle miles traveled (VMT).

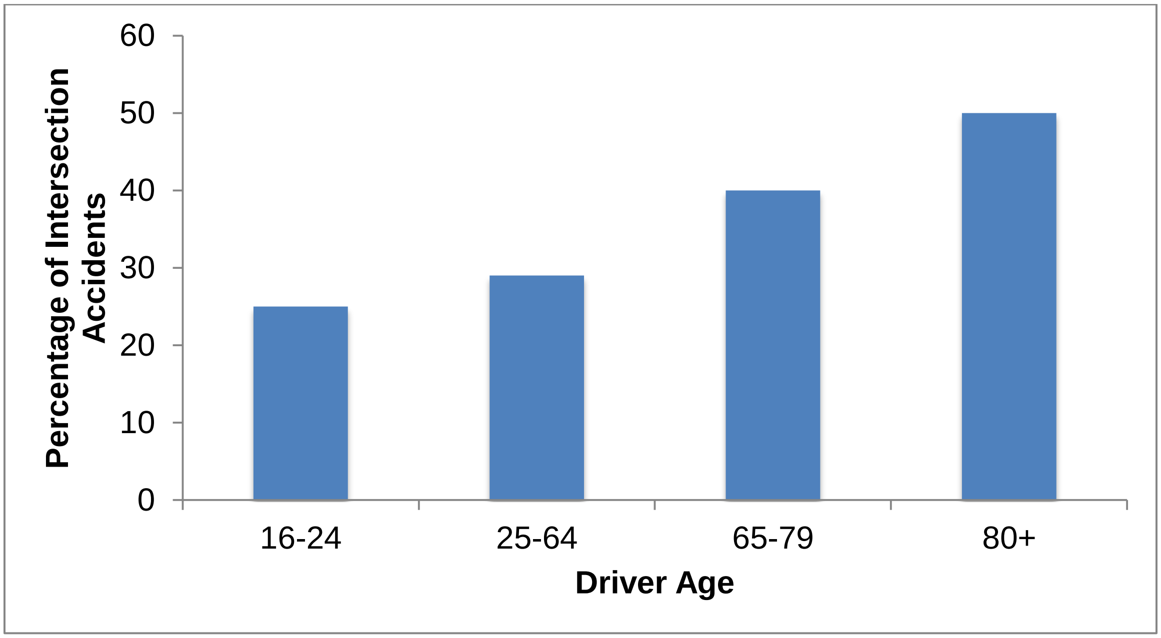
Lyman and colleagues (2002) used data from the Fatality Analysis Reporting System (FARS) from 1983, 1990, and 1995, along with estimated population data to project accident risk for older adults in 2020 and 2030. FARS data provide an index of fatal crashes within a given period. The authors projected that older drivers will account for 20% of fatal crashes in 2020 and 25% in 2030. Only young novice drivers are more likely to be involved in a crash, per VMT.

Increased fragility also contributes to higher fatality rates per VMT for older drivers. Li, Braver and Chen (2003) examined the contribution of fragility to the likelihood of a fatal crash across driver age groups and found that fragility was a significantly greater factor for older drivers than for younger adults (see also, Dellinger et al., 2002). Older drivers also pose a significant risk to their passengers and to other motorists and pedestrians. Braver and Trempel (2004) used data from fatal and non-fatal crashes in the U.S. to calculate injury rates for different groups of road users as a function of driver age. Older driver crashes resulted in higher rates of driver and passenger deaths and also a moderate increase in the likelihood of injury among occupants of other vehicles, largely due to the nature of older driver crashes (see below).

Such an increase in crash risk often leads older adults to cease driving. However, driving cessation leads to a number of negative consequences, including reduced involvement in out-of-home activities (Marottoli et al., 2000), greater likelihood of depression (Marottoli et al., 1997) and lower levels of perceived independence (Ragland et al., 2004). Driving cessation also places stress on family members or friends, who must assume driving responsibilities, and is often accompanied by relocation of the older adult to retirement homes (Hakamies-Blomqvist & Wahlstrom, 1998). Thus, it is very important to understand the factors that contribute to age-related increases in crash risk, beginning with an overview of the nature of these crashes.

Older drivers are overrepresented in specific types of crashes, particularly those occurring while turning at intersections. Stutts, Martell and Staplin (2009) used FARS and General Estimate System (GES; a representative sample of police reported crashes) data from 2002-2006 to examine characteristics associated with older driver crash involvement. Older drivers were particularly overrepresented in crashes at intersections, with crash involvement ratios generally above one. When intersection crashes were decomposed into driving maneuvers, they found that older drivers were most overrepresented in crashes during left turn maneuvers.

Chandraratna, Stamatinaidis and Stromberg (2006) compared odds ratios for older driver crash involvement for several different driving maneuvers. Odds ratios at intersections increased starting at age 65, and older drivers had odds ratios 3.2 times higher than younger experienced drivers. Braitman and colleagues (2007; Figure 5) used police crash reports, phone interviews and intersection photographs to examine the characteristics of at-fault intersection crashes among a sample of younger adults (age 35-54) and two samples of older adults (age 70-79 and 80+). Older driver crashes were more likely to result from failure to yield the right of way at intersections, especially when drivers were making left-hand turns at stop signs.



Figrue 5. Data from Braitman et al. (2007). Percentage of fatal driver accidents at intersections in 2006 by age group.

2.2.2 Factors Contributing to Older Driver Crashes

Unlike younger driver crashes, which are largely attributed to inexperience, older driver crashes have been attributed to deficits in myriad abilities that are related to driving performance, from physical factors such as reduced neck flexibility, to strategic differences. The following section reviews a subset of the literature on the proposed factors that contribute to older driver crashes.

Physical Ability. Advancing age is related to a decline in physical abilities as well as an increased risk for medical conditions, such as dementia. These factors contribute negatively to older driver crash risk. Neck and torso flexibility are especially critical to safe driving are known to decrease with age (Eby et al., 1991; Janke, 1994). Bulstode (1987), for instance, found that older drivers who reported joint pain tended to make fewer head turns and had to position the vehicle differently at intersections to see the road clearly. Janke (1994) found that older drivers with reduced neck flexibility made fewer side-to-side scans at intersections and checked their mirrors less frequently than more flexible drivers.

Falls risk is also associated with driving impairment and an increased risk for crashes among older drivers. Wood and colleagues (2008) found that, in a sample of older adult men, a history of falls was predictive of crash history (see also Hoggarth et al., 2010). Margolis and colleagues (2002) examined several physical measures and driving accident history in a sample of 1,416 elderly women. After adjusting for miles driven, falls in the previous year were the best predictor of motor vehicle accidents over the same period. In a simulator study, Gaspar and colleagues (2013) compared response times to unexpected events such as lead vehicle braking or a pedestrian stepping into the road for older adults screened as high or low falls risk. High falls risk drivers responded significantly slower than low falls risk drivers, although there was no difference in simple response time on a computer task.

Declining Attention and Cognition. The driving environment contains a large amount of information the driver must process and quickly respond to. Drivers must additionally maintain control of their vehicle and predict when unexpected events are likely to occur. Safe drivers must be able to effectively allocate and switch attention among these different tasks. In the case of older drivers, cognitive declines, primarily in visual attention and executive control, are linked to increases in accident risk.

The Useful Field of View, the area within a fixation from which observers can extract information (Sanders, 1970), has received particular focus for its importance for older drivers. The size of the UFOV declines with advancing age (Sekuler et al., 2000) and, importantly, UFOV impairment predicts both prospective and retrospective accidents in older adults (see Clay et al., 2005, for a meta analysis) and is a better predictor than standard visual function, such as acuity (Owsley et al., 1991). There are some important limitations to research on the UFOV and driving, however. Several of these studies focus specifically on older drivers who score lowest on the UFOV, and the predictive validity of the UFOV for crashes in a broader population of older adults (i.e., with less-restricted UFOVs) is unclear (see Hoffman et al., 2005, for a discussion).

The ability to detect changes in driving scenes is also a critical component of driving performance, and has been related to older driver crash risk. Hoffman and colleagues (2005) developed a measure called DriverScan, a flicker change detection task with driving images (based on a change detection task developed by Pringle et al., 2001). DriverScan was a better predictor of subjectively rated simulator driving than the UFOV in a sample of older adults who were not screened for visual impairment.

Research suggests that age differences in executive function, the set of abilities related to planning, coordinating and executive function tasks, play a critical role in driving performance. Younger adults often outperform older adults on executive function tests, particularly the ability to perform two or more tasks simultaneously (Verhaeghen, 2003). Dual-task costs (i.e., the cost of performing two tasks concurrently versus performing each task separately) typically become exacerbated with age (Kray & Lindenberger, 2000; Tsang & Shaner, 1998; Kramer et al, 1999). Executive function plays a critical role in driving. Drivers must divide their attention among several areas within the driving scene and monitor for unexpected events that could become hazards. Additionally, drivers have to maintain physical control of the vehicle and plan a specific route. Research suggests that executive function predicts prospective and retrospective accident risk among older drivers (Daigneault et al., 2002; Anstey et al., 2011). Eby and colleagues also found that divided attention performance correlates with the number of angled vehicle collisions (Eby et al., 1998). A recent simulator study by Gaspar, Neider and Kramer (2013) also suggests that executive function is important for older driver performance. Lower scores on a computer-based dual-task measure were negatively correlated with driver response times in a high-fidelity simulator. Importantly, dual-task impairment was associated with both falls risk and driving performance, suggesting that executive function might be a common mechanism of performance in complex task performance (i.e., Baltes & Lindenberger, 1997; see also Issel et al., 2006).

Strategic Differences. In addition to (or perhaps because of) these physical and cognitive limitations, older drivers demonstrate consistent differences in driving behavior, particularly at intersections, which are thought to lead to more crashes.

Strategic differences in visual scanning appear to play a critical role in older driver crashes, particularly at intersections. Romoser and Fisher (2009, Experiment 1) compared the scanning behavior of experienced younger and older drivers as they navigated several simulated intersections. They were particularly interested in the frequency of *secondary glances*, looks in the direction of oncoming traffic once the driver initiates a turn. During a left turn, for example, drivers should make a secondary glance to the left to scan for approaching traffic before pulling out into the intersection. Secondary glances allow drivers to notice additional information, such as a car that might have been occluded, before entering the intersection. Romoser and Fisher

(2009) found that younger drivers made three times as many secondary glances as older drivers (Figure 6).

