IMPACT OF DISTRACTION ON SIMULATED LANE NAVIGATION IN OLDER ADULTS WITH AND WITHOUT COGNITIVE IMPAIRMENT

By

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To my husband, Benjamin Zehner. His unfailing love and encouragement supported me through this journey.

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In healthy adults, many driving skills have become automatic, requiring little cognitive effort. However, drivers are at heightened risk of driving failures when in unfamiliar situations due to increases in required cognitive effort, and in particular if they are experiencing losses in attention due to cognitive impairment. Much research to date has examined the risk of driving with cognitive impairment in usual, low-challenge driving situations and thus not found an effect. While drivers at any age are impacted by increases in cognitive load, this study simulated complex driving, under safe and controlled conditions, to assess whether increases in challenge from single-task to divided attention (dual-task) conditions, put persons with cognitive impairment at an additional risk of driving errors.

Sixty-one community-dwelling participants age 65 and over were recruited. A consensus panel determined group status (healthy control or memory impaired) based on neuropsychological performance. Participants were administered an experimental dual-task paradigm. A driving-related task, lane navigation, was administered at two levels of difficulty (slow speed and fast speed) both alone and simultaneously with a memory recall task. As expected, all participants showed reductions in lane navigation performance when speed was increased. However, when participants were asked to complete the lane navigation task

simultaneous with the secondary paragraph recall task, they showed less deviation than when only completing the single lane navigation task. Results from the paragraph recall task show worse performance under dual-task condition. It is believed that the participants became more vigilant to the driving task while sacrificing paragraph recall due to potential safety concerns if they were driving on the road. Since no impairment interactions were found with the driving task, it is possible that the dual-task measures were not sensitive enough to detect the subtle changes in ability in those with memory impairment. While this study explored dual-task costs using measures between different modalities (visual-manual and auditory-verbal), further work should explore a dual-task driving condition using a secondary task also requiring visual-manual processing to determine if within modality interference is greater than between modality in this population.

CHAPTER 1
LITERATURE REVIEW

Adults over the age of 65 make up approximately 13% of the population of the United States of America, but this is expected to increase to approximately 17% by the year 2050 (Wang, Kosinski, Schwartzberg, & Shanklin, 2003). In absolute terms, this means the proportion of older drivers on America's roadways will also increase. In the face of enduring questions about the effects of aging, and of cognitive impairment, on the driving abilities of older vehicle operators, this line of research seems important in anticipation of the growing numbers of older drivers.

Aging and Driving

Statistics

Injuries from motor vehicle crashes are the leading cause of injury-related deaths for those aged 65 to 74 and the second leading cause for 75 to 84 year olds (behind deaths resulting from falls; Wang et al., 2003). Older adults have higher fatality rates per mile driven than any other age group, except those under age 25. This rate can be explained by two facts: drivers age 75 and over are involved in more motor vehicle crashes per mile driven than middle aged drivers and older drivers are physically more fragile. Records from 2000 indicate that of the 37,409 fatalities from crashes, 6,643 were age 65 or over. While this group represented 13% of the United States population, they accounted for 18% of traffic fatalities (National Highway Traffic Safety Administration, 2001). This proportion is only expected to increase since the number of licensed older adult drivers is expected to increase from 13 million to 30 million by the year 2020 and it is expected that the upcoming generation of older adults will drive more miles than current older drivers (Carr, Duchek, Meuser, & Morris, 2006).

Self-Regulation of Driving

Older adults tend to self-regulate their driving behavior; but this has failed to result in lowering the statistics of crashes among older adults. Self-regulation occurs as older adults feel less confident in their reaction time, chronic health problems may limit ability, and medication side effects may preclude safe driving. Such self-regulation has resulted in fewer miles driven per year for older adults. Besides driving less, they also tend to modify how and when they drive. For instance, older adults tend to avoid highways, driving during high-traffic hours, or driving in inclement weather (Florida Department of Highway Safety and Motor Vehicles [FDHSMV], 2004). On the other hand, older adults are more likely to use safety restraints and are less likely to engage in risky driving behavior, such as tailgating or speeding, than younger adults (Preusser, Williams, Ferguson, Ullmer, & Weinstein, 1998).

Despite self-regulation and increased safety among older adults, the crash rate for this age group remains elevated. This can be explained by at least two phenomena. First, many medical conditions that occur with age arise insidiously and without notice by older adults (FDHSMV, 2004). Some such conditions, like loss of peripheral vision, have a large impact on safe driving. Second, some neurological conditions (e.g., Alzheimer's disease) may impair deficit awareness, thus leading some older impaired drivers to think that they are safe behind the wheel (Wang et al., 2003; Carr et al., 2006). Nonetheless, many older adults choose to stop driving each year; however, and then they are faced with the challenge of finding alternate transportation and coming to terms with the loss of their independence.

Overview of Literature

Driving is a complex task that involves many cognitive skills, including such areas as visuoperceptual, motor, and decision-making ability to name a few. Aging is a possible source of vulnerability in each of these skills, but this study will focus mainly on cognitive changes that relate to driving. First, normative as well as pathological disorders that affect cognition will be reviewed. Next, consideration of studies of areas of cognition most relevant to driving, including different types of attention, will be discussed. These findings will then be considered in terms of their relationship to driving by discussing cognitive models of driving and studies of attention in driving. Lastly, driving and its measurement will be considered in the context of building a rationale for the chosen methods of the study.

Aging and Cognitive Changes

As adults age, there are normative changes in cognition. Most notable is that older adults are slower in responding. This translates into slower motoric reaction times and slower visual processing amongst other slight functional changes (Storandt, 1994). There is also a slow decline in fluid abilities (i.e., tasks that are novel requiring speed, perceptual, and motor processing skills), while crystallized abilities (i.e., tasks requiring stored knowledge) remain at the adulthood level well into old age (see Schaie, 1990).

Procedural Knowledge

Studies of skill expertise with older adults (e.g., typing in those who were clerical workers) that suggest that procedural knowledge ("how" to perform particular tasks) remains stable in old age (e.g., Salthouse, 1984, Charness, 1989). Procedural knowledge accounts for many activities we do in everyday life, such as driving a car, playing the piano, or spelling. These activities do not require conscious recollection of the initial learning of the task because it is implicit. In bypassing the recollection and conscious decision-making about the task and the well-learned automatic processes that occur to engage in the task, such skills are protected from the effects of the aging brain (Craik, 2000).

Attention

Attention is a multi-factorial ability, and some components of attention show age-related changes, while others do not. Selective attention, or the ability to filter stimuli, has shown age-related changes in novel tasks, while tasks that are familiar to the individual are less susceptible to age-related decline (e.g., x-ray technicians across the lifespan have similar rates of disease detection; Rogers, 2000). Focused attention, or the ability to hold attention to a target at the exclusion of everything else, has also not shown age-related degradation. A study by Nebes and Brady (1989) even suggested that those with Alzheimer's disease retain focused attention ability as long as the target is discriminable from the distractors. Sustained attention (vigilance) tasks in older adults have shown mixed results, partly due to sensory or processing-speed factors in many tasks that are not directly related to sustained attention per se. Age-related changes in divided attention ability are dependent on the complexity of the task as well as the amount of practice used. In easy tasks, there are no age differences, but as the complexity of the tasks increases so does age differences, especially if one of the tasks requires the use of memory (Rogers, 2000).

Cognitive Aspects of Driving

Attention is central to the task of driving. Driving requires continual sensing and responding to spatial and temporal stimuli as well as the coordination of head and limb movements (Stelmach & Nahom, 1992). Age alone is a poor predictor of driving ability (Dobbs, 1997; DeRaedt & Ponjaert-Kristoffersen, 2000; Carr, Jackson, Madden, & Cohen, 1992), but rather other cognitive and non-cognitive factors contribute to driving performance (Meyers, 1999). Three major models of driving behavior have been proposed and will be discussed along with a consideration of cognitive and non-cognitive factors that are related to driving.

Michon's Hierarchical Model of Driving

Michon developed a hierarchical model of driving that contained three major levels of decision-making necessary for safe driving (Galski, Bruno, & Ehle, 1991). First, *strategic decision-making* is most important and occurs often before driving because it relates to planning a route and determining general risks of traffic that one might encounter. At a second *tactical decision-making* stage, an individual makes specific decisions about handling a vehicle in traffic, such as adjusting speed. Lastly, *operational level decision-making* involves making choices about how driving will be enacted, such as steering and braking (Galski et al., 1991).

According to this model's premises, there are likely to be impairments in driving in individuals with cognitive impairment. The strategic level is likely to be affected by impairments in memory, such that the individual would have difficulty remembering routes to desired location. Also, impairments in judgment may allow for an individual to not appropriately assess danger. At the tactical level, difficulty with spatial relations and judgment may impair negotiating traffic. At the operational level, procedural knowledge about motoric maneuvering is likely to remain intact into early AD and therefore may not be affected by cognitive impairment.

Information-Processing Model of Driving

Rizzo, McGhee, Dawson, and Anderson (2001) suggested an information processing model of driving in which the risk of human error increases with deficits of attention, perception, response selection, and response implementation. Additionally, psychomotor speed and mobility may negatively impact driving ability. They also suggest that cognitively healthy individuals can often detect their own errors through monitoring and feedback; however, those with cognitive impairment are less likely to notice their errors due to loss of awareness of their deficits.

Because this model relies heavily on cognitive skills that are impaired in AD (i.e., attention, perception), this model would suggest that those with AD would have impairments in driving.

Cybernetic Model of Driving

This model proposed by Galski and colleagues (1991) was developed to help understand what factor contributes to safe driving in those with cerebral injury based on the literature that was available at that time. The most important component in their model is the "general driving program" which contains knowledge about roads and operating procedures that come from driving manuals, but this is also constantly updated with driver experiences, as well as scanning and attention necessary for safe driving. Since this relies on memory storage and retrieval, individuals with brain damage, and also AD, might show an inability to adapt or build on their prior knowledge. The second component is the "specific driving program" which monitors sensory input, coordinates sensory information, initiates motor output, and evaluates functioning. This component, like other procedural knowledge skills, is likely preserved in early AD.

Cognitive Factors Important for Driving

Visuoperceptual processing speed

Visuoperceptual processing speed, or the rate at which one can visually process and identify a target, is important for driving ability (Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Richardson & Marottoli, 2003). This allows for quick location and recognition of objects in the field of view that may be in one's pathway, such as a ball rolling onto the street, so that quick reactions with motor programs to avoid such obstacles can be executed. The most common test for assessing this ability is the Useful Field of View (UFOV; Ball & Owsley, 1993), and it has been found to significantly predict crashes in older adult (Owsley et al, 1991).

Rizzo et al. (2001) examined the types of crashes that those with AD are prone to have using a driving simulator. They found that the most common type of crash was one in which the individual was “looking without seeing” or gazing out of front windshield but never reacting to oncoming traffic or obstacles. The same type of crash has been shown to be related to dorsolateral visual association cortex lesions due to stroke or AD neuropathology (Rizzo et al., 2001).

Executive functioning

Executive functioning, or the ability to adaptively respond to novel stimuli, also contributes heavily to driving performance. Processes that fall under the term ‘executive function’ have varied effects on driving. Planning, organizing, and decision-making are necessary for such maneuvers as making lane selection choices and adequately preparing for actions that are needed up ahead, such as exiting a freeway. Self-monitoring is important for maintaining speed with the flow of traffic. Judgment is important for evaluating gaps in traffic to determine the safety of making a turn (Meyers, 1999).

Memory

Memory is integral for driving, specifically recent memory. Recent memory is needed for way-finding and following rules of road signs. Memory also allows for procedural knowledge of how to maneuver the car in certain ways, use gearshifts, and signaling devices. Thus, driving in highly familiar routes with little traffic may not be affected by memory impairment (Parasuraman & Nestor, 1991).

Attention

Selective attention, or the ability to restrict your attention to some target, is also an imperative skill for driving. This ability is important for being able to selectively focus on different stimuli in the environment while ignoring the thousands of other cues that do not require your attention (e.g., a small bug flying into the windshield is insignificant and not requiring of attention; Ward, 2004).

As noted previously, driving requires continuous adaptation to changing environments through dividing attention among multiple sources of information at a time. Despite the complexity, with practice, driving develops into an effortless task allowing the skilled driver to focus on other information during driving (e.g., listening to the radio, having a conversation; Ward, 2004). This automaticity develops under highly predictable stimulus conditions (Parasuraman & Nestor, 1991). Skilled drivers are often taken aback when reminded of the number of intricate tasks done routinely while driving because perceived divided attention demands are low. However, even skilled drivers are sometimes reminded of the difficulty of the driving task when trying to maintain a conversation upon approaching a difficult intersection (Ward, 2004). In such unpredictable or unfamiliar stimulus demands, effortful and controlled processes are used to maneuver the situation (Parasuraman & Nestor, 1991; Duchek, Hunt, Ball, Buckles, & Morris, 1997).

