THE EFFECTS OF AGING AND COGNITIVE DECREMENTS ON
SIMULATED DRIVING PERFORMANCE

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I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy with a major in Psychology/Human Factors.

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DEDICATION

To my parents who have provided encouragement and support throughout my lifetime.

To my husband Lynn who believed in me when I did not believe in myself, and who made it possible for me to follow my dream.

To my children, Stewart, Ben, Paige, and Terry, who are my cheering section.
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ABSTRACT

While most seniors are capable, conscientious drivers, some have experienced age-related declines in the skills that support safe driving, thus pose a hazard to themselves and to other road users. There seems to be agreement that older adults should stop driving when their skills have declined to the point that they pose a risk to themselves and others, but there are few guidelines to aid older drivers or their families in determining when one should no longer drive. This study was designed to identify driving behaviors and non-driving measures that predict hazardous driving errors such as leaving the roadway or hitting pedestrians other cars. Ten younger and 30 older adults participated in the study; older participants were divided into three groups of 10 based on performance on cognitive screening tests. Participants completed tests of attention, working memory, spatial memory and timing ability as well as simulated driving scenarios. The younger participants made significantly fewer hazardous errors than did the older drivers with poorer cognitive performance. Driving behaviors associated with increased hazardous errors in older participants included poor maintenance of lane position in low complexity condition and making abrupt lane changes when complexity increased. Poor performance on a measure of working memory and on an anticipation timing task were also associated with increased hazardous errors in the older participants.
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CHAPTER ONE
INTRODUCTION

Drivers over the age of 65 generally have a wealth of driving experience. They enhance their safety by avoiding driving at night, in poor weather, during rush hour, and when fatigued. (McGwin & Brown, 1999; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998), yet crash risk is higher for older adults than that of all but the youngest drivers (Cerrelli, 1998).

Older adult drivers are significantly more likely than middle-aged drivers to be in a crash (Darzins & Hull, 1999; McGwin & Brown, 1999; Ryan, Legge, & Rosman, 1998), with the crash risk for drivers over age 75 similar to that for teenaged drivers (Cerrelli, 1998). Between 1980 and 1989, overall crash fatalities in the United States declined by 20%, while fatalities for drivers aged 65 or over increased by 19% (Bedard, Stones, Guyatt, & Hirdes, 2001). It should be noted that a small proportion of older drivers contribute to this increase. When McGwin and Brown (1999) monitored traffic citation records of 426,408 drivers aged 60 and over for a period of six years, 79% had no traffic convictions; 89% of these drivers have been reported to be crash-free. Older drivers with a recent crash history have been found to drive more slowly than other drivers in an effort to reduce their crash risk (Daigneault, Joly, & Frigon, 2002a).

More seniors are driving than ever before (Bedard et al., 2001), and they drive more miles and postpone driving cessation longer than did previous cohorts (Massie, Campbell, & Williams, 1995), a trend that is expected to continue (Preusser et al., 1998). This is not surprising, given that seniors who drive are better able to remain independent, access services and participate in family and community life (Glasgow & Blakely, 2000). In focus
groups, older drivers expressed the intent to adapt their driving habits as their skills declined rather than giving up driving (Glasgow & Blakely, 2000; Yassuda, Wilson, & von Mering, 1997). Seniors equated driving cessation with a distressing loss of independence (Glasgow & Blakely, 2000). A focus group participant declared, “They will pry my cold dead hands off the wheel before I stop driving.” (Yassuda et al., 1997 page 534).

Driving Performance Measures

While statistics indicate that older adults driving skills tend to decline, there is disagreement in the literature concerning the appropriate way to measure driving performance for this age group. Crashes seem to offer a valid measure, given their cost to individuals and to society (Marottoli et al., 1997). The number of crashes per unit of distance driven provides a means of comparing the risk level across age groups that controls for drivers’ level of exposure, but this method may not accurately reflect the abilities of some drivers (Chipman, MacGregor, Smiley, & Lee-Goslin, 1993; Janke, 1991).

Crashes

An assumption that underlies the use of crashes per unit of distance driven is that each mile of roadway is similarly hazardous, but this is not the case. Janke (1991) reports that those who drive the most miles tend to frequent divided limited access highways where obstacles are relatively rare, so would be expected to have few crashes per mile. Conversely, those who drive the fewest miles, often the youngest and oldest drivers, log most of their miles on city streets with two-way traffic, numerous intersections per mile, and hazards such as parked cars and pedestrians. Chipman et al. (1993) reported similar findings: drivers who frequent rural roads have lower crash rates than those who drive
primarily in urban areas. Like highways, rural roadways have predictable traffic patterns and few intersections and hazards such as parked cars. One should take these considerations into account when interpreting crash rates based on number of miles driven.

In addition to controlling for exposure to risk in determining crash rates, one must determine which incidents to include. Self-reports of crash history are easy to obtain using questionnaires, and have been shown to be fairly reliable (Marottoli, 1997), but a number of researchers (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley, 1994) use only state-reported crashes to measure driving performance. These authors argue that self-reported crash data tend to be biased. A comparison of crashes reported by drivers with those included in state records revealed that drivers omitted some crashes included in state records (McGwin, Owsley & Ball, 1998). There were crashes reported by drivers that not included in state records; these were generally minor incidents that did not result in damage or injuries. Some authors argue that such trivial incidents are not important (McGwin, Owsley & Ball, 1998) while others contend that they may be important precursors of more serious crashes (Marottoli, 1997). State-reports offer crash data from a large number of drivers, which is advantageous when studying rare events (Marottoli, 1997), but only if the researcher can access them (McGwin et al., 1998). However, they may not include detailed descriptions of factors related to the crash that are likely to be of interest to the researcher. Details such as road and traffic conditions or whether the driver was distracted by a task such as adjusting the stereo or consulting a map are unlikely to be documented in a state report. While crash self-reports may be less accurate than those obtained from the state, they may provide a better source of information relevant to a study (Marottoli et al., 1997).
Despite their apparent utility, crashes may not be the optimal measure of age-related declines in driving capability. In addition to the difficulties cited above, crash data is likely to be confounded with a number of elements including exposure to crash risk, weather conditions, other drivers’ behavior and complexity of the driving situation (Marottoli et al., 1997). Alternative measures of driving performance include professional assessment of driving performance, either on the road or on a closed course, and driving simulator performance.

_Evaluating Driving Performance_

On-the-road driving evaluation is a credible means of evaluating an older adult’s ability to integrate the cognitive, sensory and motor tasks necessary to safe driving (Colsher & Wallace, 1993), particularly if the skills evaluated are those associated with crashes in this population (Hunt et al., 1997; McKnight & McKnight, 1999). An obstacle to conducting on-the-road research is insuring the safety of the participant, researcher and other drivers (Wood & Troutbeck, 1995). This risk can be reduced by the presence of a professional driving evaluator in the passenger seat with access to a brake pedal, who will intervene if necessary (Hunt et al., 1997). Other problems associated with on-the-road evaluations include difficulty in controlling the driving situation, and making the test difficult enough to tax participants’ abilities without making it unacceptably dangerous (Hunt et al., 1997; Wood & Troutbeck, 1994; Wood & Troutbeck, 1995).

Closed courses offer more control and reduce the risk to other drivers, but they may not incorporate some elements that are of interest in studying older drivers’ performance, including the ability to respond to unexpected actions of other drivers (Wood & Troutbeck,
1995). As with on-the-road driving, safety concerns may prevent incorporating tasks adequately difficult to tap the skills necessary to drive safely in complex conditions.

**Simulated Driving**

Driving simulators offer an alternative that maximizes safety and control at the cost of the more realistic experience offered by on-the-road and closed course evaluations. Simulators vary in the degree to which they replicate driving, but even the most sophisticated models afford only an approximation of a real driving experience. Few simulators incorporate feedback that allows a driver to have a feel for the road, regulate speed and safely navigate curves. In addition, simulator errors do not result in damage or injury (Wood & Troutbeck, 1995). Despite these limitations, studies have shown that simulator performance is predictive of real world driving. Simulator and on-the-road performances were similar in a study of the effects of a telephone dialing task on driving, although the effects of the dialing task were exaggerated in simulator performance (Reed & Green, 1999). Simulated driving performance was found to predict crash risk in a three-year prospective study involving older drivers (Cox & Taylor, 1999). Lee (2003) reported that simulator performance accounted for two-thirds of the variability in an on-the-road driving performance index.

Simulator motion sickness limits their utility in evaluating driving performance, particularly in older populations (Liu, Watson, & Miyazaki, 1999; Min, Chung, Min, & Sakamoto, 2004). Min and colleagues (2004) examined physiological changes associated with simulator sickness, and found significant changes from baseline in EEG and skin temperature readings after five minutes of simulated driving, while participants reported discomfort after ten minutes in the simulator. Simulators offer a safe, controlled means of
evaluating driving performance. Designs that incorporate short simulator scenarios separated by other tasks or breaks can prevent simulator sickness from limiting participants’ ability to complete the protocol.

Age-Related Changes that May Undermine Driving

The oldest and youngest drivers are more likely to be found at fault for a crash than are other drivers (McGwin & Brown, 1999; Preusser et al., 1998), but older and younger drivers tend to incur different types of crashes. Drivers under age 25 are most likely to be in single-vehicle crashes in which they have lost control of the car, possibly a result of the driver’s inexperience or risk-taking (McGwin & Brown, 1999). Conversely, an older driver is most likely to be in a multiple vehicle collision at an intersection (Daigneault, Joly, & Frigon, 2002b; McGwin & Brown, 1999; Preusser et al., 1998), often as a result of the older driver failing to respond to other traffic or to control lights or signs (Ryan et al., 1998). The authors of these studies emphasized that the older drivers did not intentionally disregard traffic control signals, but rather failed to notice them.

Older drivers with a recent crash history have been found to make errors rarely reported in other drivers. They tend to reject safe gaps when crossing traffic, take a path that is either too wide or too short when turning, maintain poor speed control (often driving too slowly), make position errors when merging, and make navigation errors (McKnight & McKnight, 1999). Why do older drivers, with their extensive experience and careful selection of safe driving times and routes, make these errors?
**Vision**

Because driving safely depends on responding to visual information, one would expect to find a relationship between visual acuity and crash risk. Decrements in vision that occur with normal aging seem to offer a reasonable explanation for the observed increase in older adults’ crash risk; however, the literature does not support this explanation. Studies have shown only a weak relationship between crash risk and measures of visual acuity (Burg, 1967; McGwin & Brown, 1999; Owsley, 1994). Perhaps this is not surprising given that visual functioning is generally tested using static high contrast stimuli in a quiet, well-lit environment. Conversely, driving tends to occur in a dynamic, noisy environment that has too much or too little light (Colsher & Wallace, 1993).

While the relationship between visual acuity and driving performance is weak, a stronger relationship has been reported between driving performance and measures of contrast sensitivity (McGwin, Chapman, & Owsley, 2000; Wood & Troutbeck, 1995). Cataracts, which occur with normal aging of the eye, result in the lens becoming increasingly opaque. This results in light being scattered as it enters the and consequently in reduced contrast sensitivity. Older drivers with cataracts have been reported to drive fewer days per week and to fewer destinations than those without cataracts; they also reported a higher crash rate than cataract-free drivers of similar age (Owsley, Stalvey, Wells, & Sloane, 1999). In a study evaluating the effects of impaired contrast sensitivity, older drivers with normal vision completed a closed driving course two times, once under normal viewing conditions and once with simulated cataracts. Researchers recorded the time to complete the course as well as participants’ responses to traffic signs and pedestrians, maintenance of lane position, and proficiency in maneuvering through a series of cones. In the simulated
cataract condition, participants took longer to complete the course, were less consistent in maintenance of lane position, and showed decrements in responding to potential hazards and maintaining lane position (Wood & Troutbeck, 1995). The authors propose that drivers with impaired contrast sensitivity may drive slowly in order to allow more time to detect and respond to hazards, while declines in maintenance of lane position and responses to peripheral targets indicate that this strategy is inadequate to compensate for their compromised vision.

Much of the literature on vision and driving deals with changes in the ability to detect or identify stationary targets; however, deficits in motion perception may impair driving safety. Studies have demonstrated an age-related decrease in the ability to detect and use motion information in two-dimensional (Atchley & Andersen, 1998; Wood & Bullimore, 1995) and three-dimensional stimuli (Andersen & Atchley, 1995). Wood and Bullimore (1995) found declines in motion detection, particularly in participants over the age of 70, within the age range at which crash risk increases over that of middle-aged adults (Brorsson, 1989; Darzins & Hull, 1999; McGwin & Brown, 1999; Ryan et al., 1998). Motion, whether viewed through the windshield or in a mirror, is likely to attract a driver’s attention, and alert him/her to a possible hazard. Thus, deficits in motion detection could result in increased crash risk for older drivers through degrading their ability to detect hazards.

**Cognition**

In addition to declines in vision, normal aging is associated with changes in brain structure, chemistry and function (Mattson, Chan, & Duan, 2002) which may impair an older adult’s ability to monitor the changing traffic environment, select an appropriate
responses to an unexpected event, and then coordinate and execute selected responses. Age-related changes in the ability to process and manage information quickly may underlie the observed decrements in driving performance.