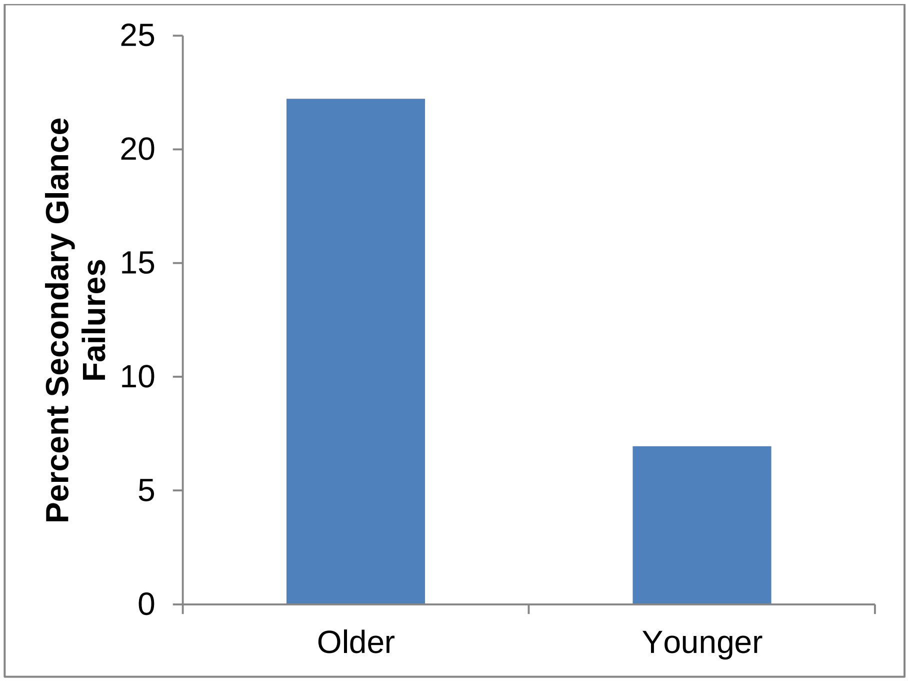


Figure 6. Data from Romoser & Fisher (2009). Percentage of failures to make a secondary glance during simulated intersection driving for young and older adults (pre-training).

Using an eye tracker, Romoser and colleagues (2013) recorded younger and older drivers' eye movements as they drove through simulated intersections. Older drivers focused predominantly on the future path of their vehicle, whereas younger drivers tended to look outside their travel path more frequently, suggesting that older adults are more likely to miss information that falls outside of the projected path of travel. The centrally focused scanning strategy of older adults is similar to the reduction in scanning area Recarte and Nunes (2003) found for distracted younger drivers.

In an on-road study, Bao and Boyle (2009) compared the scanning patterns of young, middle-aged and older drivers at busy intersections. Older drivers tended to concentrate more on one area of the driving scene and scanned a restricted range compared to middle-aged drivers. Bao and Boyle also calculated entropy rates as an index of the randomness of scanning. Higher entropy indicates that drivers scanned more areas for shorter periods of time, and thus may have been more likely to detect an unexpected target. Across several types of driving maneuvers (going straight, turning left, turning right), older drivers had significantly lower scanning entropy, demonstrating that they tended to focus on smaller portions of the scene for longer periods compared to middle aged drivers.

In addition to scanning strategies, research also suggests that older adults are slower than younger drivers to respond to unexpected events. Horswill and colleagues (2008) developed a hazard perception test battery to identify how quickly drivers identify unexpected critical events in a series of video clips recorded from the driver’s perspective. Older adults took significantly longer to identify potential hazards in driving scenes than did young adults. Horswill and colleagues also (2010) also showed that identification times on this hazard perception test predicted response times to unexpected events in a driving simulator. Horswill and colleagues also found negative correlations between cognitive measures such as the UFOV and hazard detection times.

Much of the age-related delay in response time appears to be due to slower hazard identification. Caird and colleagues (2005) used a flicker change detection task with intersection images. The participants’ goal was to decide whether or not it was safe to proceed through each intersection as quickly as possible. Some image pairs contained a critical object (e.g., pedestrian, vehicle) that changed when the images alternated, thus changing whether it was safe for a driver to proceed. Younger experienced drivers made significantly more correct go/no-go decisions than did older drivers, suggesting that older drivers were more likely to miss critical changes and had greater difficulty identifying hazards compared to younger adults.

These experimental results are supported by the epidemiological data collected by Braitman and colleagues (2007). Older driver intersection accidents are largely attributable to missing critical information. Phone interviews indicated that search and detection errors (e.g. “did not see the other car”) were the most common reasons cited for intersection crashes. Importantly, compared to younger drivers, older drivers reported making significantly more of these errors, and also reported more evaluation errors (e.g. “thought I had time to proceed”) and misjudgment errors (e.g. “thought the vehicle was going slower”). Reinfurt and colleagues (2000) similarly found that older drivers were more likely to cite “failed to see” as the cause of an at-fault collision than were younger drivers.

2.3 Older Driver Distraction

Although older drivers are currently less likely to engage in distracting activities, the number of distracted older drivers continues to grow as the driving population ages and as new generations, who are more comfortable with mobile technology (e.g., “Baby Boomers”), continue to age (Charlton et al., 2013). Thus, it is important to understand whether older drivers show increased dual-task costs, to understand the conditions in which these costs occur, and to investigate strategies for offsetting distraction.

Research generally suggests that, compared to younger drivers, older drivers are more susceptible to the costs of cognitive distraction, resulting from declining cognitive and attentional abilities. In a meta-analysis examining the effects of cell phone conversations on driving performance, Caird and colleagues (2008) included age as a moderator variable. Age was related with slower driving response times overall, but older drivers show greater costs compared to younger drivers of cell phone conversations (see also Brookhuis et al., 1993; McCarley et al., 2004; McPhee et al., 2004).

However, research has yet to compare the effect of passenger and cell phone conversations for older driver performance. Crash data generally suggests that having a passenger in the vehicle is associated with lower crash risk. Bedard and Meyers (2004) examined FARS data from 1975 to 1998 for U.S. drivers and found that passengers lowered odds ratios for crashes among older drivers (see also Lam et al., 2003; but see Hing et al., 2003). More recently, Braitman and colleagues (2013) analyzed data on fatal crashes in the U.S. between 2002 and 2009. Crash involvement was significantly lower for older adults driving with either younger or older passengers. The mechanisms behind the observed benefit of passengers for older drivers, however, are unclear. For instance, it could be the case that passenger help alert drivers by providing a second set of eyes on the road. However, it may also true that safer older drivers are simply more likely to drive with passengers and are able to resist any effects of distraction. Thus, it is important to better understand how passenger conversations affect older driver performance and whether there is a benefit over cell phone conversations.

Another critical question concerns how the driving environment affects the relationship between driver age and cognitive distraction. Many of the studies comparing the effects of cell phones on younger and older driver performance have used simple simulator or on-road assessments, such as following tasks (e.g., Strayer et al., 2004) or computer tasks with driving images (e.g., McCarley et al., 2004). Research from non-driving tasks, such as computer-based dual task tests or simulated street crossing, suggests that older adults are likely to show greater dual-task impairment when one or both of the concurrent tasks is challenging (Li et al., 2001). For instance, in a simulated street crossing task, Neider and colleagues (2011) found the largest age differences in success rates when the crossing task was difficult (smaller gaps between passing cars). This suggests that older drivers may be particularly susceptible to the costs of cognitive distraction in challenging driving situations, such as intersections and busy highways, where a majority of older driver crashes occur. In support of this, Braitman and colleagues (2013) found a reduced benefit of passengers for older drivers during intersection maneuvers.

CHAPTER 3: SUMMARY AND HYPOTHESES

The present study was designed to address two questions: 1) Are passenger and videophone conversations less distracting than cellphone conversations during intersection maneuvers? 2) Do older adults show a benefit of passenger and videophone conversations over cellphone conversations?

These questions are of both theoretical and practical importance. From a theoretical standpoint, previous computer-based studies have shown that older adults show greater costs to switching or dividing attention on simple tasks (Kray & Lindenberger, 2000; Tsang & Shaner, 1998; Kramer et al, 1999). Furthermore, older adults often demonstrate physical limitations, such as limited neck flexibility (Eby et al., 1995). However, older drivers also have considerably more experience behind the wheel, which might allow them to overcome physical and cognitive limitations. For example, Kramer and colleagues (2007) showed that older and younger drivers could benefit similarly from a collision warning system that alerted them to unexpected events, despite baseline age differences in reaction time.

From a practical perspective, the above questions are critical in the evaluation of the efficacy of the videophone intervention as a means toward mitigating driver distraction. To be an effective tool for reducing distraction, the videophone must show benefits across a range of situations that drivers typically encounter. Importantly, examining intersections addressed the question of how much information is needed to increase the situational awareness of the conversation partner. Whereas in the highway task most of the critical information (i.e., braking and merging cars) is presented on the front channel of the simulator and thus presented on the videophone, the critical information at intersections, specifically the locations of approaching vehicles from the left and right, happens outside of the videophone display (Figure 1).

For older drivers in particular, intersections pose one of the most demanding and high crash risk maneuver. Furthermore, the decision to include older drivers is also important, as the older driver population continues to grow and older drivers seek to maintain prolonged independence, of which driving is a critical component. If the videophone is effective in reducing older driver distraction, it might represent a strategy for prolonging independent driving.

Drivers were tested on simulated highway and intersection tasks. The highway task was a modified version of the simulation used by Gaspar and colleagues (in press). While this previous study showed a reduction in collision likelihood for the videophone condition relative to the cell phone condition, we were unable to determine whether these effects were driven by faster responses. Thus in the present highway task we standardized event timing (based on time-to-collision), which allowed for a more detailed analysis of response time as a function of age and task condition.

We specifically predicted that if passenger and videophone conversations reduce distraction compared to cellphone conversations, drivers would initiate faster brake responses to unexpected events. We further predicted that older drivers would generally respond slower than younger drivers. Importantly, we hypothesized that older drivers and conversation partners would be able to compensate for baseline response time differences with added experience, and thus that older drivers would show an equivalent benefit of passenger and videophone conversations over cell phone conversations in terms of response time. Based on previous results (Gaspar et al., in press), we predicted that there would be no effects of conversation condition on continuous vehicle control (i.e., speed, lane keeping).