Attention is relevant to the task of driving for older adults for several reasons. First, in addition to sensory changes in aging, deficits in attentional ability may exacerbate driving difficulties (Parasuraman & Nestor, 1991). Second, while many cognitive skills are related to the task of driving as outlined above, it is unlikely that one task would be predictive of all components of driving and there is good evidence that attention is related to safe driving independent of sensory functioning. Lastly, studies have shown that impairments in attention occur early in late-life cognitive disorders, such as Alzheimer's disease (Parasuraman & Nestor, 1991). Studying early, mild dementia is likely the best population because individuals with this level of impairment are likely to still be active drivers.

Non-Cognitive Factors Related to Driving

Older adults are more likely to have physical limitations that can impair driving. Stelmach and Nahom (1992) suggests that older adults have less flexibility, have more variable motor responses, take more time for movement, sequence movements with more complexity, and have decreased reaction time (~2% loss per five years, beginning at age 15). Visual acuity, depth perception, and contrast sensitivity are important for being able to process visual stimuli, judge gaps between cars, and recognize colors of lights and signs. Sensory integration is also impaired in older adults, which limits the ability to detect danger (Stelmach & Nahom, 1992). Additionally, medications can sometimes impair driving ability; specifically, medications with sedating side effects such as those used for sleep or pain management. Personality style also affects driving such that those who are more likely to take risks in life might also engage in risky behaviors behind the wheel. Mobility and availability of alternate transportation plays a role in driving ability, frequency, and necessity (Carr, Meuser, Berg-Weger, & Niewoehner, 2004). While these factors are important to consider, they should be common across older adults and should not be responsible for differences between those who are cognitively healthy or impaired once age is controlled.

Transitional Model of Cognitive Impairment

With increasing age, however, there is an increase in the prevalence of disorders that affect cognition. Thus, cognition in aging occurs on a continuum, with those cognitively healthy at one end, those with mild impairments in the middle, and those with severe changes at the other end. While there is some overlap on the continuum, over time transitions to higher levels of impairment may occur (Petersen et al., 1999).

Mild Cognitive Impairment

Diagnostic criteria

The middle of the continuum outlined above may be synonymous with Mild Cognitive Impairment (MCI; Petersen et al., 1999; Petersen et al., 2001). Individuals with MCI are at an increased risk for the development of AD. There are multiple presentations of MCI (e.g., single impairment in a cognitive domain other than memory, multiple domains impaired). The present study focused mainly on the amnestic type, which will be called AMCI. AMCI patients have a mild memory problem that exceeds what is expected for their age (perform $\geq$ 1.5 SD below age and education corrected norms) while other cognitive domains (e.g., working memory or language abilities) are generally preserved. The criteria also requires the individual to have a subjective memory complaint, intact activities of daily living (ADLs; i.e., bathing, dressing), and to not meet the criteria for dementia.

How AMCI differs from other impairments

AMCI differs from normal aging where there is a more general, but slight decline in most cognitive domains over the later decades of life. Moreover, AMCI differs from dementia where there is a more pronounced decline (perform >1.5 or 2 SD below age and education corrected norms) in at least two cognitive domains, most often memory and another domain, as well as impairments in activities of daily living. Many researchers believe that AMCI is a precursor to the clinical manifestation of Alzheimer pathology, notably because 10-15% of those diagnosed with AMCI "progress" to AD each year compared to 1-2% of the general population (Petersen et al., 2001).

Assessment of AMCI

AMCI assessment should include extensive neuropsychological testing including (but not limited to) the domains of verbal and visual memory, working memory, processing speed, attention, and language ability. A depression screening should also take place to rule out the possibility of low-test scores due to inattention or lack of motivation. AMCI assessments should also include an informant interview to assess activities of daily living, memory failures in the home environment, and the patient's judgment and problem solving abilities. A common interview used for this purpose is the Clinical Dementia Rating Scale (Morris, 1993) where impairments are rated from 0 (no impairment) to 3 (severe dementia), with 0.5 usually representing AMCI. Neuroimaging, genetic, and neuropathology markers for AMCI are still under investigation at this time. Due to the likely progressive nature of AMCI, follow-up assessments should take place every 6-12 months (Petersen et al., 2001).

Nomenclature for AMCI

It should be noted that the AMCI information provided herein has been that proposed by Petersen and colleagues at the Mayo Clinic in Rochester, MN. While this model has been accepted by the American Academy of Neurology via an evidence-based practice parameter review (Petersen et al., 2001), the American Association of Neuroscience Nurses, and the American Geriatrics Society, it is important to note that this model is not accepted by all in the fields of psychology, psychiatry, and neurology. In fact over the years, there have been many iterations of similar concepts, including: benign senescent forgetfulness (Kral, 1962), age-associated memory impairment (Crook, Bartus, Ferris, & Whitehouse, 1986), age-associated cognitive decline (Levy, 1994), age-related cognitive decline (American Psychiatric Association [APA], 1994), and cognitive impairment-not demented (Ebly, Hogan, & Parhad, 1995).

Alzheimer's Disease

As mentioned above, AMCI is often considered a precursor to Alzheimer's Disease (AD) because many with AMCI "convert" to AD over time. AD has an insidious onset and is a progressive, degenerative disease. Individuals with AD have a range of cognitive impairments (e.g., memory, language, visuospatial skills, and decision-making) and often persons with AD have different cognitive difficulties. However, there are trends of cognitive losses that correspond to the brain regions disrupted by the plagues and tangles, which are the hallmark neuropathological features of AD.

Diagnostic criteria

The most commonly used criteria for defining AD for research purposes is the National Institute for Neurological and Communicative Diseases and Stroke/ Alzheimer's Disease and Related Disorders Association criteria (NINCDS-ADRDA; McKhann et al., 1984). Specifically, these criteria require: deficits in two or more areas of cognition (e.g., memory, language, visuospatial skills), progressive worsening of cognitive functions, onset between the ages of 40 and 90, the absence of systemic or brain disorders that could account for the deficits in cognition, and deficits in activities of daily living (ADL's). The current edition of the Diagnostic and Statistical Manual (DMS-IV; APA, 1994) has similar criteria. It is important to note however, that Alzheimer's disease cannot be definitively diagnosed until autopsy, but specialized clinics report an average of 81% agreement between diagnosis before death and following autopsy (Knopman et al., 2001).

Progression of impairments

In the early stages of the disease, impairments are often mild and difficult to distinguish from normal aging or AMCI. Importantly, attentional difficulties often manifest before severe impairments in other areas (Parasuraman & Haxby, 1993) as AD has typically been characterized as a global cognitive disorder resulting from a failure to allocate attentional resources to all cognitive functions (Parasuraman & Haxby, 1993).

One of the earliest signs of incipient AD is difficulty laying down new memories, which often leads to repeating questions. Other early signs include forgetting names of acquaintances and not remembering where objects have been placed. With progression over time, individuals with AD develop impaired executive functions and language abilities. For example, patients with mild AD become confused with complex tasks, show difficulty finding their words to speak, have faulty judgment and problem-solving abilities, have difficulty with mathematical calculations, and have problems with spatial relations. As the disease progresses to the moderate and severe stages, individuals typically have global cognitive impairment and find it increasingly difficult to carry out both instrumental and independent activities of daily living (e.g., balance a checkbook, cook a meal, bathe, or eat). Their speech becomes empty, they have difficulty recognizing objects and family members, and comprehension of others is impaired. Eventually such changes could lead to medical complications that result in death (e.g., not swallowing food, forgetting important medications or regimens).

Cognitive Impairment Effects on Attention

As noted above, there are several cognitive processes that are affected in AD. Attention is the first non-memory cognitive operation to show declines in AD (Duchek & Balota, 2005). Generally speaking, automatic non-effortful processing in predictable situations is relatively preserved in AD, while controlled and effortful processing is impaired (Parasuraman & Haxby, 1993).

Ward (2004) suggests that even individuals with mild AD have difficulty concentrating on tasks and maintaining attention. This function has been primarily assessed with vigilance tasks where the goal is to detect a target that occurs infrequently and unpredictably among more frequent non-targets. This is typically assessed for long periods of time (upwards of 30 minutes; Parasuraman & Haxby, 1993). Findings have shown that compared to younger adults, older adults show reduced overall performance, but there are no group differences in the tendency to show decrements with increasing vigilance time. While study of sustained attention in AD has been sparse, there is evidence that individuals with AD show similar patterns as normal aging adults (Parasuraman & Haxby, 1993).

When more than one feature of a complex stimulus or when two stimuli must be attended to at the same time, or dividing attention, individuals with AD show impairments. It is suggested that this occurs because of depletion of processing resources or due to inefficient strategies to allocate resources to multiple tasks. The coordination of performing two simultaneous tasks is thought to occur in the frontal lobes, as dual-task measures have been found to be even more sensitive to frontal dysfunction than typical “frontal” measures (e.g., Wisconsin Card Sorting Test). Metabolic dysfunction of the right frontal lobe has been associated with the divided attention deficit in AD (Parasuraman & Haxby, 1993).

General Theories of Attention

Since attention difficulties are seen early in the progression of AD, it is important to consider different theories of attention in order to understanding what processing difficulty accompanies AD. In the late 19th century, William James conceptualized attention as the process by which one could focus on a particular feature of the environment. Studies of attention became popular in the mid 20th century, with some of the earliest studies using dichotic listening paradigms. As a result of these studies, Broadbent (1958) put forth his theory of attention.

Broadbent (1958) believed that the attentional system of humans had a limited capacity, allowing us to attend to only a finite amount of information at a time. He believed in a unitary system; the attentional system allowed for only one source of information to be processed at a time, filtering out all irrelevant information solely based on physical characteristics of the information. This finding was a result of early studies of speech shadowing where it was evident that some information is discarded before being fully processed. He came to believe that physical features are useful for separating what to be attended to or not because they are the only features that seemed detectable (Styles, 1997). Treisman made a slight modification of this theory after discovering that unattended information was not completely filtered out of the attentional system; he believed that unattended information is simply attenuated (Ward, 2004).

Welford (1952) proposed the central bottleneck hypothesis positing that certain central cognitive processes could not be performed in parallel at the same time. Such processes were considered central because they occurred after perceptual processing but before production of a response (Levy, Pashler, & Boer, 2006). This bottleneck has been studied by having participants make responses to two stimuli presented close temporally. The model suggests that if participants respond in the order of the stimuli presented, as the stimuli are presented closer together, the reaction time for the second stimulus should increase. This phenomenon has been named the psychological refractory period (Welford, 1952).

While these theories provided good explanations for behavior, there were still misunderstandings about the consequences of unattended information. According to Styles (1997), Deutsch and Deutsch then began to theorize about late-selection of attention. While the previous theories focused on identification of information that was presented, new research was focused closer to the response phase of attention. They suggested that a stimulus is weighted for importance and the highest level will turn on other processes, such as memory. At the time of this model's development, it was a revolutionary idea because the brain was likened to a serial limited capacity device; but now, newer models suggest that at least some aspects of attention can be processed in parallel (Styles, 1997).

More recently, Baddeley proposed a model of working memory that includes two "slave" subsystems, the phonological loop and the visuospatial sketchpad, which are controlled by a central executive. According to Baddeley, attentional deficits involve a breakdown of the central executive or one of the subsystems; such a deficit has been labeled a dysexecutive syndrome (Parasuraman & Haxby, 1993). If the breakdown of processing occurred at the central level, information from either of the subsystems may be not be properly processed and therefore show impairments in AD. Consequently, the modality of information to be processed may not be as important.

Another approach to studying attention through an evaluation of its component operations is offered by Posner and Peterson (1990), who propose that the attentional system is fractionated into three components: orienting, selecting, and sustaining. One advantage of the Posner and Peterson approach is an attempt to provide neural correlates of these component processes through an evaluation of normal performance and performance of patients with localized brain disease. According to this view, orienting involves an automatic route of attention to a stimulus through the circuitry of the posterior parietal cortex, superior colliculi, and the pulvinar of the thalamus. Selecting is the conscious choice of stimuli for further processing, which involves the anterior cingulate and other frontal areas. Sustaining is the maintenance of focus over time and is subserved by the right hemisphere through norepinephrine innervation. Their model suggests that there is no single attention center in the brain, but rather a distributed network involving both cortical and subcortical systems that mediate the different attentional operations (Parasuraman & Haxby, 1993).