*Working Memory.* Baddeley and Hitch (1974) described working memory as a system that allows one to hold information from the environment and from long-term memory temporarily, in order to manipulate it in performing cognitive tasks such as reasoning or comprehension. Baddeley’s tripartite model of working memory contains a visuo-spatial sketchpad that stores visual or spatial information, and a phonological loop that stores auditory information (see Figure 1). A central executive allocates attentional resources to these subsystems and carries out operations on the information they contain. The central executive is responsible for coordinating tasks, carrying out computation, and selecting and executing responses (Kramer, Hahn, & Gopher, 1999).

![Figure 1. Baddeley’s tripartite model of working memory.](image)


*Working Memory Capacity.* Tasks that place a substantial load on working memory capacity have been found to be problematic for older adults (Foos, 1989; Guerrier,
Manivannan, & Nair, 1999; Kramer et al., 1999). Foos (1989) offered evidence that working memory capacity declines with age. In this study, participants solved six sets of three two-digit addition problems (for example, $28 + 45; 33 + 39; 16 + 45$), and then reported all three sums. Participants over 60 years of age performed nearly as well as young and middle-aged adults on the first and third sums, but significantly worse on the second problem (Foos, 1989). The author offered these results as evidence that the older adults’ ability to process the information was similar to that of the younger participants, while their relatively poor performance on the middle problem indicated reduced working memory capacity. He argued that older participants retained the first sum because it had been rehearsed more often, and the third because it had been solved most recently. However, the solution to the middle problem, due to limitations in working memory capacity, was lost.

**Inhibition.** While attention supports identification and selection of stimuli for further processing, inhibition prevents processing of task-irrelevant information, conserving working memory resources for relevant information. Dempster (1991) described inhibition as a component of intelligence that allows one to resist interference from irrelevant stimuli, and maintained that poor inhibition would undermine intelligence. Another role of inhibition is to suppress outdated details to prevent them from interfering with currently relevant information (Bjork, 1989; Hartman & Hasher, 1991; Kieley & Hartley, 1997; Schooler, Neumann, Caplan, & Roberts, 1997; Sullivan & Faust, 1993). A number of studies have reported decrements in older adults’ ability to inhibit task-irrelevant stimuli (Hartman & Hasher, 1991; Kieley & Hartley, 1997; Schooler et al., 1997; Sullivan & Faust, 1993), although the magnitude of this effect may be influenced by elements of experimental
design. Older adults have been shown to perform inhibition tasks best in the morning, while younger adults’ best performance is late in the afternoon (Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1998; May & Hasher, 1998), thus age-related differences in performance may be over-stated or under-stated, depending on the time of day of testing, which is not often reported in the literature. In addition, there is evidence that tasks must be adequately complex in order for performance differences between young and old participants to be manifested (Verhaeghen & Cerella, 2002).

Inhibition supports selective attention, the ability to focus on task-relevant aspects of a stimulus while suppressing processing of irrelevant aspects. Some studies have shown that older adults are less likely than young participants to process distracters, especially when the perceptual load is high (Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Maylor & Lavie, 1998; Rabbitt, 1965), while other studies have shown similar inhibition performance across age groups (Intons-Peterson et al., 1998; Sullivan & Faust, 1993). Lavie and colleagues (2004) conducted a series of experiments to evaluate the effects of perceptual and cognitive load on the processing of distracters, and have proposed load theory as a model to explain differences in findings regarding inhibition performance. Load theory holds that two mechanisms support selective attention. This first is a perceptual selection mechanism, which precludes processing of distracters under high perceptual load, as when a display contains numerous distractors. This is passive; distracters are simply not processed when perceptual resources are limited. The second mechanism is attentional control, which rejects distracters that have been perceived under low perceptual load conditions. This is a more active process that relies on working memory functions to confirm that an item is a distracter. Under load theory, a task that combines low processing and high cognitive loads
would be expected to result in a higher rate of interference from distracters than would a
task with lower perceptual and/or cognitive loads.

Load theory may explain the mixed findings regarding inhibition in older adults. Only when a task’s perceptual and cognitive loads overwhelm the attentional capacity of the participant are distracters processed. Reports of successful inhibition in younger but not older participants suggest that, as compared to younger people, older adults have fewer attentional resources, so are more vulnerable to interference. Age-related declines in inhibition of task-irrelevant stimuli could account for observed decrements in older adults’ working memory capacity.

**Executive functioning.** Baddeley (1990) described a central executive responsible for managing information held in working memory. The central executive is responsible for allocating attentional resources to the visuo-spatial sketchpad and the phonological loop, and has been shown to be susceptible to age-related declines (Kramer et al., 1999). The central executive allows one to integrate information from the environment and from long-term memory (Dempster, 1991).

More recently, it has been suggested that the central executive and executive function be evaluated separately (Newson, Kemps, & Luszcz, 2003). As compared to the central executive as described by Baddeley, executive functioning is a higher order process that recruits cognitive resources in order to develop strategy, plan a response or predict consequences of an action (Loring, 1999; Luszcz & Bryan, 1999). Newson and colleagues (2003) examined executive functioning in older adults using mental synthesis tasks in which participants visualized integrating separate images into new images, for example, a capital V topped by a rotated D to form an ice cream cone. Participants performed the mental
synthesis task alone, and under a number of dual task conditions. The authors reported an age-related decline in mental synthesis, indicating a decline in executive functioning. This decline began around age 65, with a sharper decline evident in the oldest group after age 85. The age at which declines in mental synthesis are observed parallels that at which crash risk increases (Brorsson, 1989; Darzins & Hull, 1999; McGwin & Brown, 1999; Ryan et al., 1998; Wood & Bullimore, 1995).

Task Complexity

Gentile (2000) has developed a 16-level taxonomy of task complexity based on characteristics of the person performing the task, the environment in which the task is performed and the task itself. The lowest complexity tasks involve staying in one place in a static environment without manipulating anything, such as sitting in a chair. Riding in a bus while drinking a cup of coffee, which involves manipulating an object in a moving environment, would be a moderately complex task. The highest complexity tasks involve manipulating one or more objects in a dynamic environment in which other people and objects are moving unpredictably. Driving falls in the highest complexity category.

A driver must maintain and update information regarding his/her destination, monitor the movements of his/her vehicle, and coordinate those movements (through manipulation of steering wheel, accelerator and brake pedals, etc.) with the predicted movements of other vehicles while also attending to changes in road conditions, weather conditions, and traffic signals. Thus, the driver must divide attention among a number of tasks, selectively attend to those stimuli that are relevant to the driving task while inhibiting processing of other objects, and finally must prioritize the tasks. Preusser and colleagues (1998) described older drivers as having difficulty in managing complex driving situations,
for instance, when they must evaluate cross traffic from two directions when crossing an intersection.

Working memory and driving

Older women have been found to be particularly vulnerable to crashes at intersections. Guerrier, Mannivan and Nair (1999) examined left-turn decisions of women between the ages of 61 and 84. Participants viewed video clips of oncoming traffic from the viewpoint of a driver waiting to turn left. For each scenario they indicated whether the gap between cars was adequate to allow a safe left turn. Working memory was assessed using an addition task similar to that used by Foos (1989). Participants solved five sets of three addition problems. For each set, participants added a pair of numbers and held the answer in memory while they added a second pair of numbers. They then held the first two sums in memory while the added a third pair of numbers. After adding the third pair of numbers, participants recalled the answers to all three problems. Those with better working memory performance were more proficient in identifying gaps in oncoming traffic that were large enough to allow a safe turn. The authors proposed that those with better working memory performance either had greater working memory capacity, so were more capable of gathering the available information to make a decision, or had better central executive functioning, so were able to manage information relevant to gap selection, resulting in better decisions (Guerrier et al., 1999).

Neurological changes associated with normal aging

The age-related declines in cognitive ability described above may reflect physiological changes in the prefrontal cortex that occur with normal aging (Erraji
Benchekroun et al., 2005; Gutchess et al., 2005; West, 1996). Cognitive decrements observed in normal elderly people are similar to those reported in younger people with damage to the prefrontal cortex (Fuster, 1997). Likewise, elderly monkeys show cognitive deficits similar to those exhibited by younger monkeys with prefrontal damage (Arnsten, Cai, & Goldman-Rakic, 1995). These deficits may result from prefrontal cortical mirocolumnar disorganization, which has been reported in elderly monkeys (Cruz et al., 2004). The authors raise the possibility that, over time, changes in dendrites and axons undermine the structure of microcolumns. In general, as non-human animals grow old they lose proficiency in tasks that depend on frontal cortical function.

Throughout most of adult life, the structure of the human cortex is stable; there is little decline in the number of neurons. However, beyond about age 60, the size, volume and density of neurons begins to decrease (Fuster, 1997; Tisserand & Jolles, 2003). These changes are initially apparent in the prefrontal areas (Coffey et al., 1992). A study of prefrontal cortical gene expression in postmortem samples of people aged 13 to 79 years revealed transcriptional changes in a subset of genes beginning in early adulthood, and increasing with advancing age (Erraji Benchekroun et al., 2005). Age-related decreases in prefrontal neurotransmitters, particularly catecholamines and dopamine, have also been reported (Fuster, 1997; West, 1996), along with declines in cerebral blood flow (Azari et al., 1992; Shaw et al., 1984) and metabolic activity in the frontal lobes (Azari et al., 1992).

In addition to changes in neurons and in metabolism affecting the frontal lobes, evidence from healthy humans indicates that senile plaques are more mature and more prevalent in prefrontal and temporal lobes than in other regions (West, 1996). This pattern of plaque formation differs from that observed in people with Alzheimer’s disease, who tend
to have concentrated areas of senile plaques in other cortical regions. Age-related
decrements in tasks that require integration of functions across neural areas may result from
increases in lesions in white matter observed in frontal areas of aging brains. White matter
contains fibers that connect grey matter structures, so white matter lesions could undermine
the quality of communication among these structures (for a review, see Tisserand & Jolles,
2003).

Older adults’ performance on tasks that involve executive functioning provide
evidence that cognitive processes associated with the prefrontal cortex show age-related
deficits at an earlier age than do processes associated with other regions. Dempster (1991)
proposed that a variety of cognitive processes differ across the life span, and that these
differences result from changes in inhibitory processes mediated by the prefrontal cortex.
Declines in inhibitory function could explain older adults’ difficulty in updating information
(Bjork, 1989), and could leave working memory vulnerable to interference from irrelevant
stimuli (Dempster, 1991; Hartman & Hasher, 1991; Kane, Hasher, Stoltzfus, Zacks, &
Connelly, 1994).

Neuroimaging facilitates evaluation of the relationship between activity in cortical
areas and cognitive performance. Functional magnetic resonance imaging (fMRI) allows
non-invasive assessment of cerebral blood flow from which one can infer the level of neural
activity while a person is at rest and while performing cognitive tasks (Gazzaley &
D'Esposito, 2003). Aging is associated with altered patterns of activation during
performance of cognitive tasks, including general decreases in activation, along with some
areas of increased activation (Rypma & D'Esposito, 2000). These altered patterns of
activation, particularly in frontal areas, may reflect efforts of older adults to compensate for declining skills (Tisserand & Jolles, 2003).

Among the explanations advanced to account for increased activation observed in the frontal areas in older adults are compensation and dedifferentiation. Compensation theory holds that older people recruit additional neural areas to support declining cognitive performance. Studies that show similar performance in young and old participants, but differences in patterns of activation, support this view. Dedifferentiation theories maintain that pathological processes result in the observed age differences in cognitive functioning. Under these theories, age-related performance decrements result from degradation of specialized cognitive structures, which forces recruitment of non-specialized structures to perform cognitive processes. Studies that show age differences in patterns of activation associated with declines in older participants’ performance support dedifferentiation theories. It should be noted that compensation and dedifferentiation are not mutually exclusive (for review, see Gazzaley & D'Esposito, 2003).

Daselaar and colleagues (2003) used fMRI to investigate the relationship between activity in the medial temporal lobes and success in encoding episodic memories. They found that older participants who performed poorly on a recall task had less medial temporal activation that did those who performed well on the task, regardless of age. These results are consistent with those from studies that have shown older and younger participants using similar neural circuitry when encoding information, although older adults recruited larger proportions of prefrontal areas as compared to younger participants (DiGirolamo et al., 2001; Gutchess et al., 2005; Morcom, Good, Frackowiak, & Rugg, 2003). Perhaps this recruitment of additional prefrontal resources helps older adults compensate for declines in
medial-temporal processes (Gazzaley & D'Esposito, 2003; Gutchess et al., 2005); older adults’ may increase their level of executive (prefrontal) control in order to maintain their level of functioning (DiGirolamo et al., 2001; Gazzaley & D'Esposito, 2003).