The intersection task was modeled after the simulator drives from Romoser and Fisher (2009) that showed sensitivity to age differences. In this task, drivers navigated a series of six consecutive intersections with randomly generated oncoming traffic. We assessed driving performance by comparing how long drivers waited before turning, a metric that has shown sensitivity to age and cellphone distraction in a street crossing simulator (Neider et al., 2010; 2011). Furthermore, we examined visual scanning behavior, with a focus on the breadth of lateral scanning and frequency of secondary looks. We predicted that if passenger and videophones reduced cell phone distraction drivers would make faster turning decisions and make more secondary looks in the passenger and videophone conditions than in the cellphone condition. We also expected that older adults would make slower decisions (Neider et al., 2011) and complete fewer secondary looks compared to younger drivers (Romoser & Fisher, 2009). However, we hypothesized that older drivers would also benefit (i.e., make faster decisions and more secondary looks) from passenger and videophone conversations relative to cellphone conversations.

As in the previous study, we also coded and analyzed aspects of the pairs' conversations to gain insight into possible mechanisms driving distraction mitigation relative to cell phone conversations. For both the highway and intersection tasks, we computed measures of conversational complexity (number of utterances) as well references to traffic as a way to infer situational awareness. We also compared conversations during critical periods of each driving task (i.e., responding to hazards and making turning decision), to determine whether partners were alerting drivers or simply pausing during demanding periods. We predicted that conversation partners in the passenger and videophone condition would make fewer, shorter utterances and initiate more references to traffic than in the cellphone condition. We predicted that these conversational effects would be present in both driving tasks and for both driver age groups.

Finally, we also coded head turns made by the conversation partner in the passenger and videophone conditions to better understand what information conversation partners were using. We predicted that, similar to previous results (Gaspar et al., in press), passengers would spend a majority of their time looking straight ahead whereas partners in the videophone condition would divide their gaze time evenly between the driver's face and driving scene. We did not predict a difference between younger and older drivers, nor did we expect a difference between driving tasks.

CHAPTER 4: METHODS

4.1 METHOD

4.1.1 Screening and participants

Participants were recruited via advertisements in the Urbana-Champaign community and from a database of participants for other (non-driving) studies. All drivers had valid driver's licenses, at least 3 years driving experience, normal color vision and were free of medical conditions preventing safe driving or license restriction. Prior to enrollment in the study, potential participants completed a screening session for simulator sickness (Domeyer et al., 2013). In total, 102 younger adults and 150 older adults completed the screening session, with 78% of younger adults and 53% of older adults passing.

80 younger (mean age = 21.57, SD = 2.42) and 80 older (mean age = 67.28, SD = 4.73) adults who passed the screening and agreed to return were randomly paired (young/young, old/old). Two young pairs and two older pairs experienced motion sickness during the second session and these pairs were excluded from the study, resulting in a final total of 38 young adult pairs and 38 older adult pairs. Demographic information is provided in Table 1.

Table 1. Demographic Information.

	Young (N = 76)	Older (N = 76)
Age (years)	21.6 (2.4)	67.3 (4.7)
# Female	35	38
Years licensed*	5.2 (3.5)	49.4 (17.8)
Self-reported accidents (last 3 years)	11	15
Timed-Up-and-Go (s)*	7.90 (.23)	9.74 (1.4)
Total falls	0	11

4.1.2 Apparatus

The high-fidelity driving simulator at the Beckman Institute's Illinois Simulator Lab was used to assess driving performance. The simulator consists of a fully-instrumented Saturn surrounded by 8 projected screens, creating a 360 degree field of view (Figure 7). Driving assessments were created using Hyperdrive Authoring Suite and custom scripts. A dashboard-mounted SmartEye eye tracker collected head tracking. Data was collected at 60Hz. To assess simulator sickness, participants completed simulator sickness questionnaires (Kennedy et al., 1993) before and after driving.

Figure 7. The Beckman Institute Driving Simulator at the Illinois Simulator Lab.

4.1.3 Driving Tasks

Highway Task. Participants drove along a busy three-lane highway for eight minutes. Drivers were instructed to maintain 55mph and to stay in the center of the central lane. Nine vehicles (6 ahead, 3 behind) surrounded the drivers, creating a busy highway drive with dense traffic. The position of the cars varied throughout the drive and was based on time-to-contact (TTC) from the driver's vehicle. That is, if the driver increased his or her speed, the speed of the surrounding cars also increased.

To examine the impact of conversations on hazard responses, two types of events were triggered at random, pre-determined points throughout the drive. *Forward Braking Events* comprised the vehicle in front of the driver braking suddenly. All forward braking events were triggered when TTC was 2.12s. For *Merging Events,* the nearest vehicle in the left or right adjacent lane was positioned 12m from the driver's vehicle and then merged suddenly into the driver's lane. TTC for merging events was set to 2s immediately before the vehicle merged towards the driver. Pilot testing and previous experience (i.e., Gaspar et al., in press) showed that collisions were very disconcerting, particularly for older adults, because the event vehicle moved directly through the drivers vehicle in the absence of collision dynamics. Therefore, we prevented collisions from occurring during either event by stopping the event vehicle five feet from the participant when a collision was imminent (i.e., when response time was longer than TTC). Six forward braking events and eight side object events (4 left and 4 right) were triggered in each drive. Four versions of the highway task were developed, each with randomized event order and locations, and the order of these versions was counterbalanced across subjects.

Intersection Task. The intersection task was based on the simulator assessment developed by Romoser and Fisher (2009). Drivers drove through six intersections. The task was comprised of two left turns, two right turns and one straight maneuver. Each drive began with the driver located behind a lead vehicle (LV), which executed a left or right turn or proceeded straight through the intersection. Drivers were instructed to approach the intersection slowly and to turn in the same direction as the LV, but were told they did not need to follow closely.

Oncoming traffic was generated from the driver's left and right. Vehicles were generated 137m from to the left and right of the center of the intersection at a 5-10s interval, which generated gaps of varied size for the driver to select. For example, in Intersection 1 (Figure 8), the driver turned left from a two-lane to a four-lane urban road, with traffic flowing from the left and right. Thus, participants drove through the same six intersections in each condition, but traffic generation created a unique series of gaps for each trial. The complete list of intersections with descriptions is provided in Appendix A.

Figure 8. Diagram of Intersection 1. Driver approaches an urban four-lane from a two-lane road and makes a left turn. Traffic flows from the left and right and does not stop. Buildings block the driver's view. Driver should make a secondary look right before turning.

Pilot testing revealed simulator sickness was most likely during the turning portion of the drive. To minimize simulator sickness, drivers were instructed to press a button on the steering, which initiated a slow, computer-controlled turn where participants did not control speed, as the screen dimmed and the task proceeded to the next trial. To avoid participants changing their driving behavior as the result of a crash during the intersection task, we prevented collisions by controlling vehicle dynamics if a collision was imminent (similar to Romoser & Fisher, 2009).

4.1.4 Secondary Task Conditions and Procedure (Figure 1).

The experiment was a within-subjects design consisting of four blocks of conversation conditions. Upon entering the lab, one member of the pair was randomly assigned as the driver and the other member served as the conversation partner throughout the entire session. For each block, the driver completed one block consisting of both the Highway and Intersection tests. In 3 of the 4 blocks, pairs were engaged in naturalistic conversations (Gaspar et al., in press).

1. Drive-Alone. The driver drove without conversing.

2. Passenger Conversation. The driver drove while conversing with the conversation partner as an in-car passenger.

3. *Cell Phone Conversation.* The driver and conversation partner conversed remotely via a hands-free microphone and speaker. The conversation partner, located in a separate room, is unable to see the driver or the driving simulator.

4. Videophone Conversation. The driver and conversation partner conversed remotely, as in the cell phone condition. However, this time the conversation partner could see live video of the driver and driving scene presented on two 19-inch displays. The driver feed was a live camera mounted unobtrusively on the car's dashboard. For the driving scene, the front of the 8 projected simulator images was duplicated and presented to the conversation partner.

At the start of each drive, one member of the pair (counterbalanced order) began telling a story about a trip they had taken. Within a short period, pairs began conversing naturally. The pair was given no further instructions other than to continue talking. The order of the conversation conditions was counterbalanced across participants. To further minimize the incidence of simulator sickness, participants completed all four highway drives, followed by all four intersection drives, and pairs had the chance to rest between each drive. The entire session lasted 1.5 hours.

CHAPTER 5. RESULTS AND DISCUSSION

The following section contains measures of driving performance, eye tracking, and conversation for the highway and intersection tasks separately. Driving and eye tracking data were reduced and analyzed with custom MatLab scripts. Conversation recordings were coded by independent raters using custom software and analyzed with MatLab scripts.

5.1. Highway Driving Task

38 pairs of younger and 38 pairs of older adults completed the highway task and were included in the following analyses. Based on previous results (Gaspar et al., in press), it was predicted that the videophone would reduce, but not eliminate, the costs of distraction during the highway task relative to the cell phone. Driving performance was defined by response time to discrete hazards and by continuous measures of vehicle control including speed and lane keeping. To then understand whether any changes to driving performance resulted from changes in situational awareness, we compared the overall length of utterances by the driver and partner as well as references to traffic. These analyses were conducted as mixed-factor ANOVAs with conversation condition as a within-subjects factor and age as a between-subjects factor. Where appropriate, planned comparisons were used to compare individual conditions.

In addition to these established measures, the analysis also includes several exploratory measures to provide further insight into how conversation condition affected driving performance for younger and older drivers. To determine whether conversation condition affected drivers' visual scanning, we estimated the breadth of visual scanning from the eye tracking data. Additional conversational measures were also computed, specifically to provide insight into conversation partner behavior during critical events (e.g., when a vehicle was merging over). Because these analyses were defined a-priori as exploratory, this precluded statistical comparison. However, descriptive data are provided in the following tables for all reported measures.

5.1.1. Driving Performance.

The first goal was to determine what effects conversation condition and age had on driving performance. Driving performance was quantified both in terms of discrete hazard responses as well as continuous vehicle control. Previous research using an earlier version of the highway task (Gaspar et al., in press) showed differences primarily in hazard responses. That is, the passenger and videophone conditions reduced the likelihood of collisions. Driving performance results are presented in Table 2.

Table 2. *Highway Driving Results*

	Young (N = 38)				Old (N = 38)			
Measure	Alone	Passenger	Videophone	Cellphone	Alone	Passenger	Videophone	Cellphone
Merge event brake RT (s)	1.31 (.27)	1.36 (.27)	1.38 (.27)	1.46 (.36)	1.27 (.23)	1.33 (.26)	1.37 (.28)	1.45 (.18)
LV brake event brake RT (s)	1.08 (.19)	1.11 (.16)	1.13 (.20)	1.11 (.18)	1.06 (.14)	1.08 (.14)	1.12 (.19)	1.10 (.16)
(Hypothetical) collisions	1	3	1	2	5	3	8	4
Average Speed (mph)	61.5 (4.0)	62.4 (3.7)	61.2 (3.8)	62.5 (3.5)	56.0 (4.5)	56.3 (4.0)	55.7 (4.0)	56.8 (3.6)
Standard Deviation Lane Position	.37 (.08)	.34 (.09)	.37 (.11)	.35 (.08)	.35 (.09)	.35 (.11)	.36 (.12)	.35 (.09)
Standard deviation lateral gaze position	.28 (.27)	.27 (.27)	.26 (.36)	.22 (.28)	.28 (.23)	.27 (.36)	.24 (.28)	.22 (.36)

All data are displayed as mean (SD).