The widely distributed component operations of the attentional system as described provide evidence of which components might be affected by AD neuropathology. Some operations may be executed normally since they are locally performed in areas typically not affected by neuropathology or not affecting communication between brain regions. The neuropathology of AD is regionally systematic rather than diffuse throughout the brain, mainly affecting the association cortices while sparing the primary motor and sensory cortices. More specifically, AD selectively affects pyramidal cells and has a particular affinity for cell layers most responsible for corticocortical connections while relatively sparing those layers that connect with subcortical structures. Additionally, the posterior parietal lobe is one of the first brain regions to show neuropathology, which is an important for understanding why attentional functioning is impaired early in the AD disease process (Parasuraman & Haxby, 1993).

Driving with Cognitive Impairment

Since there is an increase in the prevalence of cognitive disorders with age and there is expected to be a larger percentage of the population in the age group most likely to develop dementia, it is important to consider the consequences of a greater number of persons afflicted with a progressive disease like AD. Because of the cognitive nature of the driving task outlined above, the consequence of driving should be considered.

Automatic versus Difficult Driving

In healthy adults, many required skills in driving have become automatic, requiring little cognitive effort (Duchek et al., 1997). Automatic processes have several key features: 1) occur automatically when a specific eliciting stimulus is present, 2) occur without intention, and once initiated will continue until not needed, and 3) is not in conscious awareness and does not use attentional resources. While such automatic skills, especially those that were acquired when younger, tend to be well preserved into old age and even into early dementia, the functions that allow driving to be goal-directed and purposeful may be adversely affected with dementia. When driving situations become unpredictable, or conditions become non-optimal (e.g., new neighborhood, thunderstorm, etc.), they require increased effort and controlled processing, placing drivers at heightened risk of driving failure, particularly if they are experiencing dementia-related losses in attention and cognition (Dubinsky, Stein, & Lyons, 2000). The result of inattention or distraction while driving is an impaired capacity to process relevant information (Horberry, Anderson, Regan, Triggs, & Brown, 2005; Recarte & Nunes, 2003). This automatic versus effortful processing model is examined in the current study, under the assumption that early cognitive impairment should selectively spare automatic skills needed to engage in a single-task driving condition. The real question of interest is whether these drivers are able to carry out controlled and effortful processing when challenged by a novel and difficult dual-task condition. One tragic example of how such novelty can cause problems with driving is an incident that happened in Santa Monica, CA. An older driver traveled a route many times without any difficulty until a street market was added on the side of the road of this route, and in trying to make the adjustment, the driver ran over the curb, hit, and killed several pedestrians at the market. Many other such tragedies have been noted, stressing the importance of understanding what factors are related to unsafe driving.

Driving Errors of Older Adults

Crashes and traffic violations of older adults typically reflect error of attention, failure to yield, difficulty maneuvering, and driving too slowly (Carr et al., 1992). The majority of crashes of older adults occur under cognitively demanding situations, such as intersections, suggesting that cognitive deficits may be a causative factor (Duchek et al, 1997). However, errors in driving do not imply incompetence per se, as some driving errors develop with driving experience and are merely the manifestation of bad driving habits. Furthermore, Carr et al. (1992) found that older adults made fewer driving errors than younger adults. Rather than let age be the determining factor, their skills need to be assessed.

Hunt and Weston (1999) suggest that older drivers with dementia often become stimulus bound and take cues from their environment without appropriate judgment. This is especially noteworthy at intersections when yielding at a green light to make a left turn. Those with dementia often become fixated on the car in front of them and will follow that car as it makes the turn without judging the safety of making the turn first across oncoming traffic. Assessment of motor vehicle crash data has shown that there is a two-fold increase in crash rate for those with

AD compared to normal older adults and approximately 30% of drivers with dementiawill have a crash during the course of their disease. About half of drivers with dementia stop driving within 3 years of disease onset probably because of such devastating findings (Carr et al., 2004).

Driving with Dementia

It is important to note though, that a diagnosis of dementia may not be sufficient for driving cessation. Furthermore, if a diagnosis led to automatic license revocation, it would discourage patients from seeking a diagnosis, thus delaying possible treatment options (Molnar, Patel, Marshall, Man-Song-Hing, & Wilson, 2006). Hunt and colleagues (1993) found that 62% of those with mild dementia (as rated on the Clinical Dementia Rating [CDR] scale) passed an on-the-road driving evaluation. Findings suggest that up to 50% of those with a mild AD CDR rating (1.0) will progress to the next rating within one year, thus indicating that it may be important for re-testing of driving competence every six months. However, more recent literature stresses the importance of driving cessation when CDR stage 1.0 is reached (Dubinsky, Stein, & Lyons, 2000). Even more recent work by Hunt (W. Stav, personal communication, June 20, 2007) suggests that poor performance on clinical measures alone might be a sufficient basis for revoking privileges, based on the potential risk they indicate. In other words, while older drivers might perform fine on-the-road, poor clinical test performance signals that they soon may have difficulties driving. The progressive nature of AD almost ensures that individuals with AD will at some point become incapable of driving safely (Parasuraman & Nestor, 1991). However, time to an unsafe state of driving is unpredictable at the individual level and when faced with such unpredictability, it is generally desirable to err on the side of public safety (Molnar et al., 2006).

Paradoxically, substantial research has failed to find strong effects of dementia on driving performance (Withaar, Brouwer, & van Zomeren, 2000; Reger et al., 2004). Multiple studies have found little to no relationship between the presence of dementia and driving ability. Two of the earliest studies on driving and dementia (see Lucas-Blaustein, Filipp, & Dungan, 1988 and Friedland, Koss, & Kumar 1988) found no significant relationship between severity of dementia, as measured by the Mini-Mental Status Exam, and driving or crash history despite many of the drivers with dementia having crashes. Furthermore, MMSE scores could not discriminate who still drove or not (Withaar et al., 2000). This is likely due to the MMSE not having many questions relating to attentional, perceptual, and motoric functions, which are important for driving or due to the fact that the MMSE is a poor indicator of dementia severity. Following the publication of these articles, investigations were undertaken to explore the usefulness of other cognitive measures in predicting driving ability in individuals with cognitive impairment; but no test or set of tests have yet correlated sufficiently or consistently enough to outcome measures of driving (Withaar et al., 2000).

These counter-intuitive findings have demonstrated the weaknesses of the methods for driving assessment used up to this point. First, the use of crash history data relies on statistically improbable events and is therefore not reliable. Also, using retrospective studies to examine the relationship of disease severity with driving is not advantageous; thus, prospective models should be utilized. Second, the use of self-report or crash data is unreliable because crashes are not always reported and self-report from an individual with dementia is likely to be inaccurate due to forgetting or social desirability. Third, current driving exposure of individuals with AD is less than older adults without cognitive impairment, so there may be artifactual group differences in crash probability induced by differences in driving exposure (Withaar et al., 2000).

Typical clinical and on-the-road driving research has included low-challenge, safe, optimal driving conditions, in which drivers can rely on their acquired automatic skills, and therefore dementia-related cognitive losses may have less of an impact on performance in these settings.

Theoretically, this lack of relationship appears to demonstrate the lack of understanding of the cognitive structure and ability requirements of the complex task of driving (Withaar et al., 2000). Additionally, in studying driving in individuals with AD, there is the difficulty that AD has a heterogeneous cognitive profile and has variable rates of cognitive decline (Parasuraman & Nestor, 1991).

Dual-Task Paradigms

One type of attention that is impaired in those with cognitive impairment is divided attention, which has traditionally been studied with dual-task paradigms, where individuals are given two tasks to complete concurrently. The theory of a psychological refractory period, or the delayed response to a second stimulus presented before response to the first stimulus, suggests that attentional interference occurs at the central processing level. It is difficult to perform two simultaneous tasks when both tasks require a central process of evaluation and response generation/selection (Levy, Pashler, & Boer, 2006). This field of study originated with the assumption that there is only one processing channel and thus combining two tasks would only be achieved through rapid switching of the filtering mechanism. If two tasks that are believed to require continuous processing could be performed simultaneously without deficits in speed in accuracy, then the notion of only one channel for information processing would have to be reconsidered (Styles, 1997).

Aging and Dual-Task Performance

Numerous studies, and two formal meta-analyses, have found that aging is associated with increased costs, or performance deficits, in situations calling for dual-task performance (e.g., Holtzer, Burright, & Donovick, 2004; Brouwer, Ickenroth, Ponds, & van Wolffelaar 1990; Ponds, Brouwer, & van Wolffelaar, 1988; Chen, 2000; Verhaeghen, Steitz, Sliwinski, & Cerella 2003). Generally, older adults' performance decrement on dual-task paradigms is additive, rather then multiplicative, suggesting that the age difference is due to latency costs. There are three general findings: 1. Sensorimotor tasks place less demands on attentional resources than cognitive tasks, thus show smaller dual-task costs, 2. Verbal tasks have shorter latencies than visuospatial tasks, so age differences are smaller for verbal tasks, and 3. Dual-task studies utilizing within-modality tasks (i.e., both require visual searching) have higher age-related costs than dual-task studies using between-modality tasks (i.e., one task requires visual search while the other requires listening and verbally responding; Verhaeghen et al., 2003).

Explanations for Aging Effects

There are some possible explanations for why dual-task costs are greater for older than younger adults. First, since age slows down the speed of cognitive processing, dual-task costs could simply be an accumulation of slowing across subtasks. Second, aging could provide for difficulty in coordinating two tasks into one integrated activity. Some data seems to support that latter; the magnitude of the aging effect increases as the level of response integration the two tasks require increase (Brouwer et al, 1990). Ponds and colleagues (1988) suggest that elders are simply less efficient in their control strategy for dealing with two simultaneous tasks.

Dementia Effects on Dual-Task Paradigms

Dual-task paradigms have been found to be grossly impaired in individuals with AD suggesting that the attentional deficit in AD is not a unitary phenomenon because divided attention is disproportionately impaired relative to other types of attention (Duchek & Balota, 2005). Brain regions that subserve attentional functions are susceptible to cortical atrophy or neuropathological markers of AD resulting in impaired function (Ward, 2004).

Previous Findings

Holtzer, Burright, and Donovick (2004) conducted a study examining cognitive impairment effects on dual-task performance in older adults. They recruited 60 participants from residential facilities with varying levels of care. Participants were groups into impairment status categories based on their performance on the Mattis Dementia Rating Scale (DRS; Mattis, 1988), with scores lower than 123 denoting impairment. (The mean DRS score for the 20 participants considered cognitively impaired was 118.) They examined two multi-domain dual-task paradigms, the first consisted of a visual cancellation test and an auditory digit span task; the second paradigm consisted of an alternate form of visual cancellation with a letter fluency task. The results corroborated previous findings that those with cognitive impairment have a significantly larger dual-task cost than normal older adults. This was not attenuated when the performance on the single tasks was controlled. Thus, the ability to simultaneously perform two tasks might be sensitive to subtle changes in cognition.

Some have argued that age-related or disease-related divided attention effect may be artifact of single-task performance differences (McDowd, Vercruyssen, & Birren, 1991). In order to examine this further, Baddeley (1986) equated difficulty of tasks across participants in a study investigating dual-task costs using pursuit tracking and a simultaneous digit span task. AD participants showed a significant impairment in the dual-task condition compared to the single task conditions, despite the control of task difficulty. Interestingly, they also found that the divided attention deficits increased over 18-months of follow-up (Parasuraman & Haxby, 1993).

Dual-Task Performance and Driving

As noted, when two tasks are performed at the same time, they are often performed at a lower level than if they were performed alone. It is believed that this loss of divided attention ability may be a cause of driving error since the driving task requires multiple, simultaneous complex tasks for successful completion. This dual-task cost has been found with driving, especially in younger (18-35 year olds) and older adults (over 65 year olds), such that the secondary task is often better performed at the expense of driving performance. This age discrepancy is believed to exist in the young due to their inexperience and in the older adults due to fewer available cognitive resources (Ward, 2004).

Evidence has shown that the use of a verbal identification task (indicate when you hear the letter “K” in a string of letters) concurrent with simulated driving led to more risky driving behaviors such as tailgating, pulling out in smaller gaps of traffic, and slower responding to stimuli on the road. This change in behavior along with a dual-task decrement, led the author to believe that the tasks were competing for the same attentional resources (Spence & Read, 2003). Findings like this have led some to believe that switching between spatial and auditory attention is a possible reason for dual-task decrements.

Other findings of the effect of distracted driving, or dividing attention while driving, include: increases in visual load results in speed reduction as compensation, reaction time significantly increases during cell phone conversation without respect to type of phone (hands-on or hands-free), and there is a reduction of event detection and center gaze during word production and complex conversation (Engstrom, Johansson, & Ostlund, 2005). Research has been unclear regarding the effect of cognitive load on lane keeping ability (Engstrom et al., 2005), but it is believed that engaging in concurrent verbal tasks while simultaneously being asked to stay in lane leads to more glances away from the road, increased reaction times, and increased subjective cognitive workload. Kubose and colleagues (2006) found that both producing and comprehending language while driving had detrimental effects on maintaining speed.