While a number of imaging studies have evaluated changes in areas associated with memory, including the medial temporal lobes and the hippocampus, others are beginning to focus on frontal and prefrontal areas associated with executive functioning. Studies have shown that ventrolateral regions of the prefrontal cortex are active in participants processing subcapacity levels of information, such as rehearsing two to three items (Rypma & D'Esposito, 1999); age-related deficits are not generally noted in these areas. Conversely, age-related declines have been noted in dorsolateral prefrontal areas, which have been shown to support manipulating information (D'Esposito, Postle, Ballard, & Lease, 1999) and supracapacity processes, such as rehearsing more than three items (Rypma & D'Esposito, 1999).

Rypma and D’Esposito (2000) found age differences in dorsolateral PFC activation during the retrieval component of a task, under high load conditions. Participants viewed a string of two (low load) or six (high load) letters for four seconds, followed by a 12-second unfilled retention interval. After the retention interval, participants had two seconds to report whether a single letter presented on the screen had been in the memory set. Older participants’ accuracy was similar to that of younger participants, and accuracy in each group was similar in the low- and high-load conditions. Reaction times, however, were slower for both groups in the high-load condition, and this effect was greater in older participants.
Imaging data revealed that, in young adults, increased dorsolateral PFC activation was associated with slower reaction times, but only in the high load condition. In older participants performing the same task, increased activation in this area was associated with faster reaction times. In younger participants, this positive correlation between dorsolateral activation and reaction time accounted for 71% of the reaction time variability; in older participants, the negative correlation accounted for 72% of the variability. The authors obtained comparable results when they replicated the experiment with similar stimuli, and again using images rather than letters (Rypma & D'Esposito, 2000), and describe the results as supporting the compensation theory.

Age-related cognitive changes described above could be expected to undermine older adults’ performance of complex tasks, including driving. A person with diminished ability to inhibit attention to task-irrelevant stimuli, which Dempster (1991) describes as necessary to focus on a task, could be expected to have difficulty ignoring irrelevant billboards or storefronts when making a decision about turning left across traffic. Similarly, diminished central executive functioning might hamper an older driver’s ability to respond rapidly to an unexpected event, such as a changed traffic light or another driver suddenly swerving into his or her lane. Decrements in both inhibition and central executive functioning would undermine working memory capacity and functioning, and could account for the relationship that Guerrier, Mannivan and Nair (1999) found between measures of working memory and drivers’ ability to select safe times to cross traffic. These cognitive difficulties may be exacerbated if an older driver becomes anxious when driving. Hogan (2003) reported that, in older adults, anxiety led to impaired cognitive performance. The
authors attributed this cognitive impairment to some attentional resources being diverted to worry, the cognitive component of anxiety.

**Time Estimation**

Many everyday actions, including stepping onto an escalator, merging into freeway traffic, playing pinball, and scheduling a series of errands incorporate temporal integration components (Burt, 1999; Tracy et al., 1998). Simply shaking hands with another person requires predicting when to close your hand based on the other person’s movements. Time estimation ability has been examined from a variety of perspectives. In a retrospective estimation task, the examiner asks how much time has elapsed since a given event, for example, “How long, to the nearest minute, have we been in this room?” The participant has not been advised that s/he will be asked to make the estimation. A prospective estimation differs in that the participant has been warned that s/he will be asked to estimate the interval (Hetherington, Dennis, & Spiegler, 2000).

The production task is similar; the participant is instructed to indicate when a specific amount of time has elapsed; the participant may be told, “Press the button when 30 seconds have passed.” One type of production task is the open paradigm, in which the participant is only responsible for estimating the passage of time, so is able to use a strategy, such as counting. The filled or dual task paradigm, in which the participant must perform a second task while estimating the time interval, is more difficult. In the dual task condition, the secondary task should be sufficiently demanding to prevent the participant from using a strategy to track time. Participants tend to overestimate the interval in the open paradigm, and to underestimate in the dual-task paradigm (Hancock & Manser, 1997; Hetherington et al., 2000; Tracy et al., 1998).
Block and coworkers (1998) conducted a meta-analysis of time estimation studies that included production and reproduction tasks in old and young participants. The durations in the studies ranged from 1.3 to 480 seconds. While the age groups performed similarly in reproduction tasks, there were age differences in verbal estimation and production tasks. As compared to young participants, older adults made larger verbal estimates and smaller duration judgments. The authors noted that, while the mechanisms that support time estimation are poorly understood, the results indicated an age effect on the way time is experienced. They also proposed that different mechanisms may underlie judgment of durations of less than several seconds and those of longer intervals (Block et al., 1998).

A number of driving studies have contained time estimation components. When a driver looks down the road, sees an oncoming car and determines whether there is time to cross the oncoming lane before the approaching car arrives, s/he is making at least two estimations of time intervals. One is the amount of time the driver needs to cross the lane of oncoming traffic, which may be stored in long term memory. The second is the interval that the oncoming car will take to reach his/her own car; this is a time to contact task. In making a decision regarding passing or changing lanes, these time estimations must be made in a dynamic context, requiring the driver’s own movements to be factored in as well (Hancock & Manser, 1997).

Time to contact performance has traditionally been measured using a removal paradigm. Participants observe an approaching object, which becomes invisible after a short interval. The observer indicates when the object should arrive at a specified location. Participants tend to underestimate time to contact when tested using this method. Hancock
and Manser (1997) hypothesized that these underestimations resulted from the artificiality of the task, with the approaching object simply vanishing. In real life, approaching objects become invisible only if they are occluded by another surface. The authors used a driving simulation task to compare the accuracy of time to contact estimations in the traditional vanishing situation and a similar but more natural condition in which the oncoming car was blocked by a bush. They found that participants were more accurate in estimating time to contact when the oncoming car was blocked by the bush than when it simply vanished. Thus, the ability to accurately estimate time to contact may depend in part on the context in which the task is performed.

In a similar study (Andrea & Fildes, 2000), participants viewed oncoming cars approaching a white line. The car disappeared before reaching the line, and participants were to determine whether the car would have reached the line by the time a signal (a car horn) sounded. Older males were more conservative in their responses than were other groups, regardless of the speed of oncoming cars. Older females made conservative responses at low speeds, but made riskier responses than other groups when the oncoming car was moving at high speed. Changes in the way time is experienced may underlie older adults’ errors in merging, changing lanes and turning across traffic.

Vision and Cognition: UFOV

While visual acuity decrements have been shown to impair a driver’s ability to read street signs or detect debris on the road (Higgins, Wood, & Tait, 1998), acuity is unlikely to account for the driver’s failure to detect other vehicles. Resolving fine details of static, high-contrast targets and avoiding collisions with large, high-contrast, moving vehicles could be expected to tap different skills. Older drivers tend to be in crashes at intersections,
and often report having been unaware of the presence of traffic control signals or of other vehicles (McGwin & Brown, 1999; Parsonson, Isler, & Hansson, 1999). This suggests a failure of attention rather than of acuity, and thus may reflect the cognitive decrements described earlier. Studies have generally shown that measures of visual function including visual acuity, dynamic visual acuity, color vision, and stereovision were only weakly related to accident risk. Owsley, Ball, and colleagues have shown that measures of visual attention, which depend on both vision and cognition, are better predictors of accident risk, especially in older adults. Ball, Owsley, Sloane, Roenker and Bruni (1993) depict visual acuity and cognitive ability as affecting crash risk indirectly, through their influence on visual attention, the ability to select and attend to task-relevant elements of the visual environment. Poor visual acuity impairs visual attention by degrading the quality of the available visual information. The authors describe older drivers’ limited ability to take advantage of available visual information as undermining their ability to drive safely.

Age-related changes in visual attention have been associated with crash risk (Ball et al., 1993; Owsley et al., 1998). Visual attention enables a person to detect, identify and determine the location of task-relevant objects in the environment. Ball, Beard, Roenker, Miller and Griggs (1988) describe the Useful Field of View (UFOV), a measure of visual attention, as the area within the visual field from which one can use information rapidly, without moving the eyes or turning the head. The size of the UFOV tends to contract with age (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004). Older drivers with a moderate to severe reduction in UFOV were significantly more likely to have been involved in a collision over the five-year period preceding testing (Ball et al., 1993) and in a three-
year period following testing (Owsley et al., 1998) than were older drivers with normal UFOV.

The UFOV® test is comprised of three increasingly complex components. The processing speed component requires the viewer to determine whether a silhouette presented in the center of the computer screen is that of a car or a truck. The divided attention task requires the participant to identify the central figure, and simultaneously determine the position of a second target at one of eight locations around the screen’s periphery. Selective attention requires attending to task-relevant stimuli while ignoring other objects. The selective attention task is similar to divided attention, with the peripheral target embedded in distracters. The viewer must identify the central figure, differentiate between the target and distracters in the periphery, and report the position of the peripheral target.

While UFOV® scores have been shown to predict crash risk; some researchers propose that UFOV® measures cognitive ability rather than the size of the UFOV described by the test’s developers. In a task similar to UFOV®, Seiple, Szlyc, Yang and Holopigian (1996) found an increase in errors with increased age, but the increase occurred across all eccentricities, thus the size of the field of view did not appear to be restricted. Sekuler and Bennett (2000) reported similar results, and suggested that the UFOV® test measures a person’s efficiency in extracting relevant information from a scene rather than the size of the area from which such information can be extracted (but see Coeckelbergh et al., 2004). This explanation could account for the observed relationship between crash risk and UFOV® score, as one would expect the ability to extract task-relevant information from the environment to predict the ability to detect driving hazards and thereby avoid a crash.
Cognitive Impairment and Driving

Thus far, the effects of normal aging on driving performance have been considered, but many older drivers have some form of cognitive impairment, which further erodes their ability to cope with the demands of driving. The prevalence of dementia, including Alzheimer’s disease (AD), doubles every five years beyond age 65, with nearly 50% of people over the age of 85 having some sort of dementia (Alzheimer's Disease Education & Referral Center, 1997). A number of studies have shown that many people in the earliest stages of AD continue to drive safely (Friedland et al., 1988; Hunt, Morris, Edwards, & Wilson, 1993; Hunt et al., 1997; Johansson & Lundberg, 1997; Kapust & Weintraub, 1992). However, the authors agree that, at some unidentified level of dementia severity, these drivers pose an unacceptable level of risk to themselves and others. In addition to decrements in memory associated with AD are impairments in performance of tasks that require dividing or shifting attention (Perry & Hodges, 1999). These deficits tend to follow initial memory problems, and precede declines in language and semantic memory.

Executive functioning refers to the higher-order processes that allow one to react to changing circumstances by formulating, executing and monitoring new procedures (Perry & Hodges, 1999). Even those in early stages of AD report difficulty accomplishing everyday tasks that rely on executive functioning, such as planning and preparing a meal or going to the grocery store and returning with all the needed items. This difficulty is reflected in their performance on dual-task paradigms. While those with cognitive impairment may perform the components of a dual task normally under single-task conditions, they show larger dual task costs than do age-matched controls (Baddeley, Bressi, Della Sala, Logie, & Spinnler,
These findings suggest that those with AD have lost some of their capacity to allocate resources among tasks.

The ability to formulate and execute a plan of action and to make modifications in response to changing conditions is vital to safe driving. Drivers must also selectively attend to task-relevant stimuli; disengage attention when necessary in order to apportion attention among multiple tasks, and precisely time task execution. Cognitive changes associated normal aging and with age-related disorders such as Alzheimer’s disease would be expected to interfere with the ability to integrate driving tasks.

Visual perception changes frequently reported in those with AD (Jackson & Owsley, 2003; O’Brien et al., 2001) could further compromise safe driving. Tangles and plaques that develop in the visual pathways of those with AD may result in reduced acuity and contrast sensitivity and poor stereopsis, as well as difficulty in higher order processes including visual attention, visual memory, and perceiving shape from motion (Jackson & Owsley, 2003). O’Brien and colleagues (2001) documented progressive declines in motion detection thresholds that were associated with poor maintenance of lane position in participants with AD.

An early study of the relationship between driving and “senility,” described as one or more episodes of fainting, dizziness, memory or concentration problems, slowed thinking or tremors, showed that healthy drivers over age 60 and those aged 30 to 59 had similar crash rates. The likelihood of a collision nearly doubled for those with senility, and quadrupled for people with both senility and cardiovascular disease (Waller, 1967). More recently, Friedland (1988) reported that AD patients were 4.7 times more likely than age-matched controls to have been in one or more crashes in the previous five years. People with
dementia tend to retain procedural memory, which supports carrying out familiar tasks, including starting and driving a car, longer than they retain the executive functions that allow a driver to respond quickly and appropriately to unexpected events (Parasuraman & Nestor, 1991).

There is evidence that errors commonly made by drivers with dementia are more likely to result in a collision than are those made by other drivers. Dobbs (1997) evaluated on-the-road performance of drivers who were young, old cognitively normal, and old with dementia. He found that errors such as failing to come to a complete stop at a stop sign and not driving the posted speed, which were not associated with increased crash risk, occurred with similar frequency in all three groups. Another set of errors, including poor lane position when making turns and failing to do a shoulder check when changing lanes, which were a bit more risky, were seen occasionally in young drivers, more frequently in normal old, and most often in older drivers with dementia. Finally, impaired participants made virtually all of the hazardous errors, in which a driving evaluator took control of the car in order to avoid a crash.