Hazard Response Time. Because hazard events in the present study were triggered by TTC instead of distance, we were able to compare drivers' brake response times across events and conditions. Brake response time was defined as the time from the initiation of the event (i.e., the merging vehicle crossing over the lane line or the LV's brake light illuminating) until 5% depression of the brake pedal. For merging events, there was a significant main effect of conversation condition on brake response time ($F(3,72) = 11.056$, $p < .001$, $\eta^2_p = .135$). Drivers responded fastest in the drive-alone condition and slowest in the cell phone condition. Most importantly, drivers responded significantly faster in both the passenger ($t(37) = 3.827$, $p = .058$) and videophone ($t(37) = 50.25$, $p < .001$) conditions compared to the cell phone condition. Neither the main effect of age ($F(3,72) = .035$, $p = .991$, $\eta^2_p = .001$) nor the interaction between condition and age ($F(3,72) = .252$, $p = .617$, $\eta^2_p = .004$) reached significance.

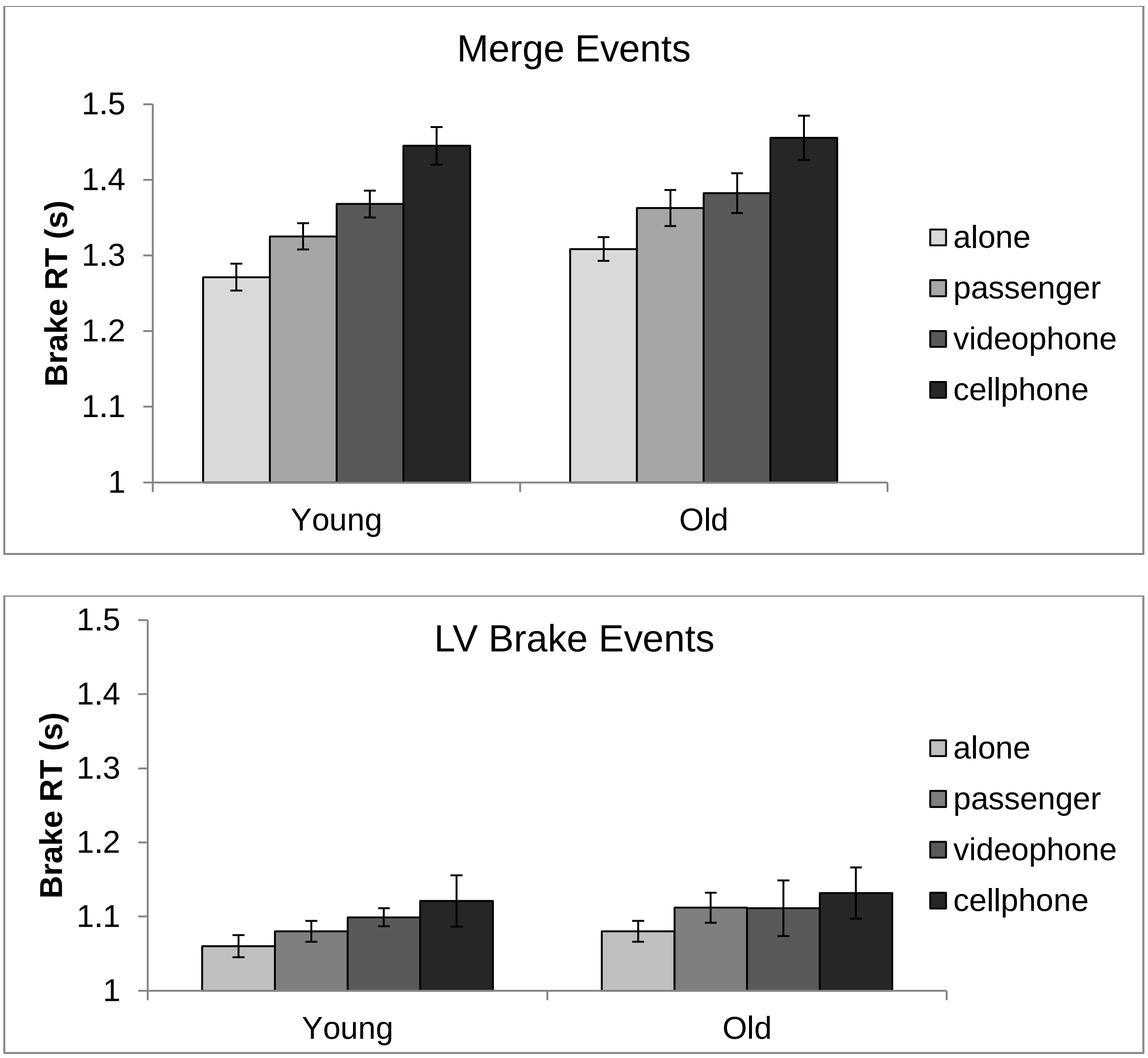


Figure 9. Brake response time to merging and lead vehicle braking events in the highway task. For each of the following figures, error bars represent within-subjects standard errors (Franz & Loftus, 2012).

For LV braking events, there was a significant main effect of conversation condition on brake response time ($F(3,72) = 2.782$, $p = .042$, $\eta^2_p = .042$). Pairwise comparisons showed that drivers responded faster in the drive-alone condition than in any of the conversation conditions and there was no difference between the conversation conditions (p's>.130). Importantly, neither the passenger ($t(37) = 1.556$, $p = .128$) nor videophone ($t(37) = 1.039$, $p = .306$) resulted in faster response times compared to the cell phone condition. Neither the main effect of age ($F(3,72) = .035$, $p = .991$, $\eta^2_p = .001$) nor the interaction between condition and age ($F(3,72) = .252$, $p = .617$, $\eta^2_p = .004$) reached significance.

Collisions. Because collisions were prevented, we were unable to directly assess collision frequency. However, because TTC was fixed for each event type (2.0s for merging events and 2.12s for LV brake events), we were able to compute the number of collisions that likely would have occurred. That is, if drivers responded slower than the initial TTC, a collision was likely to have occurred. For example, if a driver did not brake until 2.5s after the start of a merging event, a collision would have occurred had the program not intervened. Overall, very few collisions occurred and collisions were less frequent compared to the previous study (Gaspar et al., in press). The reduced number of (hypothetical) collisions may have been the result of reduced unpredictability of event onset and timing compared with the previous study. However, it is worth noting that overall more collisions occurred in the cell phone condition than in the passenger or videophone conditions.

Continuous Vehicle Control. The effects of conversation condition and age on vehicle control, including speed and lane keeping, were also compared. These measures excluded the 10s period after an event was triggered in order to remove discrete hazard responses. Speed was unaffected by conversation condition ($F(3,72) = 1.077$, $p = .303$, $\eta^2_p = .015$). There was a main effect of age on speed ($F(3,72) = 46.598$, $p < .001$, $\eta^2_p = .393$), with older drivers driving significantly slower than younger drivers. The condition by age interaction ($F(3,72) = .192$, $p = .663$, $\eta^2_p = .003$) was not significant. Lane keeping was defined by the standard deviation in lateral position, as measured from the center of the vehicle. Neither the main effect of conversation condition ($F(3,72) = .399$, $p = .530$, $\eta^2_p = .006$), age ($F(3,72) = .001$, $p = .984$, $\eta^2_p = .001$) or the condition by age interaction ($F(3,72) = .033$, $p = .856$, $\eta^2_p = .001$) approached significance.

Lateral Scanning. As an exploratory examination of how conversation condition affected drivers' visual scanning during the highway task, we computed the standard deviation in lateral gaze position as an approximation of the visual inspection window (Recarte & Nunes, 2003). Larger standard deviation in lateral gaze position indicates broader scanning, which might make it more likely that drivers would notice a hazard in their visual periphery. Standard deviation in lateral gaze position was slightly reduced for the cell phone condition compared to the no distraction condition. Importantly, there was a slight increase in lateral scanning in both the passenger and videophone conditions relative to the cell phone condition, indicating that driver scanning may have been less restricted when partners could see the driver and driving scene.

5.1.2. Conversations

The next goal was to determine whether the mitigation of driver distraction in the passenger and videophone conditions relative to the cell phone condition were associated with changes in conversation that are suggestive of enhanced situational awareness. This analysis first focused on the length of utterances and frequency of references to traffic, as these measures previously showed sensitivity to conversation condition and are thought to index shared situational awareness (Gaspar et al., in press; Drews et al., 2008). An exploratory analysis then focused on partner behavior during critical periods to suggest a mechanism by which passenger and videophone conversations speed brake response times relative to cell phone conversations. These conversational measures are reported in Table 3.

Utterances. To examine whether the conversation conditions changed the pattern of conversation, the average duration of driver and partner utterances was computed in each condition. For the duration driver utterances, the main effects of conversation condition ($F(2,73) = 2.209$, $p = .1171$, $\eta^2_p = .031$) and age ($F(2,73) = .168$, $p = .845$, $\eta^2_p = .002$), and the interaction between condition and age ($F(2,73) = 2.40$, $p = .098$, $\eta^2_p = .034$), were not significance. Of greater importance was whether partners' conversational patterns were affected by condition. There was a significant main effect of conversation condition on partner utterance duration ($F(2,73) = 23.372$, $p < .001$, $\eta^2_p = .262$). Planned comparisons revealed that partners made significantly shorter utterances in the passenger ($t(37) = 2.701$, $p = .011$; $t(37) = 5.308$, $p < .001$) and videophone ($t(37) = 2.491$, $p = .018$; $t(35) = 3.883$, $p = .001$) conditions compared to the cell phone condition. The main effect of age ($F(2,73) = 4.717$, $p = .012$, $\eta^2_p = .067$) and interaction between condition and age were not significant ($F(2,73) = 1.520$, $p = .226$, $\eta^2_p = .026$).