There are also studies that suggest that divided attention and driving is unrelated. These findings could have resulted from non-optimal secondary tasks that failed to reveal subtle changes in attentional capacity during driving. Also, it could be that divided attention is related only to high-challenge driving situations and studies may not have utilized sufficiently challenging conditions (Parasuraman & Nestor, 1991). Moreover, since divided attention declines with age, it could be that divided attention is more predictive of driving ability in older adults and this population has not been sufficiently studied.

Driving as a Real-World Model of Dual-Task

As described earlier, driving alone is a complex, multitasking environment and a good example of a real-world divided attention task (Parasuraman & Nestor, 1991). Studies have shown that inattention while driving is a major source of driving error, violations, and crashes. In addition, laboratory studies of dual-task performance and distracted driving studies show similar results. Succinctly, whenever two tasks are performed concomitantly, there is a reduction in performance on one or both tasks as compared to when the two tasks are performed alone.

Multi-Sensory Information

One way of thinking of driving as a true dual-task paradigm in itself is to consider the amount of continual sensory information that a driver is bombarded with. Not only are there constant visual cues to aid in navigation, but also there is auditory information to notify the driver of emergency vehicles or difficulties with the mechanics of their own vehicle. In addition, there are also tactile and kinesthetic cues to alert the driver of uneven terrain, icy roads, or mechanical issues. Lastly, there are also olfactory cues from the car driven as well as those around. Thus, there are multiple sensory cues that need processing to determine what, if any, action is needed. These cues alone provide for multiple streams of information that could result in slower reaction times (Stelmach, 1992).

Simulation as Good Model of Real Driving

In addition to on-the-road driving, driving simulation has over time become more life-like. Complex software has been developed to create life-like driving scenes while enabling precise measurements of behavior. Several universities and companies have developed driving simulators that utilize multiple movie-size screens that project up to180 degrees of visual cues. Most simulators have a driving area that closely resembles a real car and some are even placed on platforms that provide vestibular cues to drivers.

Past research has used simulation technology to determine the effect of dementia on driving ability while maintaining safety. The technology also allows for presenting hazardous conditions that cannot be controlled in real-world driving situations. Many early studies showed that individuals with dementia were more likely to be impaired on simulated driving tasks than cognitively healthy older adults (Brown & Ott, 2004). Rizzo and colleagues (1997) found that crashes during simulated driving were related to visuospatial impairment in dementia and have also replicated the finding (Rizzo et al., 2001). Investigating the specifics of driving impairment in dementia, Cox, Quillian, and Thorndike (1998) found that, in simulators, compared to age-matched controls, those with dementia were more likely to drive off the road, to drive slower than the posted speed limit, to apply less brake pedal pressure, and to take increased time to make left turns. Importantly, a strong correlation (0.67) between simulated driving ability and on-the-road driving ability in those with dementia has been found, suggesting that simulators may be a valid way to assess driving ability in a secured environment (Freund, Gravenstein, Ferris, & Shaheen, 2002).

A major advantage of using simulation is the ability to control the environment across participants in a safe situation without the risk of on-the-road testing (Rizzo et al., 2001). One difficulty with this type of research, despite the growing technologies, is simulation sickness. Even persons not prone to motion sickness can sometimes become ill in simulators because of non-natural discrepancies between sensory inputs (e.g., dynamic visual input without static vestibular feedback). This sickness is more often noted in older adults (Withaar et al., 2000).

Additionally, some have criticized simulation as not being an accurate replica of real-world driving. Not surprisingly, research has investigated this and found that driving simulators reliably predict on-the-road driving ability (e.g., Van der Winsum & Brouwer, 1997; Reed & Green, 1999). As noted above, a strong correlation (0.67) between on-the-road performance and simulator performance in those with dementia has been found. Lethal and hazardous errors in the simulator were also related to failing the road assessment (0.82 and 0.83, respectively). Under dual-task conditions in non-dementia samples, similar findings have been found (Reed & Green, 1999). The addition of a secondary task (dialing a phone) reduced performance in both driving simulation and on-the-road situations, with those over the age of 60 showing the greatest deficits. This study though does suggest that lane keeping is less precise in simulation, which could be due to reduced perceived threat of making the error in the simulator. Despite this, there was a correlation between the simulated task and on-the-road driving in lane keeping ability (0.43; Reed & Green, 1999). An additional study (Tornros, 1998) has shown similar results that correlations are high between assessment modalities regardless of small differences in performance between modality (e.g., speed and speed variation is often found to be higher in simulation).

CHAPTER 2
STATEMENT OF THE PROBLEM

Driving is a complex task, involving sensory-perceptual, motor, social-personality and cognitive components. Even with regard to cognition, a number of studies have implicated a variety of different cognitive functions as components of effective driving. It would follow that changes in cognitive functioning, as might be experienced in age-related cognitive decline and impairment, might also affect driving ability. Somewhat surprisingly, much research to date examining the risk of driving with cognitive impairment has found little or no effect of late-life mental changes on driving (Withaar, Brouwer, & van Zomeren, 2000; Reger et al., 2004). One possibility for this pattern of findings may relate to the kinds of driving challenges that have been studied to date. Most research with cognitive impaired individuals has relied either on archival driving records (which, beyond questionable validity, reflects driving in self-selected conditions), or on assessment of drivers in relatively low-challenge and protected driving situations (Withaar et al., 2000). Given the preservation of many self- and home-maintenance skills into early dementia (Duchek et al., 1997), it is not surprising that when driving challenges reflect acquired procedural skills, evidence of impairment may be minimal. This may explain why dementia has not been considered as a significant risk factor for driving violations and crashes.

The current study is premised under the assumption that a key loss with emerging cognitive impairment is the reduction of adaptive capacity to cope with novelty, and to cope with challenges beyond the normal scope of routinized, familiar activity. This study manipulated difficulty and complexity in a simulated driving situation, and investigated whether errors increase, and performance decreases, disproportionately in those with cognitive impairment. The research study was based on this set of premises:

1. Driving is a cognitively demanding task requiring continual coordination of movements in response to several streams of incoming sensory information.

2. In healthy adults, driving becomes relatively "automatic" under predictable conditions (implying the operation of well routinized procedural skills), and may require little cognitive effort. Such procedural skills are likely well preserved, well into the progression of a dementing illness.

3. Across the life span, drivers are at heightened risk of errors in driving when in unfamiliar and/or challenging situations, which require increases in cognitive effort. The adaptive challenges imposed by unfamiliarity and increases in difficulty ought to be particularly felt in individuals who are experiencing cognitive deficits due to cognitive impairment conditions.

4. A number of studies have shown little effect of dementia on driving ability. However, the challenge of the driving situation has seldom been systematically manipulated with cognitively impaired individuals, probably due to the questionable safety of such manipulation in on-the-road assessments. Driving simulators offer the opportunity to manipulate aspects of driving in systematic ways, but without risk of physical harm for drivers and testing personnel.

The study simulated difficult driving, under safe and controlled conditions, to assess whether increases in *difficulty* (as measured by manipulating driving speed on a curved roadway) and *complexity* (as measured by divided attention conditions), increased the risk of driving errors in older adults, and whether this risk of error is disproportionately large in those with memory impairment. There were three main goals of the study.

Equality in Task Difficulty

Aim 1

To verify that under low difficulty conditions, persons with early memory impairment show few deficits on a driving-related task (lane navigation).

Hypothesis 1

Under driving-only conditions, when there is not a secondary task and when individuals are driving at a low simulated speed (30 mph), there will be small-to-null differences between impairment groups in performance of lane navigation (operationalized as 1) the absolute mean lane deviation, 2) the standard deviation of lane deviation (not absolute), and 3) the mean number of times in lane.)

Effect of Task Difficulty

Aim 2

To confirm that there are within-person reductions in performance on the lane navigation task as task difficulty is increased (i.e., as participants move from a lower-speed driving task, 30 mph, to a higher-speed driving task, 60 mph) while still navigating a curved road.

Hypothesis 2

There will be significant within-person differences in performance on the two difficulty levels of the driving-only task. If the increase in difficulty is particularly challenging for persons with memory impairment, there will be a impairment group by difficulty interaction.

Dual-Task Effects

Aim 3

To investigate whether increases in complexity, via divided attention conditions, disproportionately increase lane navigation errors in memory impaired individuals. Complexity will be increased by having participants perform the primary lane navigation task (under both 30 mph and 60 mph conditions) concurrently with paragraph recall. A comparison of single task (driving only) with dual-task (driving while remembering) will permit the investigation of dual-task costs (on the primary task of lane navigation), and whether these costs are greater in memory impaired participants.

Hypothesis 3

All participants will experience reductions in driving-related performance (lane navigation) when asked to perform a simultaneous secondary paragraph recall task. It is expected that memory impaired individuals will perform more poorly on the secondary memory task. The critical question is whether there is a reduction in the primary task (as identified by the investigators) of lane navigation, and whether this reduction is larger for memory impaired individuals. It is hypothesized that lane navigation performance will be particularly reduced in impaired participants, both when assessed in absolute and proportional terms.

Additional Analyses

In addition, the study also permitted the examination of lane navigation errors during the encoding, rehearsal, and recall portions of paragraph recall. It is known that the brain systems used for articulation and audition are separate and impose different demands in processing and some research has suggested that the planning of speech is more distracting than the actual execution of the speech (Kubose, Bock, Dell, Garnsey, Kramer, and Mayhugh, 2006). By examining the dual-task effects during each of these phases of the dual-task condition, we examined if these effects were present in the current study's task.

While the main aim was to examine the dual-task costs in lane navigation ability when simultaneously asked to remember a story at the same time, an additional analysis examined dual-task effects on the secondary paragraph recall task as well. It was expected that participants might trade-off one task for the other. Therefore, if the results of the above analyses did not support the finding of dual-task effects on lane navigation, this analysis of the paragraph recall performance would explore whether individuals perhaps prioritize the maintenance of lane navigation performance at the "cost" or "sacrifice" of the secondary memory task.

Lastly, an exploration of possible cognitive and physical covariates of lane navigation ability was conducted. Significant covariates would permit the preliminary identification of potential variables that are particularly predictive of dual-task effects in driving. For example, indicators of attentional capacity might be particularly important in predicting participants' ability to divide attention (i.e., the less attention you have, the more poorly it can be divided), and therefore attentional variables might be particularly predictive of simulated driving performance under dual-task conditions.

CHAPTER 3
METHODS

Participants

Sixty-one community-dwelling older adults (age range 65-91) were recruited, with efforts to recruit participants of varying cognitive levels, including healthy older adult controls, mildly memory impaired older adults (those who meet criteria for the amnestic variant of Mild Cognitive Impairment; AMCI), and those with early-stage Alzheimer's disease (see Recruitment section below). Forty-six participants were classified as healthy older adult control (referred to as healthy control), while fifteen were classified as memory impaired (all had impairments in the memory domain and received a consensus classification of either AMCI or dementia). Details of the consensus process are provided below. Table 3-1 shows the demographic characteristics of the two groups. The only significant group differences were expected; the memory impaired group performed significantly worse on the TICS-M and MMSE, both indicators of cognitive functioning. However, despite the significant difference between groups on the MMSE, the mean of the memory impaired group indicates that the sub-sample was primarily non-demented based on the accepted cutoff of 24 (Holsinger, Deveau, Boustani, & Williams, 2007). Further descriptions of the cognitive performance of both groups as well as attrition information are shown in the Results chapter. The study was approved by the Institutional Review Board of the University of Florida and informed consent was obtained prior to participation.

Exclusionary criteria included: a) history of epilepsy, head injury with loss of consciousness requiring hospitalization, encephalitis, meningitis, or Parkinson's disease, b) heart attack, within the last year, c) stroke within the last year with residual motor signs (e.g., paralysis or weakness in any extremity, d) current cancer treatment (except skin cancer), e) history of cancer radiation treatment above the chest, f) never had driver's license or stopped driving more than 2 years ago, g) visual or auditory deficits that preclude testing (e.g., have severe self-reported difficulty reading newspaper, have stopped reading due to poor vision, have severe self-reported hearing difficulty when in small groups with background noise, or stopped participating in activities due to hearing loss), h) past drug or alcohol dependence that resulted in medical condition and/or withdrawal symptoms, i) history of schizophrenia, and j) failure to display memory impairment if classified as AMCI or dementia in the consensus conference (see below). These criteria are common for neuropsychological studies to rule out cognitive problems that may be non-degenerative in nature.

Table 3-1. Mean (SD) or N (%) of demographic data.