As would be expected, drivers with dementia are more vulnerable than others to getting lost while driving (Kapust & Weintraub, 1992). They had more difficulty following driving instructions; during evaluations, they were easily distracted and showed poor judgment (Hunt et al., 1993). These drivers have been reported to be overcautious (Dobbs, Heller, & Schopflocher, 1998), often driving too slowly (Hunt et. al., 1993; Wild & Cotrell, 2003) or stopping in mid-traffic (Hunt et. al., 1993). Other common errors reported in drivers with dementia include poor visual search (Dobbs et al., 1998), intersection errors (Friedland et al., 1988; Hunt et al., 1993; Kapust & Weintraub, 1992), and poor lane
position, particularly when turning (Hunt et. al., Dobbs et al., 1998; 1993; Wild & Cotrell, 2003). Drivers with dementia also made more merging and lane changing errors than did other groups. It is interesting to note that this list includes the errors (poor speed control, errors in lane position, merging, and navigation) associated with all older drivers with a recent crash history (McKnight & McKnight, 1999).

Older drivers with normal cognitive skills often voice concern about their declining ability to cope with the demands of heavy traffic (Wild & Cotrell, 2003), and take measures to avoid difficult driving conditions, including rush hour and inclement weather (Glasgow & Blakely, 2000; Yassuda et al., 1997). Conversely, those with dementia tend to declare that they are good, safe drivers (Cotrell & Wild, 1999; Friedland et al., 1988; Hunt et al., 1993; Wild & Cotrell, 2003); their family members may convey vague concerns about the person’s driving, yet often overrate the family member’s proficiency (Friedland et al., 1988; Hunt et al., 1993; Wild & Cotrell, 2003). The driver’s physician is unlikely to discuss potential driving hazards with either patients with dementia or their family members (Valcour, Masaki, & Blanchette, 2002). While there are guidelines for physicians to use in consulting with patients about whether they should continue driving (American Medical Association & National Highway Traffic Safety Administration, 2003), there is no specific cognitive benchmark signals a physician to order a driving test.

With increasing dementia, drivers may lose insight into their capability to drive. Evaluators report drivers with AD being unaware of the degree to which they irritate other drivers (Hunt et al., 1993), and failing to recall the errors they made during a driving session (Kapust & Weintraub, 1992). Unrecalled errors are unlikely to influence the driver’s sense of proficiency. A number of studies report that cognitively impaired drivers who have failed
a driving test express confidence in their driving (Cotrell & Wild, 1999; Hunt et al., 1993; Wild & Cotrell, 2003), and many continue to drive, even following a crash (Friedland et al., 1988). Given the evidence from McGwin & Brown (1999) that a small percentage of older drivers are responsible for the increase in older adults’ crash risk, perhaps older drivers with dementia are over-represented in the group of older drivers who have had recent crashes.

**Purpose**

The purpose of this study was to evaluate how age-related changes in skills including working memory, visual attention and time perception affect simulated driving performance. Participants were divided into groups based on age (old, young), with older participants further divided into three groups based on measures of cognitive performance.

Visual attention was assessed using the UFOV® test. Attention, visuospatial memory, and delayed recall were assessed using components of the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS). In addition, working memory and anticipation timing performance were tested using computer-administered applications.

After becoming familiar with the Systems Technology, Inc. Driving Simulator, participants completed three driving scenarios of varying complexity. Driving behaviors including average speed, lane position, and number of hazardous errors (leaving the roadway or hitting another car or a pedestrian) were recorded. The scenarios incorporated a secondary letter detection task, which permitted evaluating the degree to which the driving task exhausted participants’ attentional resources. Before each driving scenario participants were given a set of three target letters. During simulated driving scenarios participants were to watch for letters that appeared unpredictably along the roadway. When they detected one of the letters, they were to signal a right turn if the letter was one of three target letters, and a
left turn in response to any other letter. In order to reduce the likelihood of simulator motion sickness each driving scenario lasted less than ten minutes and scenarios were not run consecutively (Min et al., 2004).

**Hypotheses**

Hypothesis 1: older adults with lower cognitive scores would make significantly more hazardous errors during driving simulations than would young participants and older participants with higher cognitive scores. Hazardous errors are those that would be likely to result in damage or injury, and include colliding with another vehicle, hitting a pedestrian or leaving the roadway.

Hypothesis 2: among older drivers those who drove most slowly, who spent more time in the left lane and who maintained a larger buffer between their car and the one ahead in the low complexity scenario would commit more hazardous errors than would other drivers. This is based on results of a pilot study the same simulator under similar conditions.

Hypothesis 3: Performance on non-driving measures would also be correlated with hazardous errors. Scores on the working memory task, the RBANS coding task, and the anticipation timing task would be correlated with hazardous errors win older participants. This hypothesis is partially based on findings reported by Guerrier and colleagues (1999) and by Chaparro, Wood and Carberry (2005). Regression and discriminant analyses were conducted to determine the efficacy of specific driving and non-driving measures in predicting hazardous error rates.
CHAPTER TWO

METHOD

Participants

Participants included 10 younger adults (aged 23-38) recruited from the Wichita State University psychology department, and 30 older adults, aged 64-90, recruited from the community. All participants were current, licensed drivers with a minimum corrected visual acuity of 20/40. They used their customary correctional lenses as appropriate while completing the tasks. All participants provided written informed consent. The Wichita State University Institutional Research Board approved the study design.

Materials

The Mini Mental Status Examination (MMSE) and the attention index from the Repeatable Battery for the Assessment of Neuropsychological Stats (RBANS) were used to assign older participants to groups. Measures of attention and spatial memory from the RBANS battery, as well as the UFOV visual attention test, and measures of working memory and anticipation timing were included as potential predictors of driving risk. Driving was evaluated using a driving simulator, which provided scores on a variety of driving behaviors.

Mini Mental Status Examination

The MMSE is a cognitive screening instrument for older adults (Folstein, Folstein, & McHugh, 1975). The test takes about 10 minutes to administer, and includes measures of attention, orientation, memory, and the ability to follow verbal and written instructions, as well as a visuospatial measure. As Duchek (1997) notes, the MMSE provides a global
measure of performance based on scores on a small number of items that cover a variety of
cognitive skills. The MMSE was selected for use in assigning older participants to normal
or impaired groups as it provides a well-recognized, objective measure of cognitive
functioning in older adults (Lezak, 2004). Test-retest reliability has been demonstrated in
elderly participants across 24-hour and 28-day intervals and inter-rater reliability across a
24-hour interval (Folstein et al., 1975).

*Repeatable Battery for the Assessment of Neuropsychological State*

The RBANS battery was designed to evaluate cognitive status of persons aged 20 to
89 and is comprised of 12 subcomponents that assess immediate memory, delayed memory,
attention, language and visuospatial/constructional memory (Randolph, 1998). The RBANS
tasks were administered and scored as directed by the manual (Randolph, 1998). An
attention index based on digit span and coding scores was used as a grouping variable in the
current study. The figure copy initial performance and delayed recall components of the
visuospatial/constructional index were included to evaluate the relationship between
visuospatial memory and driving performance, as a driver’s understanding of spatial
relationships among road users would be expected to support judgments of when it is safe to
turn or change lanes. The digit span and coding components of the attention index were
included to evaluate their efficacy in predicting driving performance based on a relationship
between measures of attention and driving performance reported by Chaparro and

For the figure copy task, the participant was presented with a complex figure
composed of 10 elements, and allowed four minutes to draw a copy of the figure. The
participant was informed that the task would be scored on the completeness of the copy, and
not on the time on task. The figure recall task required the participant to make a copy of the figure from memory, without access to the sample. Participants did not know when they completed the copy task that they would later be asked to draw the figure from memory. Each of the 10 elements of the figure copy and recall tasks was scored based on drawing accuracy and proper placement for a possible score of 20 on each test.

Participants also completed a digit span task. The experimenter read a string of numbers at one-second intervals; the participant then repeated the string. If the participant made an error, a second string of equal length was presented. The initial string contained two numbers, and the length increased by one digit until the participant either made an error on two strings of the same length, or accurately repeated a nine-item string. Performance on the digit span task was quantified by assigning participants points according to the recall. Participants scored two points if they correctly repeated the first string of a set size, and one point if they missed the first string but correctly repeated the second, for a maximum possible score of 16.

In the RBANS coding task, the participants were presented with rows of symbols with empty boxes under each of them. They were instructed to consult a key at the top of the page to determine which number corresponded to each symbol, and to write the number in the box below the symbol. Participants were given 90 seconds to complete as many of the items as they could; they received one point for each correct item, for a maximum possible score of 89.

Reported reliability coefficients for the RBANS measures included in this study range from .83 to .88 for those aged 60 to 89; the inter-rater reliability was $r = .85$ (Randolph, 1998). Validity testing included correlations of RBANS component indices with
WAIS-R scores for similar skills. The correlation between the WAIS-R digit symbol score and RBANS attention and visuospatial/constructional indices were $r = .57$ and $r = .62$, respectively (Randolph, 1998). These measures of reliability and validity were computed from studies in which the total battery was administered. The findings may not apply to the current study, which employed only selected components of the battery.

*Useful Field of View (UFOV)*

The UFOV test is software-based, administered using a desktop computer with a color monitor. Participants viewed the screen from 24 inches (60 cm). The UFOV display is circular with a 20 cm diameter, subtending 19.2º of visual angle. In order to control for older participants’ potential inexperience using a mouse, all participants responded verbally and the experimenter entered their responses into the computer.

Performance on the UFOV ® test relies on processing speed as well as divided and selective visual attention abilities (see figure 1). The test consists of three increasingly complex elements. For each element, stimulus duration is reduced until the viewer is no longer able to respond correctly 75% of the time. Crash risk ratings have been defined by the test’s developers based on retrospective and prospective studies (Ball et al., 1993; Owsley et al., 1998), and are calculated based on the viewer’s performance on the three tasks. Those scoring within the normal range on all three components are considered to be at very low crash risk (Visual Resources Inc, 1998).

The processing speed component of the test requires the viewer to determine whether a silhouette presented in the center of a computer screen is that of a car or a truck. Normal processing threshold duration is $\leq 30$ ms. Divided attention is the ability to carry out two tasks simultaneously. The UFOV divided attention task requires the participant to identify
the figure in the center of the screen, and simultaneously determine the position of a second target, located at one of eight positions around the screen’s periphery, as illustrated in Figure 2 A, with the car in the center and the peripheral target located directly above. Normal divided attention threshold duration is \( \leq 100 \) ms.

Selective attention requires attending to task-relevant stimuli while ignoring other objects. The UFOV selective attention task is similar to the divided attention task, the difference being that the peripheral target is embedded among distracters. The viewer must identify the central figure, differentiate between the target and the distracters in the periphery, and report the position of the target. In Figure 2 B the central target is the car and the peripheral target is located directly to the right. Normal selective attention threshold duration is \( \leq 350 \) ms.

UFOV test-retest reliability, assessed in a sample of 70 participants aged 65 and over across an interval of 14 to 18 days produced reliability coefficients for the divided and selective tasks of .81 and .80, respectively (Visual Resources Inc, 1998). Validity was assessed in a three-year follow-up study of crash incidence in 294 drivers aged 56-90 in. Older drivers with 40% or greater reduction in UFOV (a low to moderate or higher risk rating) were found to be 2.2 times more likely to experience a crash than were those with less severe reductions (Visual Resources Inc, 1998).

As was the case with RBANS, the UFOV reliability and validity findings should be interpreted with the understanding that the component tasks were not presented in the same manner as in the reliability and validity testing studies. In the current study, participants completed the processing speed, divided attention and selective attention components in order as recommended by the publisher. Because a number of older participants in previous
studies have been found to perform the divided and selective attention tasks better if allowed to repeat them, these tasks were each presented two times, with the better scores recorded.

A.
B.
Figure 2. UFOV divided and selective attention tasks.
A. Divided attention: the viewer is asked to identify whether the central figure is a car or truck and report the location of the peripheral target.
B. Selective attention: the viewer must differentiate between the target and distracters in order to identify the central figure and report the location of the peripheral target.

*Working Memory*

Foos (1989) developed a working memory task in which participants solved sets of three two-digit addition problems (for example, $28 + 45; 33 + 79; 16 + 45$) and report all three sums at the end of the trial. Participants over age 60 performed nearly as well as young and middle-aged adults on the first and third problems, but performed significantly worse on the second problem. The author offered these results as evidence that the older adults’ ability to process the information was similar to that of the younger participants, but that their relatively poor performance on the middle problem indicated a reduction in
working memory capacity. Guerrier and colleagues (1999) used the working memory task developed by Foos to examine whether age-related working memory declines were associated with older drivers’ making unsafe decisions when turning across traffic.

Participants’ turning decision quality was evaluated using a video simulation. Participants viewed clips of heavy four-lane traffic (two lanes traveling in each direction) as though waiting to turn left from an intersection. They indicated instances when gaps in oncoming traffic were large enough to allow a safe turn. The results showed that participants who were proficient in performing the working memory task spent more time in evaluating the oncoming traffic and were better able to judge when a safe turn could be executed.