Table 3. *Highway Conversation Results*

	Young (N = 38)			Old (N = 38)		
Measure	Passenger	Videophone	Cellphone	Passenger	Videophone	Cellphone
Driver utterance duration (s)	5.00 (4.35)	4.28 (3.32)	3.97 (2.01)	3.36 (1.48)	3.33 (1.51)	3.06 (1.05)
Partner utterance duration (s)	3.94 (1.44)	4.25 (2.02)	5.66 (3.77)	3.60 (2.22)	3.89 (1.59)	4.64 (1.68)
Driver-initiated traffic references	6.36 (6.12)	6.8 (2.31)	2.61 (3.25)	6.29 (.005)	5.29 (2.77)	2.55 (3.97)
Partner-initiated traffic references	6.45 (3.85)	7.07 (4.22)	1.51 (1.78)	7.74 (2.30)	7.82 (2.73)	1.65 (1.19)
Driver pause duration (s)	3.72 (1.80)	3.61 (2.00)	2.57 (1.53)	5.02 (5.04)	4.43 (2.58)	3.12 (2.08)
Partner pause duration (s)	3.38 (2.29)	3.64 (2.11)	2.44 (1.70)	5.03 (4.91)	3.11 (2.17)	2.74 (3.00)
Total partner-initiated traffic references during critical periods	6	7	4	5	4	2
Proportion time partner pausing during critical periods	.81 (.09)	.82 (.12)	.69 (.15)	.84 (.10)	.82 (.11)	.68 (.16)

All data are displayed as mean (SD).

Traffic References. The frequency of traffic references provides insight into situational awareness, as they reflect the extent to which drivers and partners were attending the driving scene. The total number of driver- and partner-initiated traffic references was computed for each condition (Figure 10). There was a main effect of conversation condition on driver-initiated references ($F(2,73) = 6.300$, $p = .003$, $\eta^2_p = .085$), driven by an increase in driver-initiated references in the passenger condition compared to the videophone and cell phone conditions (p's $< .025$).

More importantly, for partner-initiated references, there was a main effect of conversation condition ($F(2,73) = 3.919$, $p = .024$, $\eta^2_p = .056$). Partner-initiated traffic references were more frequent in the passenger than in the cell phone condition ($t(37) = 3.399$, $p = .002$). Critically, partners also initiated more traffic references in the videophone condition than in the cell phone condition ($t(37) = 1.831$, $p = .038$). Neither the main effect of age ($F(2,73) = .003$, $p = .957$, $\eta^2_p = .002$) nor the interaction between condition and age ($F(2,73) = .046$, $p = .831$, $\eta^2_p = .001$) were significant.

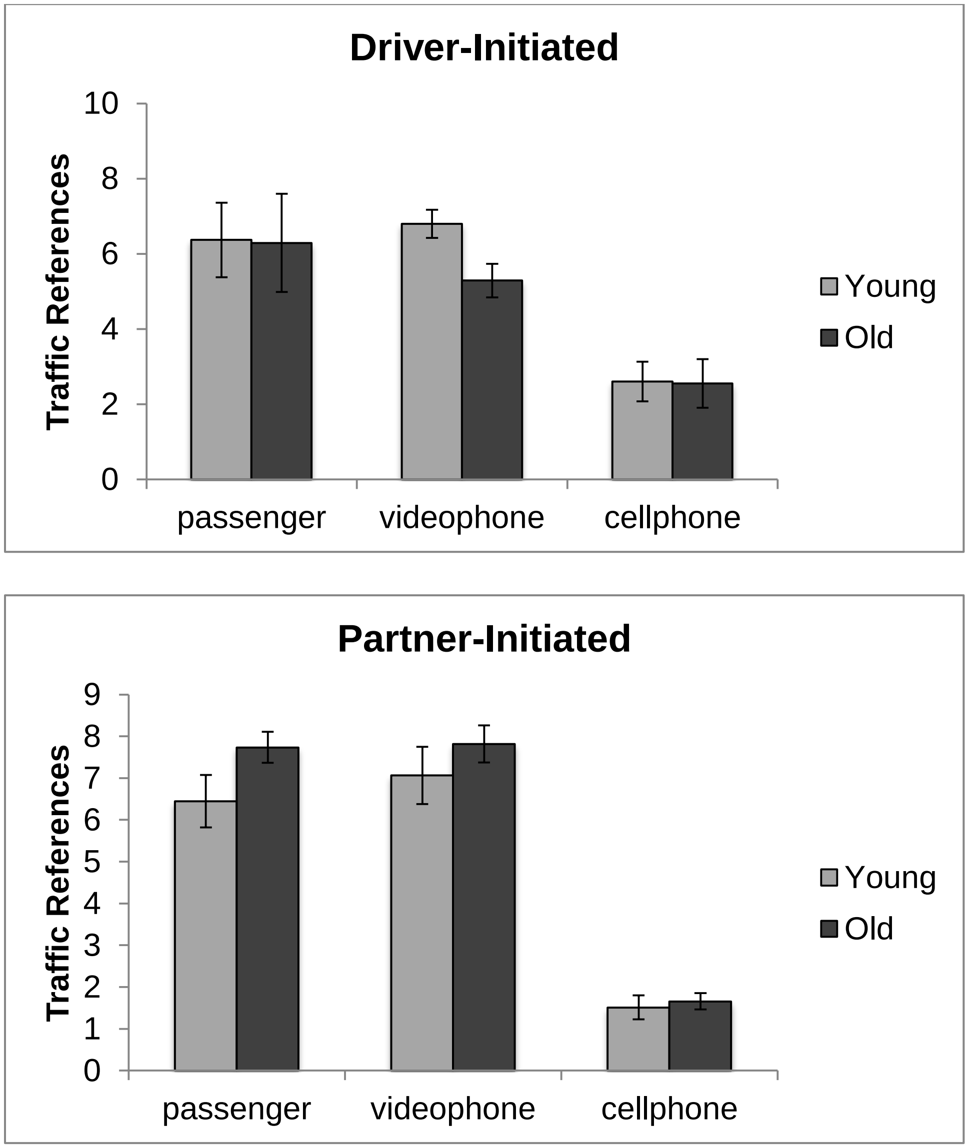


Figure 10. Driver- and partner-initiated traffic references in the highway task.

Critical Traffic References. To explore the frequency of partner alerting behavior (i.e., partners pointing out that a hazard event was occurring), we computed the total number of traffic references that occurred in the two seconds following the onset of an event. Because TTC was approximately two seconds for all events, if an alert did not occur during this period, it would not have helped the driver respond to an event. An increase in the number of partner traffic references during critical periods might suggest that one benefit of partners who can see the driving scene is to alert the driver. However, the frequency of alerts was quite low overall (only 2-7 total alerts per condition), suggesting that the primary benefit of passengers and videophone partners relative to cell phone partners was not due to partners being more likely to alert drivers to unexpected events.

Critical Pauses. Inspection of the video recordings suggested that conversation partners in the passenger and videophone conditions tended to pause their conversations during critical periods and resume conversing once the driver had safely responded. To examine this behavior, we computed the percentage of time conversation partners paused (i.e., were not talking) during the critical events across the three conditions. We compared the percentage of time the conversation paused (i.e., was not talking) in the critical region across the three conversation conditions. As predicted, on average, conversation partners paused more often in the passenger and videophone conditions (82-84% of time paused during critical periods) compared to the cell phone condition (68.5% of time paused). This suggests that instead of actively alerting drivers to the event, conversation partners may simply have paused to allow the driver to execute an undistracted response. This result is in accordance with the hypothesis that passengers and videophone partners had greater levels of situational awareness compared to cell phone partners.

5.1.3. Highway Discussion

To briefly summarize the results of the highway task, we found that younger and older drivers responded faster to unexpected merging events in the passenger and videophone conditions than in the cell phone condition. However, drivers did not show significant response time advantages for passenger or videophone conversations when responding to LV braking events. Faster response times would allow drivers to better avoid crashes with unexpected events, and most likely accounted for the differences in collision rates found previously with a similar paradigm (Gaspar et al., in press). Here, although (hypothetical) collisions were infrequent, the most collisions would have occurred in the cell phone condition. The present study also provides additional evidence that the mechanism underlying faster responses was enhanced situational awareness, as indicated by an increase in traffic references in the passenger and videophone conditions compared to the cell phone condition. Importantly, compared to the cell phone condition, the passenger and videophone conditions led to an in the frequency of pauses but not alerts during the critical event periods, suggesting that partners with views of the driving scene chose to pause their conversations when drivers were responding to critical events, thereby allowing the driver to focus on the driving task.

These results replicate the finding of Gaspar and colleagues (in press) that showed a primary benefit at the tactical level of vehicle control. In this study, neither average speed nor lateral vehicle control were affected by conversation condition, although older drivers did drive significantly slower than younger drivers. Importantly, these results also show that both younger and older drivers benefited from passenger and videophone conversations compared to cell phone conversations.

Importantly, the present study demonstrates that older drivers show a reduction in distraction and faster brake response times for the videophone compared to the cell phone. Additionally, younger and older drivers showed similar response times overall, suggesting that older drivers might overcome baseline slowing with experience. Older drivers and conversation partners also showed a similar increase in traffic references in the passenger and videophone conditions, suggesting enhanced situational awareness relative to the cell phone condition.

5.2. Intersection Task

Because of simulator sickness and data collection issues, 30 pairs of younger and 30 pairs of older adults completed the intersection task and were included in the following analyses. The primary goal of these analyses was to provide insight into whether the videophone condition could enhance situational awareness at intersections, and whether this led to a reduction in driver distraction relative to the cell phone condition. Limited research has explored both distraction and age effects in the context of intersection driving (see Romoser & Fisher, 2009 and Bao & Boyle, 2009, for notable exceptions). As such, the following analyses were classified as exploratory and do not include statistical comparisons. In addition, because the present study only included six intersections, the following measures were averaged across trials. Measures of driving performance were selected to assess driver decision making as well as the frequency of secondary glances, which have been implicated as a cause of older driver crashes (Romoser & Fisher, 2009). Additionally, we again compared conversational measures to provide insight into potential changes in shared situational awareness across conditions.

5.2.1. Driving Measures.

Wait Time. Decision making time, the time between when drivers stopped at an intersection until they initiated a turn, was used as an index of decision making. This time was calculated as the duration from reaching a complete stop (speed < 1mph and brake at least 50% depressed) until the driver pressed the button to initiate a computer-controlled turn. Longer decision times suggest that drivers had greater difficulty deciding when to execute a turn. In a simulated street crossing task, Neider and colleagues (20) found that cognitive distraction from a cell phone conversation increased the time it took participants to initiate a crossing. In the present study, younger drivers made slower turning decisions in the cell phone condition than in either the passenger or videophone conditions (Figure 11), suggesting that the videophone might help mitigate distraction. Overall, older adults took longer to initiate turns than younger drivers, and they also showed a reduced benefit for passenger and videophone conversations compared to cell phone conversations.