	Total Sample (N = 61)	Healthy Control (N = 46)	Memory Impaired (N = 15)	*p*-value
Age	76.89 (6.78)	76.07 (6.71)	79.40 (6.59)	0.10
Education	15.97 (2.51)	15.93 (2.40)	16.07 (2.91)	0.86
Sex				0.80
Male	22 (36.00)	17 (37.00)	5 (33.30)	
Female	39 (64.00)	29 (63.00)	10 (66.70)	
Race				0.72
Caucasian	58 (95.08)	44 (95.70)	14 (93.30)	
Other	3 (4.92)	2 (4.30)	1 (6.70)	
TICS	35.47 (6.02)	36.50 (6.27)	32.07 (3.47)	0.02
MMSE	28.26 (1.84)	28.80 (1.28)	26.60 (2.32)	0.00
GDS	4.93 (5.51)	4.43 (5.02)	6.47 (6.76)	0.22

Recruitment

Participants were recruited from various sources. Participant pools of the National Older Driver Research and Training Center (NODRTC) at the University of Florida (UF) and the UF Institute on Aging were used as sources for recruitment. UF Psychology Clinic Faculty who assess older adults informed patients about the study. The Clinical Alzheimer Program at UF released contact information of potential participants and one research team member made herself available during regular clinic hours to recruit face-to-face. A recruitment "town hall" meeting was held at Oak Hammock, a local continuing care retirement community. Additionally, advertisements throughout the community were used (*Gainesville Sun* newspaper ads and a local community newsletter- *The West End Journal*). Lastly, two other graduate student researchers studying a similar population provided contact information for participants who agreed to be contacted in the future for other research studies.

Procedures

Telephone Screening

All participants completed telephone consent and screening to exclude participants who did not meet the inclusion criteria as noted above (see Figure 3-1). Participants who were eligible for the study and who remained interested in participating were scheduled for an in-person neuropsychological assessment.

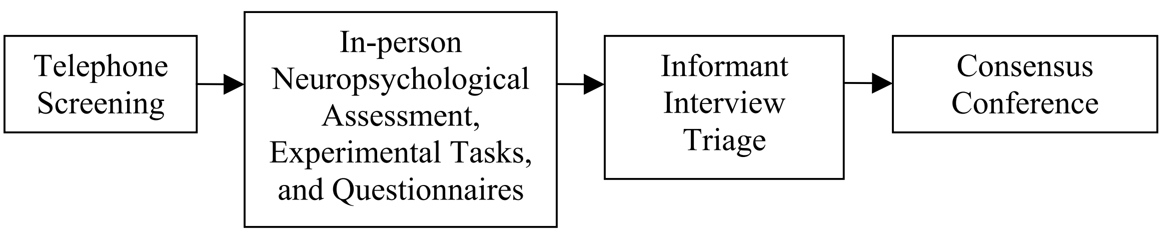

Figure 3-1. Participant Procedures.

Neuropsychological and Experimental Task Administration

After consent was obtained for the session, a neuropsychological assessment to determine cognitive status and assess potential covariates was administered. The battery took approximately 2.5-3 hours to complete, and thus was broken into three parts. (The Measures included in the battery will be described below.) First, the primary neuropsychological battery was administered to participants (about 60 minutes). Next, the experimental tasks, also described below, were administered (about 60 minutes). Finally, the secondary neuropsychological measures were administered (about 60 minutes). Two to three breaks were given during the session to decrease fatigue. If a participant was recruited from another study that had obtained one or more identical measures as the present study within the last month and the participant gave consent to obtain their scores from the other study, the measures were not re-administered. If more than one month lapsed, the measures were re-administered due to the progressive nature of AMCI and dementia so that the most appropriate group classification could be made.

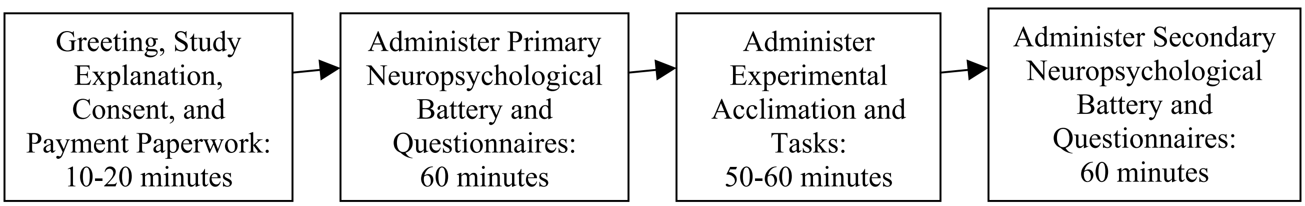

Figure 3-2. Example Timeline of Participation (Approximately 150-200 minutes).

Informant Interview Triage

The decision to collect a Clinical Dementia Rating Scale (CDR) interview was made by the members of the consensus panel when classification could not be made based solely on the neuropsychological data. The interview was completed primarily over the telephone, if indicated after the neuropsychological testing to better distinguish cognitive status (see CDR section below). On a few occasions where participants were referred from the UF Clinical Alzheimer Program and a cognitive impairment diagnosis was made known during the telephone interview, the CDR interview was completed at the time of the participant's assessment if the informant accompanied the participant to the visit; otherwise the data from these participants was collected via telephone. None of the informants were told about the participants' performance on the objective measures at any time during the study.

The Clinical Dementia Rating Scale (CDR; Morris, 1993), a measure of overall cognitive impairment severity, was used to measure (a) the cognitive and daily functioning of the participants, including activities of daily living, and (b) performance in real-world contexts as well as recent noticeable changes in cognition based on proxy informant report and self-report. The CDR scale is a semi- structured interview that was asked of an informant who knew the participant well (usually a spouse or child). The participant also answered questions of memory, orientation, and judgment and were asked to solve certain problems. The CDR contains 6 scales (Memory, Orientation, Judgment/ Problem Solving, Home/ Hobbies, Community Affairs, and Personal Care), which were rated by the interviewer on a scale from 0 (No Dementia) to 3 (Severe Dementia). A published algorithm was then used to produce an overall score from 0 to 3.

Consensus Classification

Following all data collection, a consensus conference panel (consisting of the investigator, one cognitive psychology faculty member, one neuropsychology faculty member, and one neuropsychology graduate student) convened to assign participants to groups according to their cognitive performance and ability to carry out daily functions following criterion stated earlier for AMCI and early-stage AD. A detailed list of tests used in the consensus procedure is presented in the Consensus Measures section below. All test scores were presented to the consensus panel in percentile format and attention was paid to test scores falling at or below the 7^{th} percentile (which coincides with 1.5 SD definition of impairment as outlined by Petersen; Petersen et al., 1999). CDR scores, where available, were also reviewed and considered in making the classification. Consensus members were given time to individually classify participants and then a vote was taken. If all votes were unanimous, that vote stood. If there was a discrepancy in classification for a participant, a discussion ensued about their performance and then a re-vote was taken. At this point, the majority vote stood (which was operationalized as 3 out of 4 members in agreement). After the consensus procedure took place, there was a great discrepancy in sample size between groups, so the alternative analytic strategy of using a dichotomous (healthy control and memory impaired) rather than a trichotomous conceptualization of cognitive impairment was used in the following analyses.

Measures

Measures were administered in several categories. First, participants were administered the telephone screening. The in-person visit included neuropsychological measures used in the consensus procedure, the experimental tasks, and questionnaires. The measures used for each of these parts will be described below.

Telephone Screening Measure

The Modified Telephone Interview for Cognitive Status (TICS-M; Brandt et al., 1988) was included in the telephone screening along with several questions about medical history and demographics to be sure participants met the inclusion criteria. The TICS-M is a brief test of cognitive functioning developed for situations where in-person screening is impractical or inefficient. The TICS-M is similar to the Mini-Mental Status Exam (Folstein, Folstein, & McHugh, 1975), but has a more viable memory assessment, designed for identifying dementia. Research has demonstrated that it is as reliable and valid as face-to-face administration. It has a sensitivity of 94% and specificity of 100% for distinguishing normal controls and individuals with dementia (Brandt et al., 1988) and sensitivity of 82% and specificity of 87% for distinguishing normal controls from amnestic mild cognitively impaired older adults (Cook, Marsiske, & McCoy, 2006).

Consensus Measures

Rationale for neuropsychological consensus measures

These measures were selected to ensure that participants meet the inclusion/exclusion criteria for one of the cognitive status groups: normal aging control, mildly cognitively impaired, or probable dementia. The explicit criteria that were used were outlined previously in the Literature Review. These criteria, along with the Consortium to Establish a Registry for Alzheimer's Disease (CERAD; Morris, Mohs, Rogers, Fillenbaum, & Heyman, 1988), require adequate assessment of memory functioning as well as several other areas of cognitive functioning. Following standard clinical neuropsychology practice, the measures allowed for broad and diverse assessment of all relevant domains within a reasonable timeframe to lessen participant burden. (See Table 3-2 for list of measures used for consensus classification.)

General cognitive screener

The Mini-Mental Status Exam (MMSE; Folstein et al., 1975) has been widely used as a measure of overall cognitive functioning in older adults. The MMSE is a 30-point test that examines orientation, language ability, memory, and attention. The MMSE has high test-retest reliability of between 0.80 and 0.95 within two months. It shows modest to high correlations with other brief screening instruments like the Short Blessed Test (Katzman, Brown, & Fuld, 1983) and the Mattis Dementia Rating Scale (Mattis, 1988).

Verbal memory measure

Two measures of memory were obtained in this study. The Hopkins Verbal Learning Test-Revised (HVLT-R; Brandt & Benedict, 2001) is a list-learning task with semantically related items. A list of 12 nouns was read out loud to the participant three times and each time the

Table 3-2. Measures used for consensus classification.

Cognitive Domain	Test	Variables of Interest	Published Source
General Cognitive Screener	Mini-Mental Status Exam	Total score (using serial 7 subtraction)	Folstein, Folstein, & McHugh, 1975
Memory	Hopkins Verbal Learning Test-Revised (HVLT-R)	Total Immediate, Delay, and Recognition	Brandt & Benedict, 2001
	Wechsler Memory Scale-Third Edition Logical Memory	Total Immediate, Delay, and Recognition	Wechsler, 1997
Language	Boston Naming Test 15-item CERAD version (BNT-15)	Total score	Morris et al., 1989
	Control Oral Word Association (COWAT)	Total (F, A, S)	Benton & Hamsher, 1989
	Category Fluency	Total Animals	Goodglass & Kaplan, 1972
Psychomotor Speed	Trail Making Test A and B (Trails A, Trails B)	Time for A, Time for B, Errors for A, Errors for B	Reitan, 1992
Attention	Wechsler Adult Intelligence Test- Third Edition, Digit Span Subtest	Forward Span and Backward Span	Wechsler, 1997
	Ruff 2 & 7 Selective Attention Test	Automatic Detection Accuracy, Controlled Search Accuracy, Speed-Accuracy Difference	Ruff & Allen, 1996
Construction Ability	Rey-Osterrieth Complex Figure	Copy Total	Rey, 1941
Mood	Geriatric Depression Scale (GDS)	Total score	Yesavage & Brink, 1983
Daily Functioning	Clinical Dementia Rating Scale (CDR)	Total score	Morris, 1993

participant was asked to recall all of the words they could remember. The participant was not cued that they were to remember the list, but after a 25-minute delay they were asked once more to recall all of the words from the list. Then yes-no recognition was examined by asking the participant to indicate whether each of 24 nouns, some of which were semantically related to the target items, were on the list. The HVLT-R has established test- retest reliability ranging from 0.39 to 0.74 for each derived variable in a sample over 65 years old. The HVLT-R has 94% sensitivity and 100% specificity for distinguishing AD and normal elders (Petersen et al., 2001).

The second task assessing verbal memory was the Logical Memory subtest from the Wechsler Memory Scale, Third Edition (WMS-III; Wechsler, 1997). In this task, the participant was read a short story and was asked to recall it immediately after hearing the story. Then, a second story of equivalent length was read to the participant for recall as well. After this, the second story was repeated for a second recall to measure learning ability with prose material. Each recall has a maximum score of 25. Participants were then told to remember the stories for later recall. After approximately 25 minutes of other testing that did not involve language heavily, the participant was asked to recall each story. Lastly, a recognition test was asked (15 yes/no items per story).

Language measures

Confrontation Naming. The Boston Naming Test (Kaplan, Goodglass, & Weintraub, 2001) is a confrontation-naming task that assesses the ability to generate the name of pictured objects. The Consortium to Establish a Registry for Alzheimer's Disease (CERAD) developed a short version of the BNT (15-items) for use in clinical settings. This shortened version has shown to discriminate between normal and older adults with dementia (Mack, Freed, Williams, & Henderson, 1992) and was used in this study to reduce participant burden. Just as in the original version, semantic cues were provided if participants' answer was clearly a misperception (e.g., If a participant said "toaster" for bench, then the participant will be told "it is something to sit on."). Phonemic cues were provided if the participant replied with an incorrect answer, but not misperceived (e.g., If the participant said chair for bench, then the participant was told "it sounds like 'b-e.").