The working memory task for the current study was a computer-administered, self-paced version of the task developed by Foos (1989). Participants solved ten sets of three two-digit number pairs. For each set, participants were presented with a pair of numbers. When they had solved the first equation, they indicated they were ready for the next pair, and the experimenter advanced the program. After solving the second pair, they indicated that they were ready for the third pair, and the experimenter advanced the program. After the participant indicated that the third pair had been solved, the experimenter advanced the program, and the participant reported the sums of each of the three pairs, which the experimenter entered; the sums could be reported in any order. Each set of three sums contained one pair that required a carry function, and all sums were less than 100. The software recorded time to complete the task and the percentage of correct responses.

Anticipation Timing Task

Participants performed a computer-administered anticipation timing task in which a column of 16 dots changed color (as though they lit up) in sequence from top to bottom at
240 ms intervals (see Figure 3). The interval between the top and bottom dots changing was 3.6 seconds. The top 15 dots changed from dark to bright green and the bottom dot changed from dark to bright red. The participants’ task was to anticipate the change in the lighting of the bottom dot and to tap space bar on the key board to coincide with the time when the final dot would have changed. The dots were 0.5 cm in diameter spaced on 0.67 cm centers, resulting in a column 10.5 cm tall and 0.5 cm wide. At a distance of 60 cm the column of dots subtended .48 degrees of horizontal and 10.1 degrees of vertical visual angle.

Figure 3. Anticipation timing task.

Participants performed two conditions: a non-hidden and hidden. In the non-hidden condition, the participant tapped the space bar to start a trial, and then tapped it again to coincide with the final dot changing color. In the hidden condition, only the first 12 dots
changed color; the remaining four dots remained visible but did not change color. As in the non-hidden condition, the participant tapped the space bar to initiate the task and tapped it again to coincide with the time when the final dot would have changed color. Participants were encouraged to practice the task until they felt prepared to begin testing. The testing phase included five trials in the hidden and five trials in the non-hidden conditions, in randomized order. The mean and standard deviation of the difference (ms) between the participant’s response and the actual time that the last dot changed were recorded. The mean score in the hidden condition was used in the following analyses.

This task was expected to provide information about the effect of age on the ability to temporally coordinate a response with an external stimulus. Performance on the task may be related to a driver’s ability to accurately assess time to contact of an object that cannot be continuously monitored, as when one briefly steals a glance of oncoming vehicles to assess their time to arrival before deciding to turn.

*Systems Technology, Inc. Driving Simulator*

A Systems Technology, Inc. driving simulator, version 8 (Systems Technology, Inc., Hawthorne, CA) was used to evaluate participants’ driving performance. The simulator consists of a mock-up of a car interior that includes an adjustable bucket seat, steering wheel and turn signal lever as well as accelerator and brake pedals (see Figure 4). Simulations were displayed on a 17 inch (43.2 cm) color monitor placed in front of the viewer. Participants viewed the monitor from 60 cm, resulting in a display size of approximately 30 degrees of visual angle. The driving simulation test scenarios were comprised of four-lane roadways (two lanes in each direction) lined with trees and buildings (see Figure 5). In a practice scenario participants drove through a series of six intersections followed by a series
of six curves and then by a straightaway that contained a number of slow-moving vehicles; in this last section participants changed lanes repeatedly in order to weave through the slower traffic. This practice scenario gave the participants experience controlling the simulator’s accelerator, brakes and steering in a highly predictable environment.

Each test scenario was 12,500 feet long and included six curves, six stoplights, and six straight-aways; at the posted speed limit of 40 mph, each lasted about 4.5 minutes. The order of curves, stoplights and straight-aways differed in each scenario in order to prevent participants from anticipating upcoming events. There were low, moderate and high complexity test scenarios. Complexity was manipulated by varying the number of other vehicles, pedestrians, changing traffic lights, and unexpected events (e.g., cars moving into the driver’s path). Participants were instructed to follow traffic laws, maintain the posted speed, and to drive in the left lane except to maneuver around slower traffic.

While driving, participants performed a concurrent peripheral letter detection task. Throughout the scenarios, letters appeared at 10.40° eccentricity to the right or left of the roadway centerline and moved radially outward as the participant drove along the road (as though they were posted along the roadside). Letters were white on black and subtended .38° of visual angle when they first appeared. Their size increased to a maximum of .56° of visual angle at 15° eccentricity just before they moved off the side of the display screen. At the beginning of each scenario, a set of three target letters (e.g., F, B, T) was read to the participant, who was instructed to push the signal lever up in response to a letter from the target set, and push the lever down in response to any other letter.
Figure 4. Participant operating the driving simulator.
Figure 5. The simulator display.
Note that the participant has stopped well before entering the intersection. The traffic light is red, and a pedestrian is in the crosswalk. The letter “A” at the left of the screen is a peripheral letter target.

Each scenario contained 18 letter detection stimuli. Only one of similarly-appearing letter pairs (e.g., E and F) was used. To avoid interference that could result from a target from one scenario becoming a distracter in another, no target letter was used in more than one scenario. The order of appearance, position (left or right side of the road) and number of the target vs. non-target letters was randomized and then programmed so that each participant was exposed to the same set of stimuli. Participants’ response time and accuracy
were recorded for each letter. After five seconds, a letter was considered missed. Due to the limited visual angle provided by the monitor, letters may have moved off the edge of the screen before the full five seconds had elapsed.

Participants adjusted the driving simulator seat for comfort and pedal accessibility, and the monitor was positioned 60 cm from the participant’s eyes. During the first testing session, participants completed the practice scenario followed by test scenarios of low, moderate and high complexity in order to become familiar with the simulator. The second session began with the practice scenario, followed by the three test scenarios presented in random order. Finally, participants repeated the practice scenario. Performances on the first and last practice scenarios from Session 2 were used to assess learning effect. In an effort to reduce the incidence of simulator sickness, the scenarios were not completed consecutively.

Procedure

The tasks were scheduled across two sessions in order to reduce fatigue. The second session began a minimum of one hour and a maximum of 48 hours after the completion of the first; participants chose whether to complete the sessions in a single day. Measures of vision and non-driving tasks were scheduled between the driving scenarios in order to reduce the incidence of scenario sickness, which is more likely to occur in prolonged simulated driving sessions (Liu et al., 1999; Min et al., 2004). The order of tasks during the first session was scheduled to maintain a similar time interval between the figure copy and figure recall tasks. During Session 2 the order of test scenarios was randomized. Following MMSE assessment (older participants only), participants completed testing in the following order:
Session 1
1. Simulator practice scenario
2. RBANS figure copy
3. Low complexity simulation
4. RBANS digit span
5. RBANS coding
6. Moderate complexity simulation
7. RBANS figure recall
8. Working memory
9. High complexity simulation

Session 2
1. Simulator practice scenario
2. UFOV
3. Simulation 1
4. Near acuity
5. Simulation 2
6. Far acuity, contrast
7. Simulation 3
8. Timing
9. Simulator practice scenario
CHAPTER THREE

RESULTS

The results provided support for the hypothesis that the younger participants (Y) would commit fewer hazardous errors in the simulated driving scenarios than would older participants with lower cognitive scores (OL). Older participants with higher cognitive scores (OH) did not differ significantly from either of the other groups in number of hazardous errors, however, the OH group was better able than the OL group to perform the simulator’s peripheral letter task, which suggests that the driving task absorbed a greater proportion of the attentional resources of the OL group.

Correlation analyses of older participants’ driving performance indicated significant relationships between hazardous errors and a number of driving behaviors. Measures of working memory, attention and anticipation timing were also correlated with driving performance. Regression and discriminant function analyses indicated that some driving behaviors, as well as measures or working memory and anticipation timing predicted risky driving performance in this sample.

Grouping Variables

Participants were grouped based on age and on cognitive performance (see Table 1). The 10 younger participants formed group Y. Older participants were sorted into three groups of 10 based on their MMSE and RBANDS attention scores; the attention score reflects performance on digit span and coding tasks. Ten older participants obtained MMSE scores below 29; they were assigned to the older, lower cognitive scores (OL) group. This left 5 older participants with MMSE scores of 29 and 15 with perfect MMSE scores of 30 still to be assigned to groups. Those who scored 29 were assigned to the older, moderate
cognitive performance (OM) group. Attention index scores were used to determine which of the participants who obtained MMSE scores of 30 were to be assigned to the OM group and which to the older, higher cognitive performance (OH) group. The five with the lowest attention scores were added to the (OM) group, raising the count in that group to 10, and ten with the highest attention index scores were assigned to the older higher cognitive performance (OH) group (see Table 1).

**TABLE 1. GROUP CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>MMSE</th>
<th>Attention Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>29.0 (23-38)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Older, higher cog scores</td>
<td>69.5 (65-78)</td>
<td>All scored 30</td>
<td>117.9 (100-138)</td>
</tr>
<tr>
<td>Older, lower cog scores</td>
<td>80.3 (69-90)</td>
<td>27.1 (23-28)</td>
<td>73.8 (46-103)</td>
</tr>
</tbody>
</table>

Note: Group means (range in parentheses); n = 10 for each group.

Four older participants (one with an MMSE score of 27, one with a score of 28 and two with scores of 30) experienced motion sickness symptoms of dizziness and nausea while performing the driving simulation scenarios during Session 1 and discontinued participation. These participants did not appear to differ from other participants in proficiency in controlling the simulator and represented a range of cognitive status as measured by MMSE scores. They had not completed the attention index measures before discontinuing, however, the two with MMSE scores < 29 would have been included in the OL group while
the two with scores of 30 would have been in either the OH or OM group. Additional participants were recruited to maintain equal group sizes.

In order to maximize the difference between the groups, only the scores for the younger (Y), older with higher cognitive scores (OH) and older with lower cognitive scores (OL) were included in the analyses of variance (ANOVAs). Data from all of the older participants, but not from the younger group, were used in correlation, regression and discriminant function analyses. The younger participants’ data were omitted because it was expected that behaviors that predict hazardous errors in older drivers would differ from those for younger drivers (see Table 6).

A one-way ANOVA revealed that the Y, OH and OL groups differed significantly in age, $F(2,27) = 257.61, p < .01$. More importantly, a Tukey HSD indicated that the OH and OL groups differed in age at the .01 level of significance. The OH and OL groups differed from each other in performance on the cognitive grouping variables of MMSE and RBANS attention scores, $t_{obs}(18) = 5.75, p < .01$ and $t_{obs}(18) = 6.21, p < .01$, respectively (see table 1).

All scores were screened for outliers, $z$ scores $> 2.58$ (Tabachnick & Fidell, 2001), before the data were analyzed. Outliers’ scores were replaced with scores beyond the most extreme non-outlying score in order to maintain their rank order while reducing their effect on further analyses (Tabachnick & Fidell, 2001). Instances of replaced outlying scores are noted with the description of each analysis.

**Learning Effects**

Scores from the practice scenarios completed before and after the Session 2 test scenarios were compared to determine whether there were differences in the degree to which
the groups’ performance improved during the testing session (see table 2). An interaction between group and testing time (baseline, post test) in a repeated measures ANOVA would indicate a differential learning effect between at least two groups. The results indicated no significant difference in hazardous error scores. The differences in variance between the Y and OL groups, $F_{\text{max}} < 10$ at both baseline and post testing, violated the assumptions of ANOVA, therefore, only data from the OH and OL groups ($F_{\text{max}} = 3.41$ at baseline and 3.54 at post test), were included in a repeated measures ANOVA. The results indicated an improvement from baseline to post testing in the OH and OL groups, but the interaction was not significant, thus, the groups received similar benefits from increased familiarity with the simulator. Observation of the data suggests that group Y showed less improvement in peripheral letter performance from baseline to post test; this may be the result of a ceiling effect as their baseline scores were relatively high. If the older participants experienced a greater learning effect than the younger group, then the results of the following comparisons of the groups would yield a conservative measure of the differences between these groups.
TABLE 2. MEAN HAZARDOUS ERROR AND PERIPHERAL LETTER SCORES AT BASELINE AND POST TEST

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Baseline</th>
<th>Post test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>0.00 (.00)</td>
<td>0.00 (.00)</td>
<td></td>
</tr>
<tr>
<td>Hazardous Errors</td>
<td>OH</td>
<td>0.00 (.00)</td>
<td>0.22 (.67)</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>0.20 (.63)</td>
<td>0.40 (.97)</td>
</tr>
<tr>
<td>Y</td>
<td>81.33 (4.70)</td>
<td>83.78 (3.59)</td>
<td></td>
</tr>
<tr>
<td>Peripheral Letter Task</td>
<td>OH</td>
<td>56.22 (15.22)</td>
<td>71.67 (17.49)</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>35.40 (28.12)</td>
<td>43.00 (32.92)</td>
</tr>
</tbody>
</table>

Note. Scores are the mean (SD) for hazardous error and the peripheral letter task.