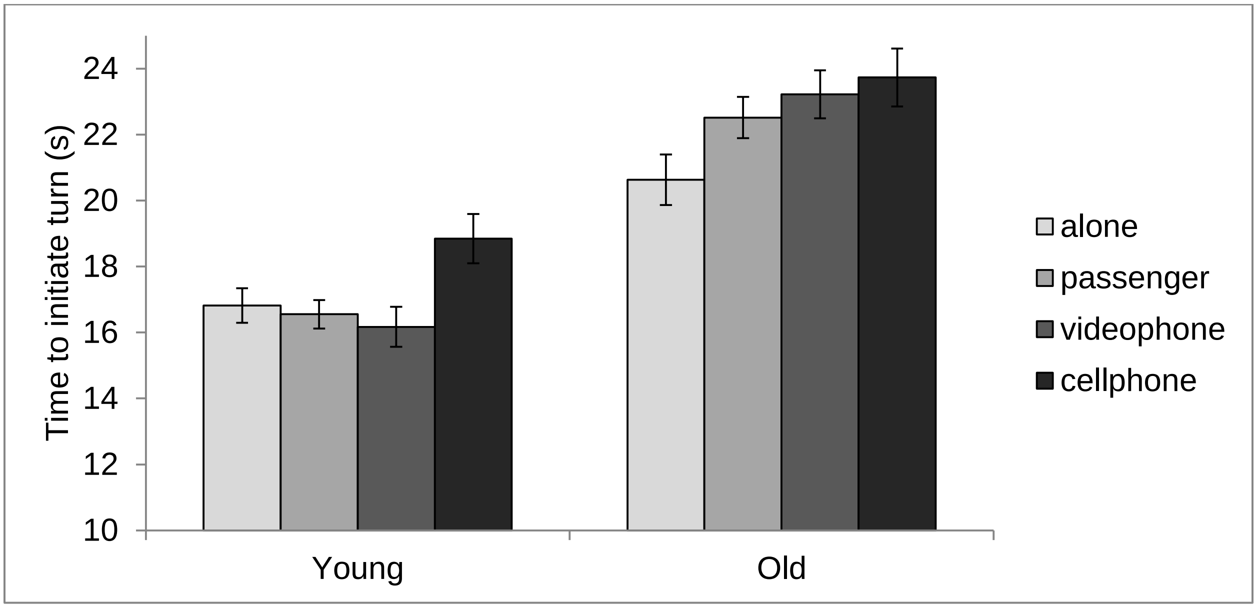


Figure 11. Time to initiate turns at intersections across condition and age. Error bars represent within-subjects standard errors (Franz & Loftus, 2012).

Secondary Looks. Secondary glances were computed using head tracking data to examine whether conversation condition and age affected drivers' visual scanning after a turn was initiated. A secondary glance was defined as a look opposite the direction of the turn (head movement greater than 15 degrees opposite turn direction) in the three seconds after the driver pressed the button to initiate the turn. For instance, during a left turn, a secondary look was identified if the driver looked back to the right after initiating the turn. The frequency of secondary looks did not vary across conversation conditions (Figure 12). As expected, younger drivers completed more secondary looks than older drivers.

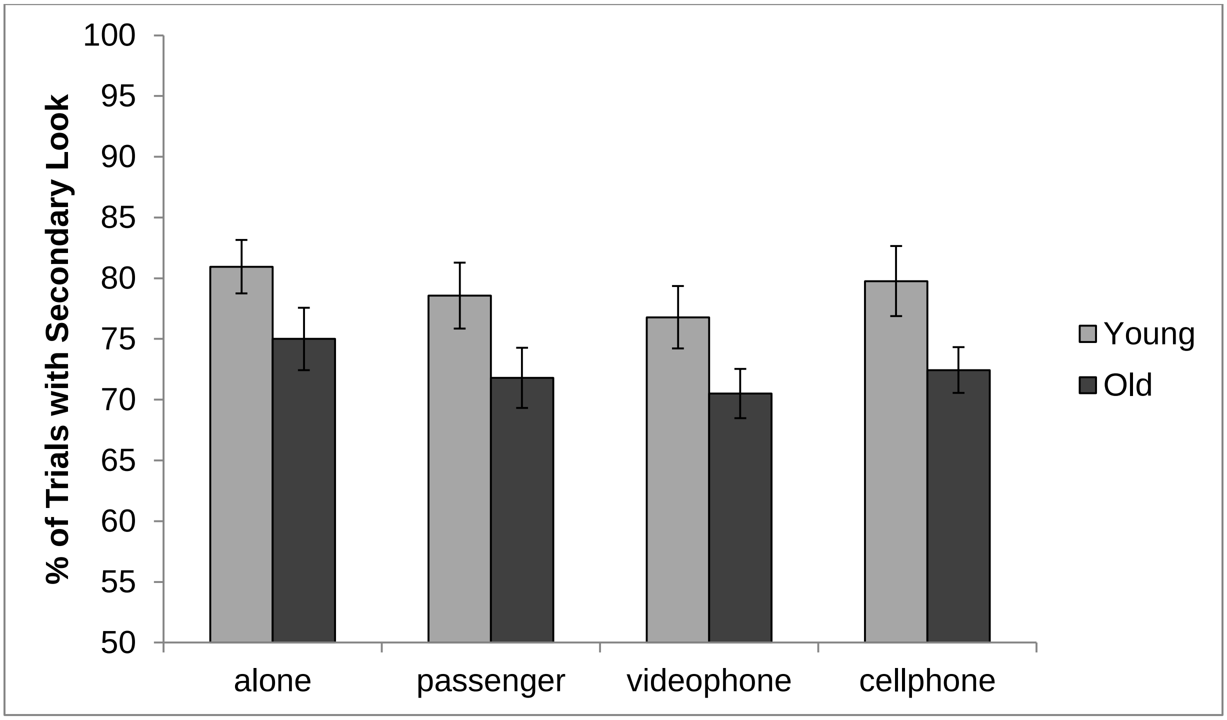


Figure 12. Percentage of trials in each condition where drivers executed a secondary look for young and older drivers. Error bars represent within-subjects standard errors (Franz & Loftus, 2012).

5.2.2. Conversations

The next goal was to determine whether the passenger and videophone conditions resulted in changes to conversations suggestive of improved situational awareness. We first compared the length of utterances and frequency of references to traffic, measures that showed sensitivity to distraction in the highway task and other studies (Gaspar et al., in press; Drews et al., 2008). Because differences between conversation conditions appear to have been most pronounced during the decision making phase of the intersection task, we also focused on the frequency of traffic references and pauses during these segments of each drive. All conversational measures are reported in Table 4.

Utterance Duration. The average duration of driver and partner utterances was calculated across the entire drive. The duration of driver utterances was similar across conditions for younger and older drivers. The duration of partner utterances increases slightly (0.5-1.0s) in the cell phone condition compared to the passenger and videophone conditions. Overall, the duration of driver and partner utterances was similar for younger and older adults.

Table 4. *Intersection Conversation Results*

	Young (N = 38)			Old (N = 38)		
Measure	Passenger	Videophone	Cellphone	Passenger	Videophone	Cellphone
Driver utterance duration (s)	2.43 (1.19)	2.25 (.68)	2.34 (1.37)	2.67 (2.02)	2.57 (1.38)	2.22 (1.24)
Partner utterance duration (s)	2.58 (1.32)	2.69 (1.31)	2.98 (.92)	2.77 (1.70)	2.55 (1.76)	3.32 (1.88)
Driver-initiated traffic references	6.67 (3.82)	4.20 (2.75)	2.10 (1.18)	5.67 (3.91)	3.97 (2.92)	1.63 (1.22)
Partner-initiated traffic references	4.00 (2.21)	3.73 (2.75(	1.23 (.85)	4.07 (2.88)	3.90 (2.43)	.83 (.75)
Driver pause duration (s)	4.39 (1.89)	4.20 (2.00)	3.00 (1.75)	5.42 (5.16)	5.08 (2.64)	3.52 (2.25)
Partner pause duration (s)	5.01 (1.90)	4.67 (2.14)	3.42 (1.81)	5.96 (5.19)	4.97 (2.65)	3.68 (2.24)
Proportion of partner-initiated traffic references during decision period	.69	.68	.51	.68	.71	.52
Proportion time partner pausing during decision period	.65	.56	.41	.68	.54	.40

All data are displayed as mean (SD).

Traffic References. The average number of traffic references in an individual trial was used as an index of situational awareness (Figure 13). On average, drivers made between two and seven references to traffic in each trial. The passenger condition resulted in the most driver traffic references (6.17), followed by the videophone condition (4.05), and then the cell phone condition (1.87). Most importantly, partners initiated more traffic references per intersection in the passenger (4.04) and videophone (3.82) conditions compared to the cell phone condition (1.03). These results suggest an increase in driver and partner situational awareness in the passenger and videophone conditions relative to the cell phone condition. Importantly, the increase in traffic references was observed for both young and older adults, both as drivers and as partners.