Fluency. To assess the spontaneous production of words, the Control Oral Word Association Test (COWAT; Benton & Hamsher, 1989) was administered. The participants were given a letter and were asked to generate words beginning with that letter within a limited time frame (one minute). Words were generated across three letters (F, A, and S). Snow and colleagues (1988) report test retest reliability of 0.70 in older adults and inter-rater reliability near perfect. Category fluency (Goodglass & Kaplan, 1972) or verbal association fluency, was measured using the category of animals with a one-minute time limit.

Processing speed measure

Trail Making Test A and B (Trails A, Trails B; Reitan, 1992) is a task requiring concentration, psychomotor speed, visual scanning and sequencing, and cognitive flexibility. In Trails, the participants drew a line as fast as they could to connect the circles in the prescribed order. Snow and colleagues (1988) report test retest reliability of 0.64 for Trails A and 0.72 for Trails B in older adults.

Attention measures

Verbal Attention. To assess verbal attention, the Digit Span subtest from the Wechsler Adult Intelligence Scale-III (Wechsler, 1997) was used. This test contains two parts. First, participants were read a string of digits and were asked to repeat them back to the examiner. In the second part, participants were read a string of digits, and were asked to repeat the string back to the examiner in the reverse order. For example, if the string were "9-1-7-3", the correct response would be "3-7-1-9." The length of the strings for both parts of the test began at two digits and progressed to a maximum length of eight digits. The participants were given two strings at each length. As long as the participant reported at least one of the two strings correctly, they progressed on to the next greater length. When the participant responded incorrectly to both strings of a given length, the test was stopped.

Selective Attention. The last measure of attentional abilities was the Ruff 2 & 7 Selective Attention Test (Ruff & Allen, 1996). This test was developed to measure both sustained and selective attention. The test consists of twenty, 15 second trails of visual search and cancellation where the participant was asked to strike through each of the targets "2" and "7." Half of the trials required automatic detection because the numbers were embedded with letters of the alphabet and were easily noticed, whereas the other half of trials required controlled detection because the targets were embedded with other numbers. Correct hits and omissions were calculated to determine speed-accuracy tradeoff as well as differences between automatic and controlled processes.

Constructional ability measure

To assess constructional ability, the Rey-Osterrieth Complex Figure Copy Task (Rey, 1941) was administered. The participant was shown on a card a complex figure and was asked to copy to the figure onto their paper. The task was scored by taking into account the accuracy of the drawing as well as its location within the figure. Recall of this measure was not assessed.

Mood assessment

The Geriatric Depression Scale (GDS; Yesavage, 1983) was administered to the participants because of the established relationship that cognition can be affected by depression (see Lockwood, Alexopoulos, & van Gorp, 2002). The GDS is a 30-item self-report scale of yes/no questions about symptoms of depression (e.g., Do you feel that your life is empty?). This measure has been shown to be a reliable and valid measure of depressive mood in older adults. This measure was included to assess any contribution that depression may have on memory and attentional performance and to rule out depression as a potential cause for cognitive impairments.

Potential Correlates

While the above measures were part of the neuropsychological battery to classify participants on the basis of cognitive impairment level, other potential correlates of the driving task were also administered to aid in understanding our findings. Below are the descriptions of these measures.

Visual processing speed measure

Visual processing speed declines with age, such that 30-50% of those over 65 years old are impaired. The Useful Field of View (UFOV; Ball & Owsley, 1993) has widely been used in driving studies to measure multiple aspects of visual attention. UFOV performance has been shown to be related to traffic crashes in older adults. This task taps three areas of attention: sustained, selective, and divided attention. The task was computer-administered and had three subtests that took a total of approximately 15 minutes. Each part of the task was adaptive to the performance of the participant, such that the score derived is the fastest rate at which 75% of stimuli were correctly identified. In the first task, the participant was to identify a target (car or truck) presented in a central fixation point. The second subtest measures divided attention and involves not only identifying the central target as previously, but also required the participant to identify the location of a simultaneous peripheral target (car). The third was the same as the second subtest, however there was an addition of triangles throughout the visual display to assess selective attention ability. Test-retest reliability of the UFOV has been found to be high (Edwards et al., 2005). A fourth experimental subtest was administered. In this subtest, the participant was shown two stimuli in the central fixation point as well as a simultaneous peripheral target. The participant had to answer if the central targets were the same or different objects as well as identify where the peripheral target was located.

Working memory measure

An auditory n-back task was computer-administered using Direct RT software to assess for working memory ability. Participants heard a single letter presented from a sound file and had to decide if that letter matched a given target letter (e.g., “N”) as fast and as accurate as possible. In the 1-back condition, participants judged whether the current letter matched the immediately preceding letter (e.g., “G” followed by “G” was a yes). When the target letter matched, the participant clicked the right mouse key. When the target did not match, they were instructed to click the left mouse key. In the 2-back condition, participants judged whether the current letter matched the letter presented 2 letters previously (e.g., “G, T, G” was a yes while “G, T, X” was a no). Similarly, in the 3-back condition, participants judged whether the current letter matched the letter presented 3 letters previously. There was a one-second inter-stimulus interval and both accuracy and response time information was collected.

Driving Habits Questionnaire

A Driving Habits Questionnaire (Owsley, Stalvey, Wells, & Sloane, 1999) was administered to assess the participants’ amount of driving experience (e.g., approximately how many miles have you traveled in the last week when you were driving?), their use of compensatory strategies (e.g., rate the extent to which you avoid driving at night, avoid driving on a highway), and a rating of how difficult or stressful certain traffic situations are to them (e.g., having to make a left turn at a red light, having to merge into traffic on a highway). Thus, scores for driving exposure, perceived driving difficulty, and driving avoidance was obtained.

Everyday Attention Screener

To determine how much attention difficulty plays a role in participants’ everyday life, the Adult Self-report Scale Screener (ASRSS; World Health Organization, 2003) was administered. The screener is a six-item measure where participants rated how much certain behaviors are affected by their level of attention on a 5-point Likert scale from Never (scored 0) to Very Often (scored 4). Two example items include: how often do you have difficulty getting things in order; when you have a task that requires a lot of thought how often do you avoid or delay starting. A score of 11 or more indicates possible adult attention deficit disorder (AADD; World Health Organization, 2003). This screener has been shown to be more effective at discriminating between normal adults and those with AADD than the full 18-item version (Adult ADHD Self-report Scale (Kessler et al., 2005).

Measure of Visual Acuity and Audition

Participants' corrected visual acuity was measured to ensure that participants could see the stimuli appropriately. This was measured using a GoodLite Sloan Letter Chart. Participants stood 10 feet from the chart and read across letters in several progressively more difficult rows until they missed more than one-third of any row. Their score was converted into an acuity score. Because all participants had vision equivalents of 20/40 or better, which is the state limit in many states including Florida, the distance vision score was not used as a potential covariate in the analyses. For parsimony, reading acuity was not measured since distance has more relevance to driving. Audition was not objectively measured, however the telephone screening questionnaire elicited, by self-report, how difficult it is for participants to hear in crowds and in normal conversation.

Medication Usage

Each participant's current medication regimen was recorded, with particular interest in whether or not participants were using potential cognitive enhancing medications such as tacrine (Cognex), donepezil (Aricept), rivastigmine (Exelon), galantamine (Reminyl or Razadyne), and memantine (Namenda). Participants were instructed to bring their medication bottles with them so that all medications and dosage information could be collected in person to reduce error. Over-the-counter medications (e.g., vitamins and herbal supplements) were also recorded.

Experimental Design and Procedures

Conditions

After completing the neuropsychological battery, participants completed an *acclimation task* (5 minutes) to become familiar with the driving equipment. Then, the following five experimental conditions were presented: 1) paragraph recall, 2) lane navigation- slow level, 3) lane navigation- fast level, 4) lane navigation- slow level with simultaneous paragraph recall, and 5) lane navigation- fast level with simultaneous paragraph recall. (See Table 3.3.)

The experimental driving tasks were broken into two segments, each containing 3 subconditions based on difficulty (speed of lane navigation). The segments were each 13.5 continuous minutes long, but separated by at least a 4.5-minute break (see Figure 3-3 below). It was decided to break each condition into three subconditions so that the participants did not become fatigued within conditions. Each subcondition consisted of both levels of complexity (single and dual-task). Each participant was randomized to one of three condition orders using a random number table (see Table 3-4 below). Each segment represented a block of stories and the third segment was the paragraph recall single-task condition, which was presented during the neuropsychological testing so not to have too many stories to provide interference. This ordering of conditions was chosen to aid in randomization as well as to minimize fatigue.

Table 3-3. Study Design.

Within Person Difficulty	Slow Speed (30 mph)		Fast Speed (60 mph)	
Within Person Complexity	Single Task	Dual-task	Single Task	Dual-task
Between Person	Cognitive Impairment Level: Normal or Impaired			

Table 3-4. Story sets to be used per segment based on randomization.

	Paragraph Recall	Segment 1	Segment 2
Condition Order 1	Story set 1	Story set 2	Story set 3
Condition Order 2	Story set 2	Story set 3	Story set 1
Condition Order 3	Story set 3	Story set 1	Story set 2

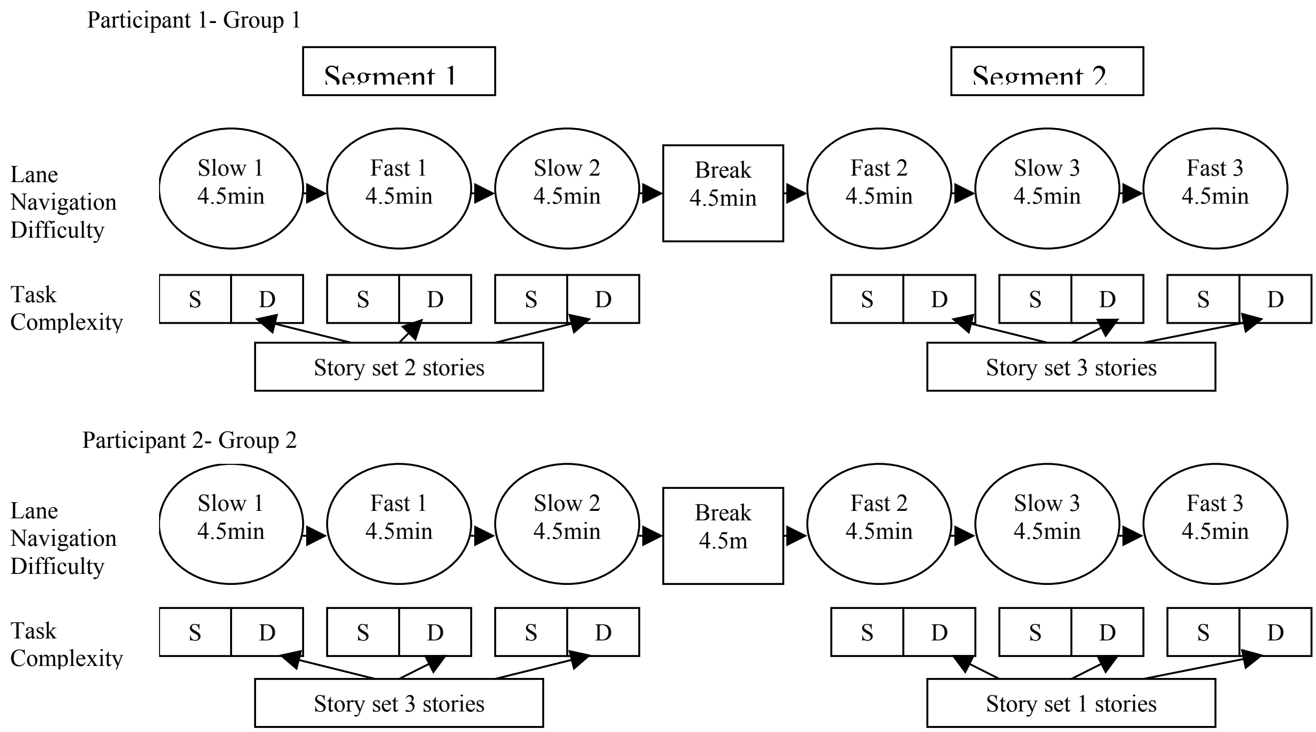

Figure 3-3. Examples of Condition Ordering. S = Single task driving condition, D = Dual-task driving condition; not shown is the paragraph recall single-task condition which will be completed during neuropsychological testing.