Simulated Driving Performance

Hazardous errors. It was hypothesized that older participants with poorer cognitive scores (OL) would exhibit more hazardous errors, defined as hitting another car, a pedestrian or leaving the roadway, during the driving simulations than would young participants (Y) or older participants with higher cognitive scores (OH). Because most participants made few hazardous errors (see Table 3) and because a repeated measures ANOVA revealed no significant group by complexity interaction, the hazardous errors from the three test scenarios were combined to form the hazardous error score used in the following analyses. Two participants had outlying hazardous error scores of 14, \( z = 3.6 \); these scores were replaced with extreme, non-outlying scores of 7.5, \( z = 2.56 \); it should be
noted that both participants with outlying hazardous error scores were members of the (OL) group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1.00</td>
<td>1.05</td>
</tr>
<tr>
<td>OH</td>
<td>2.00</td>
<td>1.25</td>
</tr>
<tr>
<td>OL</td>
<td>3.65</td>
<td>2.63</td>
</tr>
</tbody>
</table>

Note. Scores reflect total hazardous errors across the three test scenarios; \( n = 10 \) for each group.

A one-way ANOVA comparing hazardous errors in Y, OH and OL groups partially supported the hypothesis. There were significant differences among the groups, \( F(2,27) = 5.62, p < 0.01 \) (see Figure 6). Tukey HSD revealed that the Y group scores were significantly better than OL scores at the .01 level of significance; the mean hazardous errors score for the OH group was lower than that for the OL group, but this difference did not reach significance, \( p = .11 \) (see Table 3). Because it was hypothesized that the OH group crash rate would be lower than that of the OL group, an independent samples t-test was conducted to evaluate the difference between these groups. Although the difference only approached significance, \( t_{obt}(18) = 1.81, p = .09 \) (95% confidence interval, 3.74 to -0.34), there was a moderate to strong group effect size, Cohen’s \( d = .82 \).
Figure 6. Hazardous errors.  
Means for younger (Y), older with higher cognition scores (OH) and older with lower cognition scores (OL).  Error bars represent one SD.

To further explore differences in hazardous errors among these groups, chi square analysis was performed.  Participants were placed into high and low risk groups based on their hazardous error scores.  The high risk group (N = 7) was comprised of those with more than three hazardous errors (an average of > one hazardous error per scenario) while those with three or fewer hazardous errors (N = 23) were placed in the low risk group.  The results, $\chi^2(2, N = 30) = 7.08, p = .03, \phi = .49$, supported the ANOVA results reported above (see table 4).  The younger (Y) participants were most proficient, with no members in the high-risk category.  Group OH followed with only two high-risk members while the OL group showed the poorest performance with five members categorized as high-risk.
### TABLE 4. CHI SQUARE HAZARDOUS ERROR BY GROUPS

<table>
<thead>
<tr>
<th>Group</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Expected Count</td>
<td>7.7</td>
<td>2.3</td>
</tr>
<tr>
<td>OH</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Expected Count</td>
<td>7.7</td>
<td>2.3</td>
</tr>
<tr>
<td>OL</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Expected Count</td>
<td>7.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

**Note.** Groups are younger (Y), older, higher cognitive performance (OH), older, lower cognitive performance (OL).

*Peripheral letter task.* Performance on the peripheral letter task offers evidence of poorer simulator performance in the OL as compared to the OH group. The simulator recorded participants’ performance in responding to peripheral targets (e.g., the letter A at the left side of the monitor in Figure 5). The percentage of correct responses was computed for each participant at each level of complexity. There was no significant interaction between group and complexity level, so the average percentage of correct responses was calculated for each participant and this average percent correct was used in the following analyses. Statistical analysis revealed that the data violated assumptions regarding equal variance across the groups that were not resolved through arc sine transformation. The difference in variance between the Y and OL groups was too great to include both groups in an ANOVA, $F_{max} > 10$, however, the difference in variance between the OH and OL groups
was small enough to meet the assumptions of ANOVA, \( F_{\text{max}} = 2.18 \) (see Table 5).

Therefore, an independent samples t-test between the OH and OL groups was conducted. The results indicated a significant difference between these groups, \( t_{oh}(18) = 3.57, p < .01 \), with a strong effect size, Cohen’s \( d = 1.25 \) (see Figure 7). Performance on the peripheral letter task offers a measure of the extent to which driving absorbed a participant’s attentional resources. The task requires attention to stimuli that are not relevant to the task of driving, so those with better scores on the peripheral letter task may have a more complete understanding of the driving environment, and therefore be better able to detect and respond in a timely manner to potential hazards.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>70.13</td>
<td>2.13</td>
</tr>
<tr>
<td>OH</td>
<td>50.49</td>
<td>12.34</td>
</tr>
<tr>
<td>OL</td>
<td>23.64</td>
<td>19.69</td>
</tr>
</tbody>
</table>

Note. Mean percent correct over the three test trials; \( n = 10 \) for each group.
Thus, younger participants made fewer hazardous errors in the simulated driving task than did older participants with lower cognitive performance (see Table 3). The number of hazardous errors incurred by older participants with higher cognitive performance did not differ significantly from the other two groups; however, the OH group was better able to perform the peripheral letter task (see table 5).

*Relationships between Hazardous Errors and Driving Variables in Older Participants*

The aim of this study was to evaluate factors associated with driving performance in older adults. Because variables that predict errors in older drivers would be expected to differ from those that predict errors in younger drivers (see Table 6), only the older
participants were included the remaining analyses. In order to maintain rank order and reduce the effect of outliers on further analyses, outlying scores were replaced with extreme, non-outlying values (Tabachnick & Fidell, 2001). Data from two participants, one from the OM group and one from the OL group were not included in the following analyses. The OL participant was an outlier on multiple variables; the OM participant’s driving data from the moderate complexity scenario was lost due to computer malfunction. All further analyses were conducted using data from the remaining 28 older participants. The sample included 14 males and 14 females; they ranged in age from 64 to 90 years, with an average age of 74.9.

TABLE 6. CORRELATIONS BETWEEN DRIVING BEHAVIORS AND HAZARDOUS ERRORS IN GROUP Y

<table>
<thead>
<tr>
<th></th>
<th>Lane position SD (low)</th>
<th>Lateral velocity (high)</th>
<th>Working Memory</th>
<th>Arrival Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous errors</td>
<td>- 0.21</td>
<td>- 0.55</td>
<td>0.39</td>
<td>0.29</td>
</tr>
<tr>
<td>Lane position SD (L)</td>
<td>----</td>
<td>- 0.14</td>
<td>- .54</td>
<td>- 0.19</td>
</tr>
<tr>
<td>Lateral velocity (H)</td>
<td>----</td>
<td>- 0.25</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Working Memory</td>
<td></td>
<td></td>
<td>0.24</td>
<td></td>
</tr>
</tbody>
</table>

55
It was anticipated based on results from a pilot study that low complexity lane position would be correlated with the number of hazardous errors. This relationship did not reach significance \( r = .28, p = .08 \), however the relationship between lane position standard deviation and hazardous errors was significant, \( r = .38, p = .02 \) (see Table 7). Lane position standard deviation score in the low complexity scenario indicated the degree to which the participant maintained lane position (lower scores), as opposed to weaving within the lane (higher scores). Participants with lower scores were more consistent in their lane position and committed fewer hazardous errors. The remaining driving variables significantly correlated with hazardous errors, lateral velocity and lateral velocity SD in the high complexity scenario were also marginally correlated with each other (see Table 7).

<table>
<thead>
<tr>
<th>Complexity:</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lane position SD</td>
<td>Lateral velocity</td>
</tr>
<tr>
<td>Hazardous errors</td>
<td>.38*</td>
<td>-.52**</td>
</tr>
<tr>
<td>Lane position SD (L)</td>
<td>----</td>
<td>-.09</td>
</tr>
<tr>
<td>Lateral velocity (H)</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

Note. * \( p < .05 \), ** \( p < .01 \)
Lateral velocity refers to the speed (in feet per second) and direction of lane changes (negative values indicate moving to the left, positive values indicate moving to the right). Higher absolute values, whether positive or negative, are associated with faster, more abrupt, lane changes. Participants who made more hazardous errors tended to have relatively negative average lateral velocity scores with more extreme absolute values. Such scores reflected drivers moving smoothly into the right lane (despite instructions to stay in the left) when neither lane held a blocking vehicle, and later making an abrupt change to the left lane when another vehicle blocked their path (see Figure 8). Drivers who made smooth lane changes in both directions received lateral velocity scores near zero. Those who remained in the left lane until forced to change to the right lane by a blocking vehicle obtained positive average scores.
Figure 8. Interpreting lateral velocity

Notes. A and B above each represent two lanes of traffic traveling in the same direction. Participants were instructed to drive in the left lane except to pass a slower vehicle.

A. The participant (gray car) is following instructions to remain in the left lane except to pass a slower vehicle (white cars). The driver makes more abrupt lane changes to the right (indicated by a shorter arrow, circled), resulting in positive average lateral velocity.

B. The participant starts in the left lane, but moves smoothly to the right lane and remains there until forced into the left lane to pass a slower vehicle. Because this participant makes more abrupt lane changes to the left (indicated by a shorter arrow, circled), the average lateral velocity is negative.
Regression analysis confirmed that low complexity lane position $SD$ and high complexity lateral velocity contributed significantly to the prediction of hazardous errors; $R^2 = .38$, adjusted $R^2 = .33$. $F(2,25) = 7.65, p < .01$ (see Table 8). Participants who maintained consistent lane position and who executed smoother lane changes, especially when moving from the right to the left lane tended to commit fewer hazardous errors. These drivers may have been better able concurrently manage the tasks of monitoring lane position and maintaining their awareness of the changing driving environment.

**TABLE 8. REGRESSION COEFFICIENTS FOR DRIVING PREDICTORS OF HAZARDOUS ERRORS**

<table>
<thead>
<tr>
<th></th>
<th>$B$</th>
<th>$SE B$</th>
<th>$\beta$</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane position $SD$ (L)</td>
<td>5.69</td>
<td>2.67</td>
<td>.34</td>
<td>2.13</td>
<td>&lt; .05</td>
</tr>
<tr>
<td>Lateral velocity (H)</td>
<td>-44.83</td>
<td>14.55</td>
<td>- .49</td>
<td>- 3.08</td>
<td>&lt; .01</td>
</tr>
</tbody>
</table>

Note. The regression equation for hazardous errors = -6.10 + 5.69 (low complexity lane position) -44.83 (high complexity lateral velocity).

**Correlations between Hazardous Errors and Non-Driving Variables**

A number of non-driving variables were significantly correlated with hazardous errors, including working memory, figure recall and anticipation timing (see Table 9). Regression analysis was conducted to identify reliable predictors of hazardous errors among these variables (see Table 9).
TABLE 9. CORRELATIONS BETWEEN NON-DRIVING VARIABLES AND HAZARDOUS ERRORS

<table>
<thead>
<tr>
<th></th>
<th>Working memory</th>
<th>Coding</th>
<th>Figure recall</th>
<th>Anticipation timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous errors</td>
<td>- .40*</td>
<td>- .38*</td>
<td>- .48*</td>
<td>.47*</td>
</tr>
<tr>
<td>WM</td>
<td>----</td>
<td>.73**</td>
<td>.48*</td>
<td>- .08</td>
</tr>
<tr>
<td>Coding</td>
<td>----</td>
<td>.56**</td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td>Figure Recall</td>
<td>---</td>
<td></td>
<td>- .39*</td>
<td></td>
</tr>
</tbody>
</table>

Note. Higher scores on working memory, coding and figure recall indicate better performance; lower scores on hazardous errors and anticipation timing indicate better performance. * $p < .05$, ** $p < .01$

Of these measures, working memory and anticipation timing contributed significantly to the prediction of hazardous errors; $R^2 = .35$, adjusted $R^2 = .30$. $F(2,25) = 6.84, p < .01$ (see Table 10). Participants who were most proficient at holding information in memory while manipulating new information as measured by the working memory task, and who responded more accurately in the anticipation timing task made fewer hazardous errors. It should be noted that coding and figure recall scores were also significantly correlated with hazardous error scores; a different sample might yield a different set of predictors from among those included here.
TABLE 10. REGRESSION COEFFICIENTS FOR NON-DRIVING PREDICTORS OF HAZARDOUS ERRORS

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipation timing</td>
<td>.003</td>
<td>.001</td>
<td>.44</td>
<td>2.72</td>
<td>.01</td>
</tr>
<tr>
<td>Working Memory</td>
<td>-.029</td>
<td>.013</td>
<td>-.37</td>
<td>-2.29</td>
<td>.03</td>
</tr>
</tbody>
</table>

Note. The regression equation for hazardous errors = 3.73 - .03 (working memory) - .003 (anticipation timing).