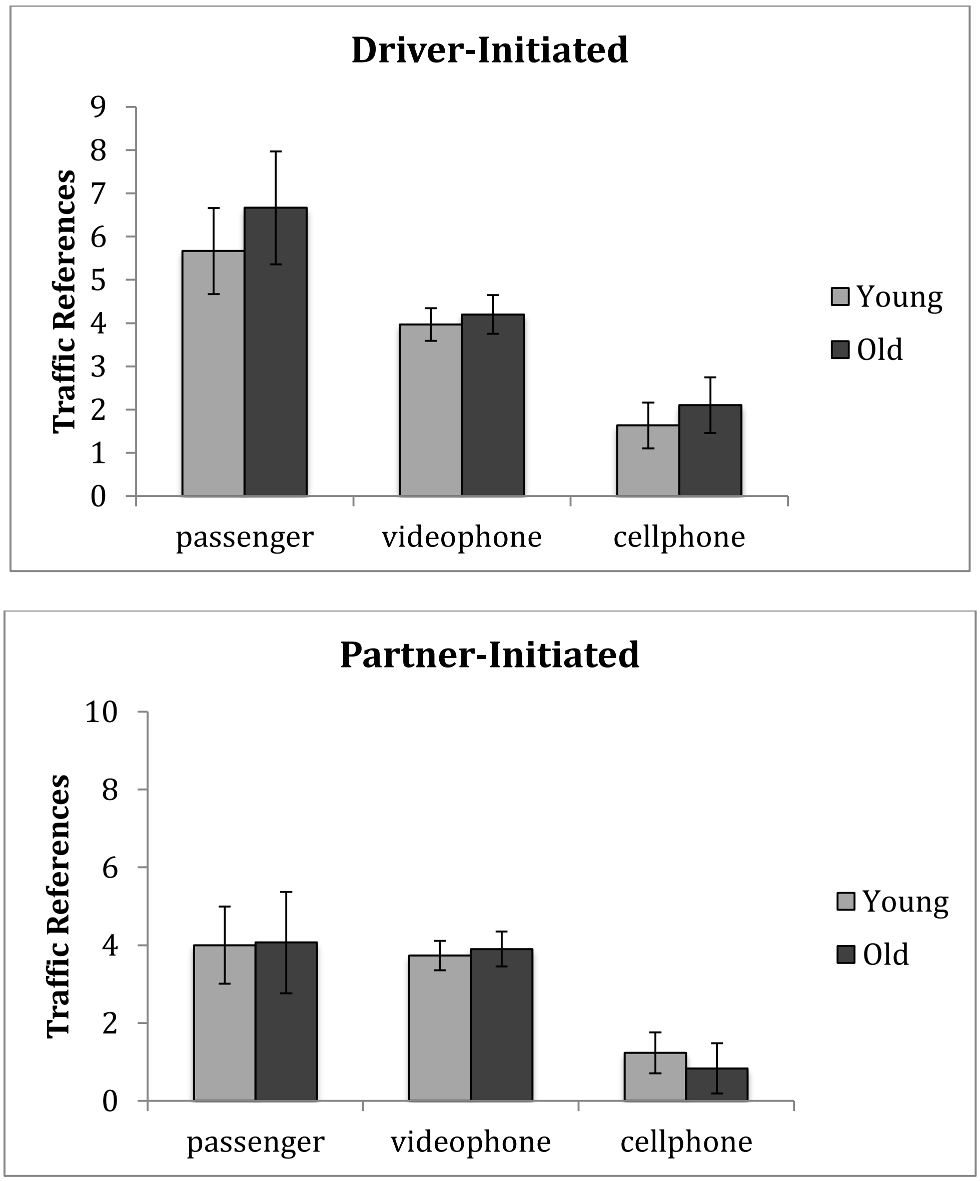


Figure 13. Driver- and partner-initiated traffic references in the intersection task. Error bars represent within-subjects standard errors (Franz & Loftus, 2012).

To examine whether conversation partners moderated their conversations during the period where drivers were deciding when to initiate a turn, we compared aspects of the partner's conversation across conditions. As suggested by Romoser and Fisher (2009), the period up to and including initiating a turn is theorized to play the most pivotal role in intersection crashes, particularly for older drivers. This period was again defined as the time between the driver reaching a full stop until pressing the button to initiate a turn.

Critical Traffic References. The frequency of partner-initiated traffic references during the decision period was first compared across conditions by computing the percentage of traffic references during a trial that occurred in the critical (decision) region. Partner-initiated traffic references during this period could help keep the driver focused on the driving task. A higher percentage of partner-initiated traffic references occurred here in the passenger (69%) and videophone (68%) conditions than in the cell phone condition (51%), and were consistent across age.

Critical Pauses. Inspection of the video recordings also suggested that conversation partners in the passenger and videophone conditions tended to pause as drivers were scanning the intersections and deciding when to initiate a turn. We compared the percentage of time the conversation paused (i.e., was not talking) in the critical region across the three conversation conditions. Partners tended to pause most often in the passenger condition (65% of the time) compared to 56% in the videophone condition and 41% in the cell phone condition. This provides some evidence that one result of providing conversation partners views of the driver and driving scene was an increase in pauses during the critical decision making period of the intersections.

5.2.3. Intersection Discussion

To summarize the exploratory results of the intersection task, conversing had a negative impact on decision making at intersections, with drivers waiting longer to initiate turns relative to the no distraction condition. Importantly, this cost was reduced in the passenger and videophone conditions relative to the cell phone condition. Increases in wait time in other tasks have been posited as an index of decision making efficiency (e.g., Neider et al., 2011).

Additionally, there was evidence that passenger and videophone conditions enhanced partner situational awareness relative to the cell phone condition. Passengers and videophone partners made more references to traffic per intersection compared to the cell phone condition. As in the highway task, conversation partners who were aware of the driving situation were more likely to pause than were partners in the cell phone condition, particularly during the most critical decision making period of a trial. Importantly, whereas younger drivers showed a reduced cost to decision making time in the passenger and videophone conditions, older drivers showed comparable costs to decision making time across all three conversation conditions compared to the baseline drive.

As expected, there were also general age differences in intersection driving performance. Older drivers were slower to initiate turns and were less likely to make secondary glances upon initiating a turn than were younger drivers. This replicates previous research showing significant reductions in secondary glance frequency and impaired decision making with age (Romoser & Fisher, 2009; Bao & Boyle, 2009).

5.3. Partner Looking Behavior

To examine conversation partners' distribution of attention when they had access to views of the driver and driving scene, we again had raters code partner glance behavior in the passenger and videophone conditions and computed the percentage of time the conversation partner looked at the driver versus the driving scene in the passenger and videophone conditions (Figure 14). Compared to the video condition, younger ($t(29) = 71.59$, $p < .001$) and older ($t(29) = 71.59$, $p < .001$) conversation partners in the passenger condition spent significantly more time looking at the road, and less time looking at the driver. In the videophone condition, however, partners' attention was evenly distributed for both the young ($t(29) = .417$, $p = .680$) and older ($t(29) = .211$, $p = .835$) drivers.

These results replicate and extend those of Gaspar and colleagues (in press), who showed that drivers spent significantly more time looking at the driving scene in the passenger condition but equivalent time looking at the driver and driving scene with the videophone. The present results demonstrate that partner glance patterns were unchanged by the driving tasks, or by driver age. Both younger and older drivers appear to have employed similar strategies of allocating their attention in the passenger and videophone conditions.

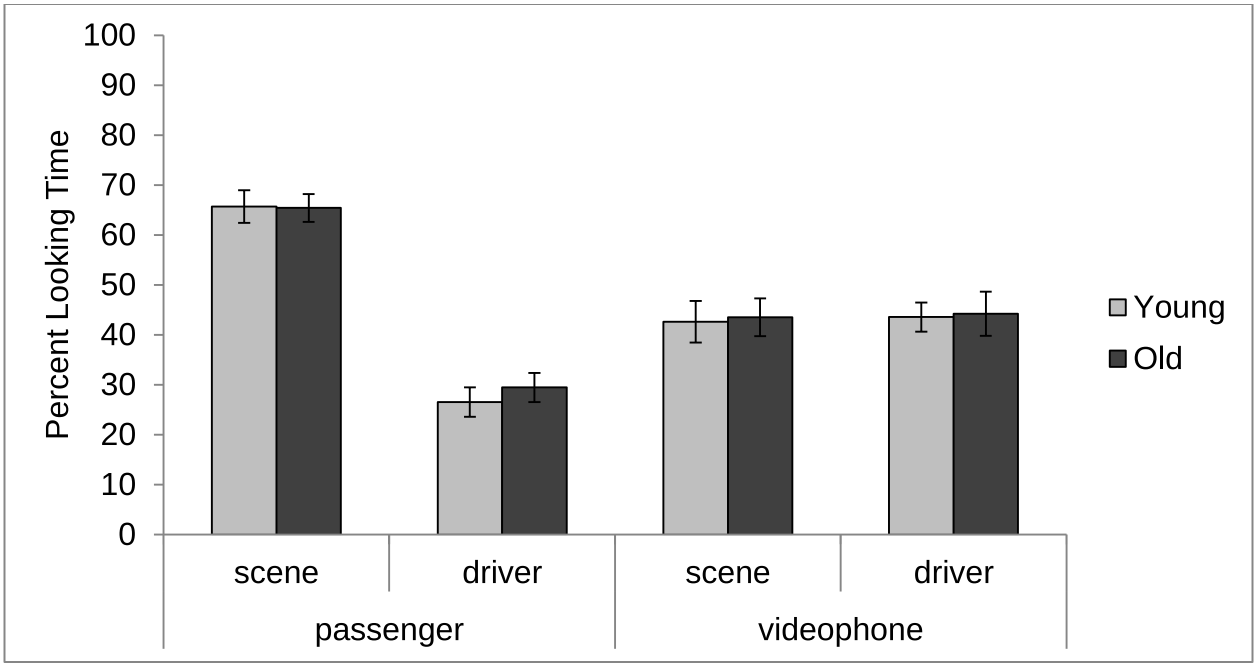


Figure 14. Percentage of time conversation partners spent looking at the driver and driving scene in the intersection task. Error bars represent within-subjects standard errors (Franz & Loftus, 2012).

To understand what might have prompted the videophone partner to spend a greater percentage of time looking at the driver's face compared to the passenger condition, we computed the percentage of time the videophone partner looked at the driver's face as a function of whether the driver was or was not talking (Figure 15). Videophone partners (both young and old) were more likely to look at the driver's face when the driver was talking. This suggests that conversation partners treated the videophone display somewhat like an in-person conversation, looking at the driver when he or she was talking but otherwise focusing on the driving scene.

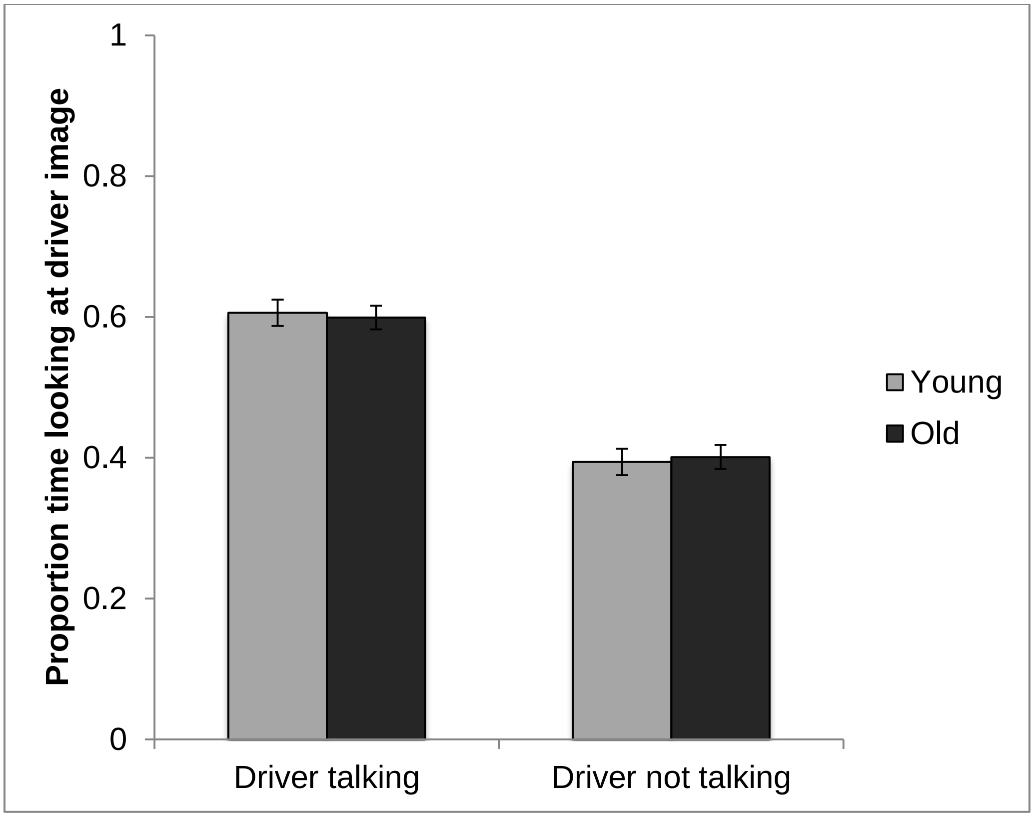


Figure 15. Percentage of time videophone partners looked at the image of the driver's face as a function of whether the driver was or was not talking. Error bars represent within-subjects standard errors (Franz & Loftus, 2012).