Driving simulation software and hardware

Lane navigation was measured using scenarios created using STISIM Drive software. While many driving simulation researchers use a 180-degree visual presentation, the scenarios in this study were presented by desktop computer rather than by a traditional driving simulator due to the high incidence of simulator sickness in the older adult population. Scenarios were presented using a Dell Optiplex GX270 CPU, 19-inch flat screen monitor, and Logitech MOMO Force Feedback Steering Wheel (see Figure 3-4). Participants were seated at a desk with the steering wheel attached to the desk in front of them. The monitor was situated 18 inches from the front of participants' heads. To become acclimated to driving with this equipment, the participants completed two, 2.5-minute scenarios, which were designed to simulate a racetrack with four 90-degree turns. One acclimation scenario had exclusively right turns for 5 laps while the other had exclusively left turns for 5 laps.

Figure 3-4. Driving Simulation Desktop Setup.

Lane navigation condition

Rationale. The task chosen to measure an aspect of driving ability was lane navigation. This was chosen as a sustained attention task because prior research has shown that lane drift has increasing variability over time (Parasuraman & Nestor, 1991), that there is a significant relationship with the complexity of visual demands and reduced lane keeping (Engstrom et al., 2005), and that impaired lane navigation is significantly related to failing on-the-road driving tests (Hunt et al., 1993). Furthermore, cognitively loading tasks, such as word production or holding a complex conversation while driving has been shown to reduce gaze towards the road and to therefore affect lane navigation ability (Engstrom et al., 2005).

Task. There were two lane navigation conditions comprising two different levels of difficulty. The slow level was presented at 30 miles per hour (mph) and the fast level at 60 mph; each condition was 13.5 minutes in duration. Participants did not control the speed themselves; rather the software was configured to present the stimuli at the designated speeds. Thus, while this design permitted experimental control, the inability to slow down for turns was artificial and detracts from the ecological validity of the measure. While the study was designed to control speed across participants, the participants were only engaged in part of the driving task (i.e., steering). Thus, the overall level of driving difficulty was reduced. The slow condition was comprised of 4.5 miles of driving. The fast condition was comprised of 9 miles of driving. The amount of visual complexity (i.e., scenery; number of turns to be executed) between the two conditions was controlled such that the only difference between the conditions was the speed of presentation and therefore the length of roadway driven. (See Figure 3-5 for a screenshot.) Since the fast level simulated a driving scenario that was twice the distance of the slow level, the amount of visual complexity in the fast level was also doubled (to appear the same as the slow level). The dependent variables of interest were: 1) the absolute mean lane deviation, 2) the standard deviation of lane deviation (not absolute), and 3) the mean number of times in lane.

Figure 3-5. Screenshot of STISIM Drive software.

Paragraph recall task

Rationale. Memory for stories was assessed using a paragraph recall task. A memory task was chosen as the cognitive task for a few reasons. First, those with AMCI and AD were likely to have deficits in this area as previously described. Thus, it was believed that a concurrent memory task would be particularly demanding of attentional and processing capability due to decreased resources secondary to their brain dysfunction. Memory is also an integral piece in driving (Parasuraman & Nestor, 1991), and therefore should be studied concurrently with simpler driving skills since this simultaneous processing is part of the regular task of driving. Also, there is a growing literature on distracted driving suggesting that holding conversations while driving increases driving error (Engstrom et al., 2005). While this memory task was not identical to holding a conversation, it is believed that there are similar qualities. Both have a listening component, a processing and understanding component, and oftentimes both require verbal production based on the previous information.

Story composition. A total of 9 stories were used across the three segments (paragraph recall single task segment and the 2 driving segments). While having this many stories increases significantly the amount of testing time for participants, because a study like this has not been conducted previously, reliability of the measure was of utmost importance. Four of the stories used were from the Paragraph recall task of the Rivermead Behavioral Memory Test (Wilson, Cockburn, & Baddeley, 1985). The other five stories were created for a memory training study (Ball et al., 2002) and were developed using an algorithm that makes them correspond directly with the Rivermead paragraphs in terms of complexity, sentence structure, and number of propositions. Each story was written in a news-like fashion and contains 21 propositions; each was scored based on the number of propositions correctly or partially recalled.

All stories, which took approximately 28 seconds to read, were presented through computer audio as sound wave files spoken by a male voice. After presentation, the participant was given 35 seconds to rehearse the story to themselves and then had one minute to recall the story as completely as possible. The experimenter digitally recorded and then transcribed the participants' recall of the stories.

For the paragraph recall only condition, the participants were read a total of three stories, with order based on their group. This testing was done during the neuropsychological testing so not to overload participants to cause interference. In each of the dual-task conditions, which will be described below, two segments of three stories each were presented for recall. While the order of the conditions was based on grouping across participants, all participants will hear the identical stories by the end of the third segment.

Scoring. A total score was derived for each of the story sets of paragraph recall administered. The scoring was based on the accuracy and completeness of recall, with each of the 21 propositions receiving a score of 0, 0.5, or 1 point based on how detailed the response (Wilson, Cockburn & Baddeley, 1985). Since this scoring method involves minimal subjectivity, the raters completed reliability training before scoring participants data. The training consisted of 20 stories and reliability had to reach at least 85% to score participant data. Beyond the training reliability, throughout data collection, approximately half of the participants were chosen for a reliability check across raters. Correlations between story scores in the single-task (paragraph recall only) condition were significantly correlated with one another ($p < 0.01$, r ranging from 0.62 to 0.69).

Dual-task conditions

Two dual-task, or divided attention, conditions were utilized to measure within-person complexity. Each level of difficulty of the lane navigation task, slow (30 mph) and fast (60 mph), was administered with the paragraph recall task such that the participant attempted to navigate the lane appropriately while simultaneously listening, rehearsing, and recalling heard paragraphs. Again, the main dependent variables of interest were: 1) the absolute mean lane deviation, 2) the standard deviation of lane deviation (not absolute), and 3) the mean number of times in lane.

CHAPTER 4
RESULTS

Overview

This study examined the simulated lane navigation performance of a group of adults aged 65 and older who ranged from cognitively normal (healthy control) to memory impaired. The effect on lane navigation (i.e., the ability to stay in lane on a computer screen, using a steering wheel controller) under two levels of difficulty (fixed speed of 30 mph and fixed speed of 60 mph) was examined. The study also determined how a secondary task condition (a paragraph recall task) would affect lane navigation, and whether this effect would be similar for healthy control and memory impaired participants. This study examined three main experimental hypotheses. First, the study sought to verify that there would be small to null differences between the healthy control and memory impaired older adults in low difficulty driving lane navigation ability (single task at 30mph). Second, the within-person effect of task difficulty was examined, assuming that as speed increased performance would decrease. Lastly, the study determined if increases in task complexity, via divided attention conditions, disproportionately decreased lane navigation performance in memory impaired individuals. A comparison of single task (driving only) and dual-task (driving while remembering) allowed the investigation of dual-task costs (on the primary task of lane navigation), and whether these costs were greater in the memory impaired. In addition, the study permitted the examination of several secondary questions, including: 1) whether the effect of adding a secondary task (paragraph recall) diminished lane navigation less over time (i.e., with practice), 2) whether the phases of learning and recall differentially affected driving (i.e., lane navigation ability was affected differently during the encoding, rehearsal, and recall portions of paragraph recall), and 3) whether particular neuropsychological, cognitive, and non-cognitive correlates might be particularly related to lane navigation ability under single- and dual-task conditions.

Preliminary Analyses

The memory impaired group consisted of older adults with one of three different classifications. Nine participants were classified with amnestic MCI (memory-only impairment) and three were classified with multi-domain MCI (memory impaired plus one more domain but not at the level to meet criteria for dementia). Three participants were felt to meet the criteria for dementia. Because the sample size for each classification was small, these groups were combined into one memory impaired group. The paragraphs that follow briefly provide additional validation information regarding cognitive status.

First, in the consensus conference, the neuropsychological information was supplemented with data from the CDR. In this study, of the ten participants for whom a CDR was obtained to clarify their neuropsychological battery scores, only one participant received a score of 0 and the other nine had a score of 0.5. Six participants for whom a CDR was recommended in the consensus panel were missing informant CDR data due to lost follow-up or refusal to give investigators informant contact information. Further analysis revealed that one participant with CDR = 0 were classified as healthy control while eight participants with CDR = 0.5 were classified as memory impaired. No participants subsequently classified as memory impaired had a CDR = 0 and only one participant classified as healthy control had a CDR = 0.5. Thus, there was substantial dependency between CDR status and impairment status ($\chi^2(1) = 4.44$, $p = 0.04$).

Second, as noted in the Measures section, information on participant medications was also collected because of a particular interest in whether memory impaired individuals were taking medications for cognitive enhancement. Six participants were taking one of these medications at the time of testing. Five of the six participants taking such a medication were classified in the memory impaired group. Thus, chi-square analysis showed significant dependency between cognitive enhancing medication usage and impairment status ($\chi^2(1) = 12.38$, $p < 0.001$). Thus, only one participant classified as healthy control was taking a cognitive enhancing medication, and ten individuals whom we classified as memory impaired did not report taking such a medication at the time of testing.

Before conducting analyses for the aims of this study, some preliminary analyses were conducted to examine the differences in performance between the healthy control and memory impaired older adults on the neuropsychological battery and other cognitive tests. The neuropsychological measures were heavily used in making group assignment decisions during the consensus conference, and therefore the table that follows demonstrates how performance differed between groups; it provides a window into the classification rules used by the consensus team. Table 4-1 shows the mean performance on all of the tests by cognitive status groups. As expected, the memory impaired group performed significantly worse, and often within the clinically impaired range, than the healthy control group on most of the neuropsychological measures. The table also illustrates that effect sizes for between group differences varied from small to large (i.e., Cohen's D convention is 0.2 for small effect, 0.5 for medium effect, and 0.8 for large effect; Effect size r convention is 0.1 for small effect, 0.3 for medium effect, and 0.5 for large effect).

Participant Sickness

While no participants withdrew consent or were withdrawn by investigators, some participants were unable to complete the driving task due to simulator sickness (Kennedy, Lane, Berbaum, & Lilienthal, 1993). Four participants were not able to tolerate the driving acclimation tasks and therefore are excluded from further analyses. Of the four, one was classified as

Table 4-1. Means, variance, and group differences for performance on neuropsychological measures by cognitive status.

Measure	Mean		SD		Levene's Test		Independent Sample			
	Control	Impaired	Control	Impaired	F	*p*-value	*t*	*p*-value	Cohen's D	Effect size r
TICS-M Score	36.50	32.07	6.27	3.47	0.49	NS	2.52	0.02	0.77	0.36
MMSE Score	28.80	26.60	1.28	2.32	10.81	< 0.01	3.51	< 0.01	1.38	0.57
HVLT-R Total Score	27.20	17.80	4.42	4.93	0.14	NS	6.95	< 0.01	2.07	0.72
HVLT-R Delay	9.83	3.00	1.77	2.24	1.13	NS	12.15	< 0.01	3.61	0.87
WMS LM I	45.76	28.60	8.34	7.95	0.07	NS	7.00	< 0.01	2.08	0.72
WMS LM II	28.67	13.47	6.33	8.30	2.02	NS	7.47	< 0.01	2.22	0.74
COWA Total	16.39	13.00	4.39	3.98	0.47	NS	2.21	0.03	0.28	0.14
Category Fluency	20.76	16.13	5.74	5.10	0.01	NS	2.78	< 0.01	0.83	0.38
BNT Total Score	14.67	13.80	0.56	1.15	12.7	< 0.01	2.84	0.01	1.18	0.51
Rey-O Score	29.53	25.03	4.89	5.21	0.71	NS	3.05	< 0.01	0.91	0.41
Trails A Time	33.57	45.07	11.93	10.97	0.18	NS	-3.31	< 0.01	0.98	0.44
Trails B Time	85.95	128.45	43.45	62.69	2.37	NS	-2.93	< 0.01	0.87	0.40
WAIS Digit Span	18.74	16.33	4.66	3.81	1.01	NS	1.81	NS	0.54	0.26
UFOV Proc. Speed	23.74	28.36	21.70	28.45	0.34	NS	-0.64	NS	0.20	0.10
UFOV Divided Attn	85.53	191.07	89.90	165.35	10.11	< 0.01	-2.28	0.04	0.94	0.42
UFOV Selective Attn	261.47	352.71	114.37	136.92	1.46	NS	-2.47	0.02	0.76	0.36
UFOV Exp. Subtest	384.42	454.57	90.96	65.98	1.75	NS	-2.66	0.01	0.82	0.38
1-Back Accuracy	0.95	0.97	0.13	0.03	1.12	NS	-0.54	NS	0.14	0.07
2-Back Accuracy	0.91	0.90	0.08	0.10	1.26	NS	0.53	NS	0.14	0.07
3-Back Accuracy	0.79	0.79	0.07	0.06	1.13	NS	-0.14	NS	0.04	0.02
Ruff Auto Speed	137.65	116.93	30.69	30.78	0.13	NS	2.27	0.03	0.67	0.32
Ruff Auto Accuracy	95.11	91.35	5.90	5.18	0.55	NS	2.20	0.03	0.66	0.31
Ruff Cont Speed	123.07	110.80	29.99	28.56	0.03	NS	1.39	NS	0.41	0.20
Ruff Cont Accuracy	92.29	88.62	6.74	6.05	0.46	NS	1.88	NS	0.56	0.27
Ruff Total Speed	104.35	90.27	21.56	24.42	0.31	NS	2.13	0.04	0.63	0.30
Ruff Total Accuracy	94.26	73.87	16.64	27.98	7.61	< 0.01	2.67	0.02	1.02	0.46
GDS	4.43	6.47	5.02	6.76	1.60	NS	-1.25	NS	0.37	0.18
Everyday Attention	7.13	8.07	3.88	5.21	1.09	NS	-0.73	NS	0.22	0.11