Regressions Using Driving and Non-Driving Variables as Predictors of Hazardous Errors

It would stand to reason that combining driving and non-driving predictors of hazardous errors would improve the model’s ability to predict hazardous errors particularly if the driving and non-driving measures are not significantly correlated. Lateral velocity in the high complexity condition was not significantly correlated with either the working memory or anticipation timing measures. The correlations between lane position SD and working memory and anticipation timing approached significance, p = .07 and .08, respectively (see Table 11).
**TABLE 11. CORRELATIONS BETWEEN ALL REGRESSION PREDICTORS AND HAZARDOUS ERRORS**

<table>
<thead>
<tr>
<th></th>
<th>Lane position ( SD ) (L)</th>
<th>Lateral velocity (H)</th>
<th>Working memory</th>
<th>Anticipation Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous errors</td>
<td>.38*</td>
<td>-.52**</td>
<td>-.40*</td>
<td>.47*</td>
</tr>
<tr>
<td>Lane position ( SD ) (L)</td>
<td>-.09</td>
<td>-.33</td>
<td>.35</td>
<td></td>
</tr>
<tr>
<td>Lateral velocity (H)</td>
<td>0.12</td>
<td></td>
<td>-.16</td>
<td></td>
</tr>
<tr>
<td>Working memory</td>
<td></td>
<td></td>
<td>-.08</td>
<td></td>
</tr>
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</table>

Notes. The correlations between lane position \( SD \) (L) and working memory and anticipation timing approached significance, \( p = .08 \) and \( .07 \), respectively. \( * \) \( p = .05 \).

When the measures were combined, lateral velocity in the high complexity scenario as well as working memory and anticipation timing contributed significantly to the prediction of hazardous errors; \( R^2 = .52 \), adjusted \( R^2 = .46 \). \( F(3,24) = 8.69, p < .01 \) (see Table 12). Lane position in the low complexity condition did not contribute significantly to the regression due to its marginal relationship with working memory and anticipation timing (see Table 11). Thus, driving measures accounted for 33% of the variance in hazardous errors and non-driving measures accounted for 30%. However, when the model included both driving and non-driving predictors, the proportion of variance accounted for increased to 46%.
TABLE 12. SUMMARY OF REGRESSION COEFFICIENTS FOR DRIVING AND NON-DRIVING PREDICTORS

<table>
<thead>
<tr>
<th></th>
<th>$B$</th>
<th>$SE B$</th>
<th>$\beta$</th>
<th>$t$</th>
<th>$p$</th>
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</thead>
<tbody>
<tr>
<td>Lateral velocity(H)</td>
<td>-38.336</td>
<td>13.255</td>
<td>-.417</td>
<td>-2.89</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Anticipation timing</td>
<td>.003</td>
<td>.001</td>
<td>.375</td>
<td>2.62</td>
<td>.03</td>
</tr>
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<td>Working memory</td>
<td>-.025</td>
<td>0.011</td>
<td>-.323</td>
<td>-2.26</td>
<td>.02</td>
</tr>
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</table>

Note. The regression equation for hazardous errors = 3.24 -3.34 (high complexity lateral velocity) - .025 (working memory) + .003 (anticipation timing).

Discriminant Function Analyses

Standard discriminant function analyses were performed using driving variables, non-driving variables, and both driving and non-driving measures to determine which were more valuable predictors of hazardous errors. Driving risk rating was based on the total hazardous errors participants committed across the three test scenarios. High risk performance was defined as committing more than three hazardous errors (more than an average of one per scenario); low risk performance was defined as three or fewer hazardous errors. Driving predictors were lane position $SD$ in the low complexity scenario and lateral velocity in the high complexity scenario. Non-driving predictors were working memory and anticipation timing performance. Because there were only two risk groups a single standard discriminant function was calculated. The counts of the risk groups were unequal with 21 low risk group members and only 7 high risk group members. Therefore, the analyses were conducted without the assumption of equal group sizes.
There was significant association between driving predictors (low complexity lane position SD and high complexity lateral velocity) and risk group; $\chi^2 (2) = 11.08, p < .01$. The function correctly classified 19 of the 21 the low risk participants (90.5%) and 4 of the 7 high risk participants (57.1%), for a total accuracy rate of 82.1%. A cross-validation was conducted to assess the stability of the classification in which each case was classified based on functions derived from the other cases. This level was retained in the cross-validation.

Similar results were obtained when only non-driving predictors were used (working memory and arrival time), $\chi^2 (2) = 9.56, p < .01$. The function correctly classified 19 of the 21 low risk participants (90.5%) and 4 of the 7 high risk group (57.1%); in all, 82.1% of the cases correctly classified. Cross validation resulted in the correct classification of 78.6% of the cases; 19 of the 21 low risk participants (90.5%) and 3 of the 7 high risk participants (42.9%) were classified correctly. As with the driving variables, the function was a better predictor of safe drivers than of risky ones. While one would prefer to identify a greater proportion of the drivers more prone to making hazardous errors, however, these functions identified more than half of the riskier drivers in the sample while incorrectly categorizing less than 10% of the less risky participants. It should be noted that only one of the participants in this study obtained an MMSE score indicating mildly impaired cognitive status. It is possible that the modele would have better identified risky drivers had the sample included a greater number of participants with cognitive impairment.

Thus, analyses based on the driving and the non-driving predictors resulted in correctly classifying all but two of the low risk participants; the models were less accurate in assigning high risk participants. When both driving and non-driving measures were included, there was some improvement in classification of high risk participants; $\chi^2 (4) =$
15.75, $p < .01$. As in the analyses using only driving or only non-driving predictors, 19 of the 21 low risk participants (90.5%) were correctly classified, but classification of high risk drivers improved somewhat, with 5 of the 7 (71.4%) correctly classified. These results offer evidence that, while driving and non-driving measures were similarly effective in differentiating between low and high risk participants, considering both types of predictors may improve the identification of high risk drivers.

As compared to members of the low risk group, high risk drivers had more difficulty simultaneously holding information in memory while manipulating similar information in the working memory task and in estimating a brief time interval in the arrival time task. In simulated driving, higher risk participants were less consistent in their lane position in the low complexity scenario and changed lanes more abruptly to the left than to the right in the high complexity scenario. The similarity in the predictive power of the driving and non-driving variables may indicate that changes in driving behavior result from age-related changes in other skills; however, there were few significant correlations among the driving and non-driving variables that were predictive of hazardous errors (see Table 11). Had the driving and non-driving predictors been more highly correlated, the combination of driving and cognitive predictors would have been unlikely to improve the predictive power of the models.
The objective of this study was to examine how age-related changes in specific driving behaviors and in measures of attention, working memory, and anticipation timing may impair safe driving in older adults. It was hypothesized that younger participants (Y) and older participants with higher scores on cognitive measures of mental status and attention (OH) would commit fewer hazardous errors during simulated driving tasks than would older adults with lower scores on the cognitive measures (OL). The results provided support for this hypothesis; the Y group made significantly fewer hazardous errors than did the OL group. The OH participants did not differ reliably from either of the other groups in number of hazardous errors; however, they were better able than the OL group to respond to peripheral letter targets in the simulated driving scenarios, which suggests that they were better able to take advantage of the available visual information.

Correlational analyses of relationships between hazardous errors and driving behaviors in the older participants revealed that those with elevated hazardous error rates generally exhibited poor maintenance of lane position and tended to spend more time driving in the right lane despite instructions to stay in the left lane expect to pass slower vehicles. Many moved into the right lane when it was clear and then made abrupt lane changes to the left when forced to do so by a blocking vehicle. Those with higher hazardous error rates also performed more poorly than other older participants in measures of cognitive processing (the coding task), working memory, visuospatial memory (figure recall) and anticipation timing.
These findings offer evidence that age-related changes in driving behaviors and in non-driving skills exhibited by some older adults result in a diminished ability to manage the simulated driving task and potentially in real world driving as well. A set of measures was identified that may distinguish at risk drivers from the population of high functioning active older adults. The hazardous errors in the driving simulator generally resulted from the driver failing to respond in a timely manner to a potential hazard. This is consistent with findings reported by Rumar (1990) that the majority of real-world automobile crashes result from the driver detecting a hazard too late to respond appropriately.

A number of the OL participants adopted a strategy of slowing down as they approached intersections, sometimes to between 10 and 20 mph (or to a complete stop) in the 40 mph zone. This is consistent with older adults’ on-the-road driving performance; drivers with cognitive decrements tend to drive too slowly or to stop when the driving task becomes unmanageable (Dobbs et al., 1998; Hunt et al., 1993; Wild & Cotrell, 2003). A number of the participants in the current study who slowed as they approached intersections stated that they wanted to be able to stop if the light changed. The simulator traffic lights were programmed to change from green to yellow when the participant was two seconds away from the center of the intersection (participants were instructed to stop at yellow lights). A participant driving 40 mph was about 115 feet (35 m) from the center of the intersection when the light changed; at 30 mph, the light changed when the driver was about 90 feet (27.5 m) away. Participants driving these speeds were generally able to stop well before entering the intersection.

When participants approached intersections at 20 mph or slower, the light changed when the driver was so near that the traffic light was at the top of the display screen; many
of these participants failed to notice that the light had changed. Because they were so near the intersection when the light changed, they did not encounter the potential hazards associated with the intersections; cross traffic and pedestrians entered the intersections only after the participant had cleared it. Thus, a number of the older participants were exposed to fewer hazards than were those who drove faster, yet as a group, they committed more hazardous errors than did members of group Y. These drivers’ hazardous error scores might have been higher had the traffic lights been triggered when the participant reached a specific distance from the intersection, rather than being triggered by a time interval.

Predictors of Hazardous Errors

Evaluation of the relationships among older participants’ hazardous error rates and their driving behaviors and non-driving skills offer insight into the kinds of age-related changes that may underlie declines in driving performance. Because predictors of hazardous errors in older drivers would be expected to differ from those for their younger counterparts, only older participants’ scores were considered.

Driving Behaviors

The driving behaviors associated with increased hazardous error rates were poor maintenance of lane position and keeping to the right lane except when forced into the left lane to pass a blocking vehicle. Those who followed instructions to drive in the left lane except to pass and who performed similarly smooth lane changes in each direction logged fewer hazardous errors. The most proficient participants appeared to recognize a potential obstruction early enough to respond in a controlled manner. These participants seemed to have a better grasp of the overall traffic pattern, whereas those with higher hazardous error
rates appeared to focus only on the elements of the driving environment nearest them thus failing to anticipate hazards.

Participants were most likely to make hazardous errors at intersections or when changing lanes. They often verbalized that they did not see the other vehicle or changing traffic light; at other times, they responded verbally to an event but failed to respond in time to avoid a crash. This vulnerability of older drivers to errors at intersections has been reported in studies of on-the-road driving (Daigneault et al., 2002a; McGwin & Brown, 1999; Preusser et al., 1998), with the drivers often reporting not having seen a signal light or other vehicle in time to respond (Ryan et al., 1998). Poor maintenance of lane position and error in changing lanes have also been reported in high risk older drivers in the real world (McKnight & McKnight, 1999).

Situation Awareness

The increased hazardous error rates observed in some of the older participants may reflect age-related changes in their ability to maintain situation awareness, a concept from aviation research that describes one’s understanding of a dynamic environment. Endsley (1997) described three levels of situation awareness that support strategizing and decision-making processes. The first level is the perception of characteristics of the environment, as when a driver notes the position, heading and speed of other vehicles and the state of a nearby signal light. Novice and experienced drivers may perform similarly at this level of situation awareness. The second level involves integrating and making sense of the environmental stimuli as they relate to the driver’s goal of reaching a destination. The novice driver’s awareness at this level is unlikely to be as complete as that of the experienced driver, who would be expected to identify and integrate more relevant
environmental elements and to recognize potential conflicts that the novice might miss. The third level requires projecting the near future environmental status based on information from the first two levels. This allows the driver to plan and execute responses to facilitate navigating safely and efficiently toward a destination. At this level the expert’s performance is likely to be far superior to that of the novice, particularly in heavy traffic.

*Working Memory*

Declines in executive functioning may limit older drivers’ situation awareness and consequently their ability to interact effectively in complex traffic situations. Executive functioning is a higher order process that supervises other cognitive activity; it supports situation awareness by enabling a driver to combine information from the environment and from long-term memory to interpret the current status of the driving situation and to predict the consequences of a selected action, the third level of situation awareness described above.

In the working memory task used here, executive functioning would facilitate acquiring the problems from the computer display and accessing semantic long-term memory for the means of solving the problems. In the driving simulator (and on the road), executive functioning would support combining information from the driving environment with information from long term memory to interpret the present and project the near future status of the traffic situation. In the driving scenarios, participants with executive functioning deficits may have failed to process stimuli at greater distances in order to focus on more immediate potential hazards; this would result in their observed tendency to delay maneuvering around slower vehicles.

Baddeley and Hitch (1974) proposed a tripartite model of working memory comprised of separate stores for auditory (the phonological loop) and visual and spatial
information (the visuospatial sketchpad), as well as a central executive responsible for allocating attention to and manipulating information in the subsystems (see Figure 1). This model was based on the observation that phonological information was relatively immune to visual interference and visual information to phonological interference; limitations in working memory were ascribed to limited attentional resources available to the central executive. In the tripartite model the central executive apportions attentional resources to the appropriate slave loop and for integrating information from the loops.