CHAPTER 6: GENERAL DISCUSSION

The present study provides important extensions of the driver distraction literature with respect to the relationship passenger, cell phone, and videophone conversations, as well as age differences in dual task performance. The following section discusses both theoretical and practical implications of the results.

Importantly, the present results replicate and extend the finding of a reduced cost for passenger and videophone conversations over cell phone conversations in the context of highway driving, particularly when responding to unexpected merging events. Similar to Gaspar et al. (in press), we found that the reduced costs of passenger and videophone conversations relative to cell phones were present primarily at the tactical level of driver control, which comprises control of the vehicle under hazard conditions (Michon, 1985) and is critical to avoiding crashes. Previous results showed that drivers were less likely to be involved in a collision with a merging vehicle when talking with a passenger or on a videophone than when talking on a cell phone (Gaspar et al., in press). Our results extend these findings by revealing the mechanism of collision avoidance. Drivers showed a diminished cost to response time to unexpected merges in the passenger and videophone conditions relative to the cell phone condition. Importantly, it bears mention that neither the present study nor the previous study (Gaspar et al., in press) found a reduced RT cost in responding to LV braking events. This suggests that the primary benefit of passenger and videophone conditions relative to cell phones for hazard responses is in responding to events in the periphery of the visual field, as opposed to directly in front of the driver where their gaze is likely to already be focused.

The present results further suggest that the reduced cost in hazard responses for passenger and videophone conditions was driven by changes in the pairs' conversations, likely as a result of changes in situational awareness. These results support the hypothesis proposed by Drews and Strayer (2008) that being able to view the driving scene led to enhanced situational awareness for the conversation partner, relative to the cell phone condition, and subsequently reduced distraction by altering the structure and content of conversations. Specifically, pairs, and particularly partners, changed the way they conversed in the passenger and videophone conditions during the highway task. Pairs made fewer, shorter utterances and more references to traffic, which supports the situational awareness hypothesis. The reduction in utterances likely reduced cognitive workload for drivers compared to the cell phone conversations, and the increase in traffic references is likely to have kept drivers' attention more focused on the driving task.

One critical caveat worth noting here is that the conversation partner, whether as a passenger or remote partner, must be actively attending the driving scene to engender the reduction in distraction relative to traditional cell phone conversations. Although the present study did not manipulate partner workload, a recent AAA study by Strayer and colleagues (2013) showed that distracting passenger conversations, where the passenger did not reference the driving scene, had a negative effect on driver performance similar to a hands-free phone conversation. This suggests that in order for videophone conversations to be effective in reducing cell phone distraction, conversation partners must remain undistracted and be engaged in the driving task. Whether remote videophone partners are willing to remain attentive and undistracted is an important question for future research.

The present study also attempted to determine whether the safety benefit of passenger and videophone conversations extends to intersection driving. Though exploratory, the results suggest that passenger and videophone conversations might reduce some of the costs associated with cell phone conversations. Drivers took longer to initiate turns in the cell phone condition, and longer turn initiation times are theorized to index impaired decision making (Neider et al., 2011). Furthermore, there was also evidence that videophones enhanced partner situational awareness relative to the cell phone condition. Compared to the cell phone condition, videophone partners made more references to traffic and paused more as drivers were initiating turns. Importantly, the reduction in the cost of distraction occurred despite videophone partners seeing only a subset of the driving scene without views of vehicles approaching from the left and right. Thus, it appears the just knowing that the driver is approaching an intersection is enough to change conversation patterns, such as pausing as the driver scans the intersection.

A theoretically and practically important question prompted by the present research is whether there is an additional benefit to providing videophone partners a broader view encompassing oncoming traffic. New technology, such as Google Glass, may allow video capture from the driver's point of view. It is unknown whether such additional information would be useful to conversation partners, and how that information might be presented. Furthermore, providing too much visual information risks overwhelming or disorienting the conversation partner. It is also important to point out that the benefits of passenger and videophone conversations relative to the cell phone condition were nearly identical. This suggests that there may be a limited benefit to providing videophone partners with more complete views of intersections. The amount of information provided to the conversation partner also likely has implications for partner workload and involvement in the driving task.

While much of the driver distraction literature has focused on simple driving tasks such as lead vehicle following (see Horrey & Wickens, 2004), less research has been devoted towards understanding the effects of cognitive distraction in more complex situations. Such research, however, is critical to enhancing the generalizability of simulator research to results commonly found in naturalistic driving. The present results demonstrate that cognitive distraction can disrupt certain intersection behaviors, such as deciding when to initiate a turn, but that visual scanning was largely unaffected by cognitive distraction.

The second critical question addressed by the present study was whether older drivers would show a reduced cost from videophone conversations compared to cell phone conversations. Younger and older drivers showed an equivalent decrease in brake response time to merging events in the passenger and videophone conditions compared to the cell phone condition. Furthermore, in no case did older drivers show greater costs from passenger or videophone conversations than did younger drivers. Finally, older drivers and conversation partners showed similar changes in conversation patterns, suggesting the passenger and videophone conversations enhanced older partner situational awareness to the same extent as younger adults compared to the cell phone condition. These data are supported by a study by Kramer and colleagues (2007) that showed that despite baseline differences in simple reaction time, older drivers could utilize a side collision warning system just as well as younger drivers. Our results support a similar conclusion, at least in the context of highway driving maneuvers.

From a theoretical perspective, it is likely that older adults were able to utilize their extensive driving experience, both as drivers and passengers, to overcome baseline physical and cognitive deficits. The expertise literature suggests that experts can utilize different strategies to offset age differences in factors like physical or cognitive ability (see Kramer & Morrow, in press). In the present study, we older conversation partners could draw on years of experience as drivers and passengers. From a practical standpoint, these results provide promising support for the efficacy of videophone interfaces in improving older driver safety during certain tasks.

As expected, older drivers showed deficits in intersection driving compared to younger drivers, particularly in terms of decision making and secondary looks. These results replicate the findings of Romoser and Fisher (2009), who showed that older drivers were significantly less likely to make secondary looks than younger drivers. Several explanations exist for age differences in scanning behavior at intersections and more work is needed to understand the complex relationship between age and crash risk.

Interestingly, although passengers spent most of their time looking out the windshield at the roadway, videophone partners, both young and old, distributed their gaze evenly between the driver's face and the driving scene in each driving task. These data replicate those of Gaspar and colleagues (in press) and shows that older passengers and videophone partners utilized a similar strategy as younger partners. This raises the question of whether the videophone interface could be optimized. One potential strategy would be to provide only the image of the driving scene via the videophone, as this is the information passenger viewed nearly exclusively. However, conversation partners may also find the videophone more engaging because they can see the driver's face and read non-verbal communication. Indeed, partners engaged with the videophone displays like they would with an in-person conversation.

Clearly, more data is needed to fully understand the potential benefits and drawbacks of videophone conversations across driving tasks and driver groups. For instance, more research is needed to establish whether the present simulator results can translate to on-road performance. Promisingly, Strayer and colleagues (2013) found that the effects of different secondary tasks were nearly identical in simulator and on-road (instrumented vehicle) assessments. In addition, understanding the efficacy of videophone conversations for novice drivers is a critical next step in this line of research. Young novice drivers represent the highest crash risk per VMT, and young drivers are also more likely to interact with technology, such as cell phones, while driving. Furthermore, young novice passengers are typically distracting, not helpful. Instead of having a protective effect, having novice passengers in the vehicle with novice drivers substantially increases crash risk.

It is also worth noting that more work is needed to understand how issues in the implementation of videophone interfaces might affect usability and driver safety. For example, older adults might have difficulty viewing small displays, such as a smart phone, which may limit the ability requisite information. Other factors, such as lag in video transmission, are beyond the scope of the present results but will be critical factors in future assessment of videophone interfaces for safe driving.

For the foreseeable future, drivers will continue to use cell phone while driving. The prevalence of in-car systems and voice controls increases the potential for distraction (Strayer et al., 2013). Providing remote conversation partners visual information thus far appears to be a promising way to enhance partner situational awareness and reduce driver distraction compared to talking on a cell phone.

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APPENDIX A.

Intersection 1. Driver approaches an urban four-lane from a two-lane road and makes a left turn. Traffic flows from the left and right and does not stop. Buildings block the driver’s view. Driver should make a secondary look right before turning.

Intersection 2. Driver approaches an urban four-lane road from two-lane road and proceeds straight. Traffic flows from the left and right and does not stop. Buildings block the driver's view.

Intersection 3. Driver approaches an urban four-lane from a two-lane road and makes a right turn. Traffic flows from the left and right and does not stop. Buildings block the driver’s view. Driver should make a secondary look left before turning.

Intersection 4. Driver approaches a two lane rural road from a two-lane road and makes a left turn. Traffic flows from the left and right and does not stop. Driver should make a secondary look left before turning.

Intersection 5. Driver approaches a two lane urban road from a two-lane road and makes a left turn. Traffic flows from the left and right and does not stop. Trees and buildings block the driver's view. Driver should make a secondary look right before turning.

Intersection 6. Driver approaches a two lane industrial road from a two-lane road and makes a left turn. Traffic flows from the left and right and does not stop. Trees block the driver's view to the left when stopped. Driver should make a secondary look left before turning.