In the tripartite model, the central executive component is responsible for coordinating tasks, dividing attention between concurrent tasks, and possibly for switching attention between tasks. While these processes have been supported by a body of research (for a review see Baddeley, 2001), the model does not account for retrieval of information from and encoding information into long term memory or for integrating information from the two subsystems. To address these limitations, Baddeley and colleagues (2000) incorporated an additional component into the model, an episodic buffer (see Figure 9 below). In this model the central executive can temporarily maintain visuospatial and phonological information in the episodic buffer, and can access information from long term memory. The central executive can manipulate and bind the information in the episodic buffer into a meaningful episodic representation. The episodic buffer and central executive components of this model carry out the tasks ascribed to executive functioning described above. Under this multi-component model, the central executive is responsible for allocating attention and for selecting and manipulating information within the episodic buffer. The ability to maintain an integrated representation in working memory, a function carried out by the episodic buffer, has been associated with activation in the prefrontal...
cortex; unintegrated representations, which are maintained in the phonological or visuo-spatial loops, are associated with posterior activity (Palmer, Verghese, & Pavel, 2000).

Figure 9. Multi-component model of working memory

Performing the working memory task in the current study required accessing the numbers to be added from the display and the means of adding the numbers from semantic long-term memory. The central executive processed the numbers in the episodic buffer to generate a meaningful episodic representation: a sum. The sum was stored temporarily in the phonological loop until it could be reported after the third number pair was added. Foos (1989) described age-related deficits in his addition task as resulting from a decline in working memory capacity. However, given the requirement to hold information, to access the slave loops and semantic memory, and to generate a new number, the central
executive/episodic buffer process in Baddeley’s multi-component model may better describe the task.

Changes in the prefrontal cortex resulting from injury (Fuster, 1997) or aging (Erraji Benchekroun et al., 2005; Fuster, 1997; Gutchess et al., 2005) have been associated with declines in central executive performance. Thus, age-related changes in the prefrontal cortex associated with normal aging could be expected to result in degraded central executive functioning and consequently poorer performance in the working memory task. Similarly, one would expect such declines to restrict an older adult’s ability to gather and integrate environmental information in a complex driving scenario and in real world driving. These declines may underlie the observed deficits in maintaining lane position and in the failure to use all of the available environmental cues in responding to potential hazards in the simulator and on the road.

Baddeley’s multi-component working memory model describes a process for managing information in order to perform complex tasks like the working memory task and the driving scenarios in this study, as well as real world driving. In the current study, single task addition performance was not scored; however, participants seemed to have similar addition abilities. Deficits were apparent only when participants were required to hold sums in memory while they added subsequent pairs. Similar effects were apparent in simulator performance; few participants made hazardous errors during the low complexity scenario. Differences in the ability to avoid hazards were evident only under higher levels of task complexity.

Age related changes in the neural structures that support higher order cognitive processes would be expected to affect the ability to maintain control of all elements of a
complex task. A study of executive control in younger and older participants in a dual task paradigm offered evidence that older participants were disadvantaged in combining tasks; differences in performance between older and younger participants were exacerbated when the overlap between the tasks was increased (Holtzer, Stern, & Rakitin, 2004). Participants in the current study performed numerous largely overlapping driving tasks of maintaining speed and lane position, monitoring other road users and traffic signals and watching for peripheral letters. Those whose attentional resources were essentially absorbed by the driving task would be expected to exhibit poorer performance on some or all of these measures.

**Anticipation Timing**

Performance on the anticipation timing task was associated with participants’ ability to avoid hazards in the driving scenarios, and may indicate the effects of declines in the ability to accurately time driving responses. The ability to estimate the future positions of moving vehicles relative to one’s own future position would be expected to support performance of tasks including turning across traffic, merging and changing lanes. Older drivers have been shown to be at increased risk for crashes as compared to middle-aged drivers in all of these situations (McGwin & Brown, 1999).

**Useful Field of View**

UFOV divided and selective attention scores, which were expected to predict hazardous errors in older drivers failed to reach significance in this study. This may have resulted from the relatively good UFOV performance of the majority of the participants in the sample. Twenty-five of the 28 older participants obtained UFOV scores indicating very
low crash risk. Of the remaining participants, one received a low risk rating, one a low to moderate risk rating and the third received a high risk rating. The participant with the high UFOV risk rating was one of the seven members of the high hazardous error group, however, those receiving the low to moderate and low ratings were in the low hazardous error group; conversely, six of those who made more than three hazardous errors were rated as very low risk according to their UFOV scores.

Ball and colleagues (1993) demonstrated the utility of UFOV scores in classifying drivers based on their crash history over the previous five years into groups that had experienced zero, one to three and four or more at-fault crashes. Because they were interested in evaluating the efficacy of the UFOV test in identifying unsafe drivers, drivers who had been found at fault in at least one crash in the previous five years were over-represented in the study; 33% of their sample had been found at fault in one to three crashes and 18% in four or more crashes in the previous five years. In addition, the majority of the participants had a UFOV restriction of at least 40%, which corresponds to a rating of low to moderate risk or higher in the current study. Only 7% (2) of the older participants in the current study reported instances of at-fault crashes in the previous five years; none reported more than one such crash. Only one had a UFOV risk rating higher than low to moderate. Given the differences in the crash histories and UFOV performance between participants in the two studies it is not surprising that the results reported by Ball and colleagues (1993) did not generalize to the current study.

Characteristics of the driving scenarios may have affected the relationship between UFOV and hazardous error scores. Due to limitations of the equipment, the scenarios did not require participants to perform some tasks that have been shown to be particularly
difficult for older drivers, including unprotected left turns and merging into highway traffic. If UFOV performance predicts errors that result in crashes associated with left turns and/or merging, then UFOV scores would not be expected to be correlated with hazardous errors in these scenarios.

Age was not significantly correlated with hazardous errors. People vary tremendously in the degree to which they experience age-related declines in areas including vision, cognition, physical strength and flexibility. While an increase in the proportion of crashes incurred by older drivers is a legitimate societal concern, it is important to recognize that the majority of older drivers have no history of recent crashes. Research should focus on identifying those drivers who represent an unacceptable safety risk to themselves and to other road users, then to determine the extent to which they can take measures to regain skills that have declined. Only in cases where a driver’s skills have degraded to the point where he or she can no longer drive safely and appropriate remediation efforts have failed should driving privileges be revoked.

Potential Interventions

The results reported here could guide the development of screening and training programs for older drivers. A computer-administered battery that included tests of working memory, anticipation timing and spatial memory similar to those in the current study would be of benefit to physicians whose patients include older drivers, to organizations such as the American Red Cross who rely on older adult volunteer drivers and to senior centers and other organizations that offer services to older adults.

Training programs could be offered to enable older adults to regain skills that have declined. Visual attention training has been reported to transfer to improvements in driving
performance in older adults (Roenker, Cissell, Ball, Wadley, & Edwards, 2003); training in anticipation timing might offer similar benefits. Anticipation timing has been shown to transfer to improved ability to interact with a dynamic environment in athletes (e.g., McNevin, Magill, & Buekers, 1994; Williams & Jasiewicz, 2001), so may offer an additional avenue to improve older drivers’ ability to safely navigate complex driving environments. This could be particularly useful in older drivers who, like the sample in the current study, have retained their visual attention skills.

The results could also guide the criteria used by evaluators of older drivers’ on-the-road performance. As noted by McKnight & McKnight (1999), evaluations of routine safe driving practices may not reveal unsafe older drivers; the types of errors associated with hazardous errors in this population differs from that in young and middle-aged drivers. The results of this study support the contentions of other authors that consistency in lane position, lane change performance, appropriateness of intersection decisions and the ability to follow instructions be considered in evaluating older drivers’ performance (Hunt et al., 1993; McKnight & McKnight, 1999; Wild & Cotrell, 2003).

Although the sample size in this study was too small to yield statistically significant results based on self-reported crash history, participants were asked for details of any crashes they had experienced over the past five years. Only four of the older participants reported such an experience. Two were found not at fault in the crashes; one was hit from behind while legally crossing an intersection controlled by four-way stop signs. The other was driving on the highway when a vehicle ahead swerved into the participant’s lane to avoid a car stopped along the roadside. The participant slowed so as not to hit the leading vehicle and was hit from behind. Both of these participants were in the OH group, had very
low risk ratings based on their UFOV scores, and each committed only one hazardous error
during the test scenarios.

Of the participants who reported at-fault crashes in past five years, one fell asleep
while driving on the highway on a clear afternoon in light traffic. The participant was a
member of the OH group, had a very low UFOV risk rating and committed 3 hazardous
errors. One participant committed an error at an intersection that was typical of crashes
involving older drivers as reported in the literature (Cerrelli, 1998; Daigneault et al., 2002a;
McGwin & Brown, 1999; Preusser et al., 1998; Ryan et al., 1998). The participant turned
across an intersection in front of an oncoming vehicle at an intersection controlled by signal
lights, and later reported not having seen the other vehicle. This incident occurred during
the daytime in clear weather. This participant was a member of the OL group with a UFOV
score indicating a very low risk rating, however, working memory and anticipation timing
scores correctly predicted that this participant would make more than three hazardous errors
in the simulator scenarios.

Conclusions

Future study is needed to determine whether the findings reported here, particularly
the cognitive measures, generalize to real world driving. The findings regarding driving
variables associated with increased risk reflect those in the literature (Hunt et al., 1993;
McKnight & McKnight, 1999). This offers evidence that the hazardous errors measure is a
valid measure of real world driving errors, so the relationship reported here between the
working memory and arrival time tasks may also hold true on the road.

Other skills that may decline with age, and which may impair the safety of older
drivers, include declines in motor control, particularly in the ability to plan, coordinate and
execute tasks with both hands and one foot, as would be required in concurrently steering, signaling a turn and braking or accelerating. This ability to perform multiple limb tasks has been shown to decline with age (Serrien, Swinnen, & Stelmach, 2000); however the tasks used were not familiar. It is possible that in an over-learned task such as driving, declines with age would be more moderate.

Older adults’ ability to simply add number pairs as compared to their ability to perform the working memory task reported here highlights the difficulty older adults may have in performing complex tasks, including driving. Those with some decline in cognitive ability are likely to retain their ability to perform component parts of the tasks, such as navigating through traffic in the low complexity simulator scenario or making a routine trip to the grocery store. Deficits become apparent when tasks must be performed concurrently, as when one must monitor speed and lane position while avoiding unexpected hazards in the high complexity simulator scenario or when driving to the grocery store while refereeing an argument between the children in the back seat.

The results regarding declines in anticipation timing performance suggest that tasks which require coordination of timing of various sub-tasks, as when slowing, signaling a turn and turning at an intersection, may also be difficult for some older drivers.

The increase in hazardous errors with declining scores on non-driving measures points toward the need for care in recommending in-vehicle guidance and safety devices to older drivers. Research should be conducted to determine whether alarms such as those that signal a warning if a driver is backing toward an obstacle are effective for older drivers, or whether they simply add to an already overwhelming stimulus array. As the number of in-car guidance, communication and entertainment devices increases, age-related declines in
tolerance for driver distraction should be evaluated. In addition, the effects of age-related illnesses and the medications taken to address those conditions should be considered when making driving decisions. Physicians and pharmacists should inform their clients of the possible effects of their conditions and medications on their driving safety.

The current study offers evidence that measures that assess executive functioning, like the working memory task used here, can be used to determine whether an older adult may benefit from an on-the-road driving evaluation. The results also offer insight into the types of driving errors associated with increased crash risk in older drivers. These include an inability to maintain lane position in low complexity conditions, as well as difficulty in managing complex situations such as merging into traffic, changing lanes and making left turn decisions. The arrival time results indicate that driving evaluators should also consider the older driver’s ability to temporally integrate driving tasks.

Despite a variety of age-related changes, including those in vision and cognition, many older adults continue to be safe drivers. Most have extensive experience on the road, and many report awareness of their declines in vision and reaction time and are concerned about their driving ability. These people often avoid driving in situations where they feel uncomfortable, including night and rush hour driving (Wild & Cotrell, 2003). It is likely that these individuals’ concerns about their changing driving skills lead them to exercise caution in selecting where and when they choose to drive; thus they are likely to be among the 89% of older drivers who have not recently been involved in a crash (Daigneault et al., 2002a).
LIST OF REFERENCES
REFERENCES


APPENDICES
APPENDIX A

TABLE 13. CORRELATIONS BETWEEN HAZARDOUS ERRORS AND HYPOTHESESIZED PREDICTORS

<table>
<thead>
<tr>
<th>Driving measures (low complexity scenario)</th>
<th>Non-driving measures</th>
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<td>Speed (L)</td>
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<tr>
<td>Lane position (L)</td>
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<td>Time to collision (L)</td>
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<td>Working memory</td>
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APPENDIX B

Source Tables for ANOVAs

TABLE 14. ANOVA: GROUP BY HAZARDOUS ERRORS

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Note. Groups: Y, OH, OL

TABLE 15. ANOVA: GROUP BY AGE

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Note. Groups: Y, OH, OL
### TABLE 16. ANOVA: GROUP BY MMSE SCORE

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</tbody>
</table>

Note. Groups: OH, OL

### TABLE 17. ANOVA: GROUP BY ATTENTION INDEX SCORE

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>$F$</th>
<th>partial $\eta^2$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1</td>
<td>38.57</td>
<td>.68</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>Within Groups</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Groups: OH, OL