Note: TICS-M = Modified Telephone Interview for Cognitive Status; MMSE = Mini-Mental Status Exam; HVLT-R = Revised Hopkins Verbal Learning Test; WMS LM= Wechsler Memory Scale Logical Memory Subscale; COWA = Controlled Oral Word Association Test; WAIS = Wechsler Adult Intelligence Test; UFOV = Useful Field of View; GDS = Geriatric Depression Scale; Normal group N= 46; Impaired group N= 15; NS= Not significant at 0.05 level; Levene's test examined the homogeneity of variance between the Normal and Impaired groups; significant tests suggest unequal variance between groups. Independent samples t-tests compared group differences in mean on each variable. Where Levene's test was significant, a t-test with adjusted degrees of freedom was used; Cohen's D and Effect Size r were adjusted for different sample sizes and the absolute value is presented.

memory impaired. All other participants' data were used in the following analyses, regardless of the number of trials completed due to the reliability of the substantially large number of datapoints collected (10 per second). In other words, for participants with partial data, their scores in each of the experimental conditions were computed only for the trials in which they were presented. Two participants stopped the driving task after the second trial; seventeen were not presented with the second segment (Trials 4-6) due to fatigue, complaints about how the driving made them feel, or severe level of frustration with the task. Chi-square analysis revealed that there was not a significant dependency ($p = 0.23$) between completing the driving task and being in the memory impaired group. See Table 4-2 for information regarding number of participants with complete or partial data. Table 4-3 displays that there are not many differences between those who completed the driving task with those who dropped out.

Table 4-2. Number of participants with complete or partial data by impairment status.

	Normal	Impaired
Complete Data	35	9
Partial Data	8	5
No Data	3	1

Analyses for Main Hypotheses

Three separate repeated measures analyses of variance (RM-ANOVA) were conducted to examine the effect of task difficulty and complexity and the potential added effect of impairment level on three separate dependent variables of interest. The first dependent variable was absolute mean lane deviation (i.e., the participant's average deviation from the center of the lane throughout each single or dual-task condition, as sampled at 10Hz (i.e., 10 times per second), regardless of whether that deviation was to the left or the right); this was a measure of, on mean lane deviation (i.e., the participant's average deviation from the center of the lane throughout each single or dual-task condition, as sampled at 10Hz (i.e., 10 times per second),

Table 4-3. Demographic and mean time spent in lane for those completed and those who attrited.

	Total Sample (N = 61)	Completers (N = 44)	Drop Outs (N = 17)	*p*-value
Age	76.89 (6.78)	77.09 (6.82)	76.35 (6.84)	0.71
Education	15.97 (2.51)	15.77 (2.52)	16.47 (2.48)	0.33
Sex				0.21
Male	22	18 (82.00)	4 (18.00)	
Female	39	26 (66.67)	13 (33.33)	
Race				0.83
Caucasian	58	42 (72.40)	16 (27.60)	
Other	3	2 (6.67)	1 (3.33)	
TICS	35.47 (6.02)	36.32 (4.02)	33.13 (9.39)	0.21
MMSE	28.26 (1.84)	28.48 (1.86)	27.71 (1.72)	0.14
In Lane Slow/Single	0.95 (0.12)	0.97 (0.04)	0.87 (0.22)	0.12
In Lane Slow/Dual	0.95 (0.13)	0.98 (0.05)	0.85 (0.22)	0.07
In Lane Fast/Single	0.76 (0.15)	0.79 (0.10)	0.65 (0.23)	0.04
In Lane Fast/Dual	0.80 (0.14)	0.81 (0.11)	0.75 (0.21)	0.36

regardless of whether that deviation was to the left or the right); this was a measure of, on average, how capable the participant was of remaining centered in the lane. The second dependent variable was the within-person standard deviation of lane deviation. This provided a measure, independent of the magnitude of lane deviation, about how consistently the participant stayed in the center of the lane. Higher levels of variability on this measure indicated more "weaving." The final dependent variable was a recoded version of the absolute lane deviation, reflecting the proportion of time the participant stayed within lane during each single- and dual-task condition. This variable addressed "functional" driving; that is, since departures from a lane signal a heightened risk of collision/crash, this analysis addressed whether our experimental variables put participants at differential crash risk. Driving data was trimmed for outliers by excluding datapoints +/- 3 standard deviations from each individual participant's own mean performance to account for any gross errors in driving.

Absolute Mean Lane Deviation

The first analysis was a 2 X 2 X 2 RM-ANOVA design using two levels of within-person task difficulty (Slow and Fast) crossed with two levels of task complexity (Single and Dual) and two levels of the between-person factor of impairment group (healthy control vs. memory impaired) to examine their effect on absolute mean lane deviation. Means of task difficulty (speed) show that there is more lane deviation at the faster speed ($M \pm SE = 4.20 \pm 0.23$) than at the slower speed ($M \pm SE = 2.24 \pm 0.20$). This observation was supported by a main effect of task difficulty, $F(1,54) = 101.69$, $p < 0.01$, $\eta^2 = 0.65$. Means of task complexity show that there was more lane deviation in the single task ($M \pm SE = 3.34 \pm 0.18$) than in the dual-task ($M \pm SE = 3.09 \pm 0.22$). This was supported by a main effect of task complexity, $F(1,54) = 5.78$, $p = 0.02$, $\eta^2 = 0.10$. Means of impairment group revealed that the memory impaired had more lane deviation ($M \pm SE = 3.59 \pm 0.33$) than did the healthy controls ($M \pm SE = 2.85 \pm 0.19$). There was a trend for the main effect of impairment, $F(1,54) = 3.76$, $p = 0.06$, $\eta^2 = 0.07$.

There was no two-way significant interaction between task difficulty and impairment group, $F(1,54) = 0.38$, $p = 0.54$, $\eta^2 = 0.01$, but there was a trend towards a two-way interaction between task complexity and impairment group, $F(1,54) = 2.98$, $p = 0.09$, $\eta^2 = 0.05$. No significant interaction was found between task difficulty and task complexity, $F(1,54) = 0.96$, $p = 0.33$, $\eta^2 = 0.02$. The three-way interaction between task difficulty, task complexity, and impairment group was also non-significant, $F(1,54) = 1.58$, $p = 0.22$, $\eta^2 = 0.03$. Table 4-4 displays the means for this three-way interaction. Figure 4-1 graphically shows these findings

Table 4-4. Means $\pm$ standard errors of three-way interaction for absolute mean lane deviation.

	Task Difficulty- Slow		Task Difficulty- Fast	
Impairment Group	Single Task	Dual-task	Single Task	Dual-task
Healthy Control	1.86 ± 0.21	1.75 ± 0.21	3.90 ± 0.22	3.87 ± 0.28
Memory Impaired	2.73 ± 0.37	2.61 ± 0.37	4.89 ± 0.39	4.13 ± 0.48

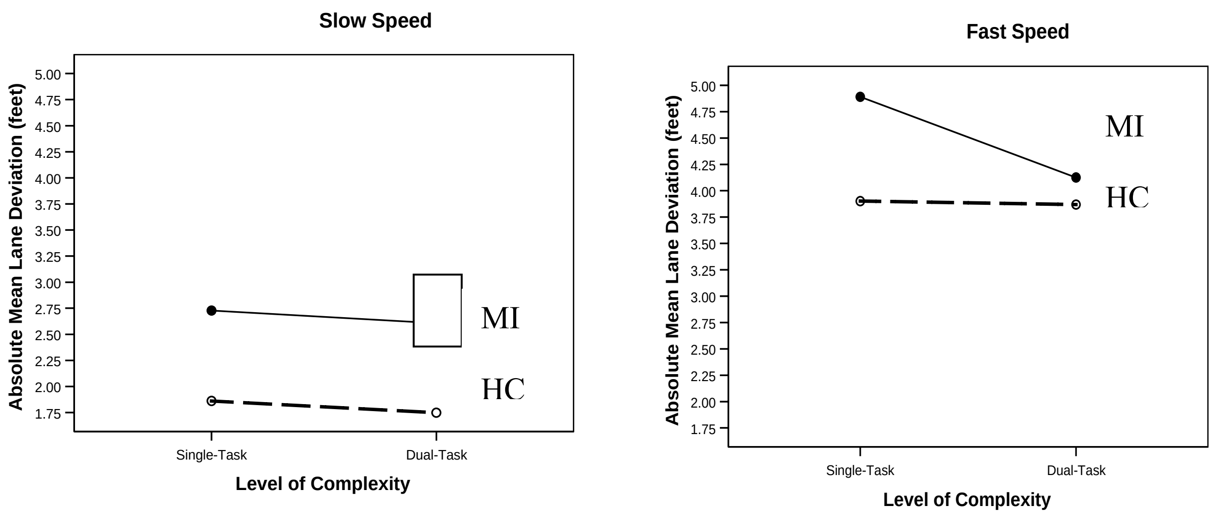

Figure 4-1. Line graphs of level of difficulty and level of complexity by impairment status for absolute mean lane deviation (feet). Memory impaired (MI) participants show more lane deviation than healthy controls (HC), and participants showed more lane deviation at fast speeds than at slow speeds. However, under dual-task conditions, participants showed marginally less lane deviation when a secondary memory task was added.

Standard Deviation of Lane Deviation

The second analysis was a similar 2 X 2 X 2 RM-ANOVA design using the same two levels of within-persons task difficulty (Slow and Fast) crossed with two levels of task complexity (Single and Dual) and with two levels of the between-person factor of impairment group (healthy control vs. memory impaired) to examine their effect on the standard deviation of lane deviation. The results were similar to those seen in the analyses of Absolute Mean Lane Deviation. Means of task difficulty (speed) show that there was more deviation in lane maintenance at the faster speed ($M \pm SE = 4.99 \pm 0.26$) than at the slower speed ($M \pm SE = 2.70 \pm 0.31$). This observation was supported by a main effect of task difficulty, $F(1,53) = 73.20$, $p < 0.01$, $\eta^2 = 0.58$. Again, counterintuitively, means of task complexity showed that there was more deviation in lane maintenance in the single task ($M \pm SE = 4.02 \pm 0.24$) than in the dual-task ($M \pm SE = 3.68 \pm 0.29$). This was supported by a main effect of task complexity, $F(1,53) = 7.12$, $p = 0.01$, $\eta^2 = 0.12$. Means of impairment group revealed that the memory impaired group had more deviation of lane maintenance (M ± SE = 4.27 ± 0.44) than the healthy control group (M ± SE = 3.43 ± 0.25). This finding was supported by a marginally significant trend toward a main effect of impairment, $F(1,53) = 2.78$, $p = 0.10$, $\eta^2 = 0.05$.

There were no significant interactions found for this dependent variable (task difficulty by impairment group, $F(1,53) = 0.18$, $p = 0.68$, $\eta^2 = 0.01$; task complexity by impairment group, $F(1,53) = 0.16$, $p = 0.70$, $\eta^2 = 0.01$; and task difficulty by task complexity, $F(1,53) = 0.02$, $p = 0.88$, $\eta^2 = 0.01$). The three-way interaction between task difficulty, task complexity, and impairment group was also non-significant, $F(1,53) = 0.24$, $p = 0.62$, $\eta^2 = 0.01$. Table 4-5 displays the means for this three-way interaction. Figure 4-2 graphically shows these findings.

Table 4-5. Means ± standard errors of three-way interaction for deviation of lane maintenance.

	Task Difficulty- Slow		Task Difficulty- Fast	
Impairment Group	Single Task	Dual-task	Single Task	Dual-task
Healthy Control	2.40 ± 0.31	2.06 ± 0.31	4.74 ± 0.24	4.51 ± 0.31
Memory Impaired	3.33 ± 0.56	3.04 ± 0.55	5.60 ± 0.43	5.11 ± 0.56

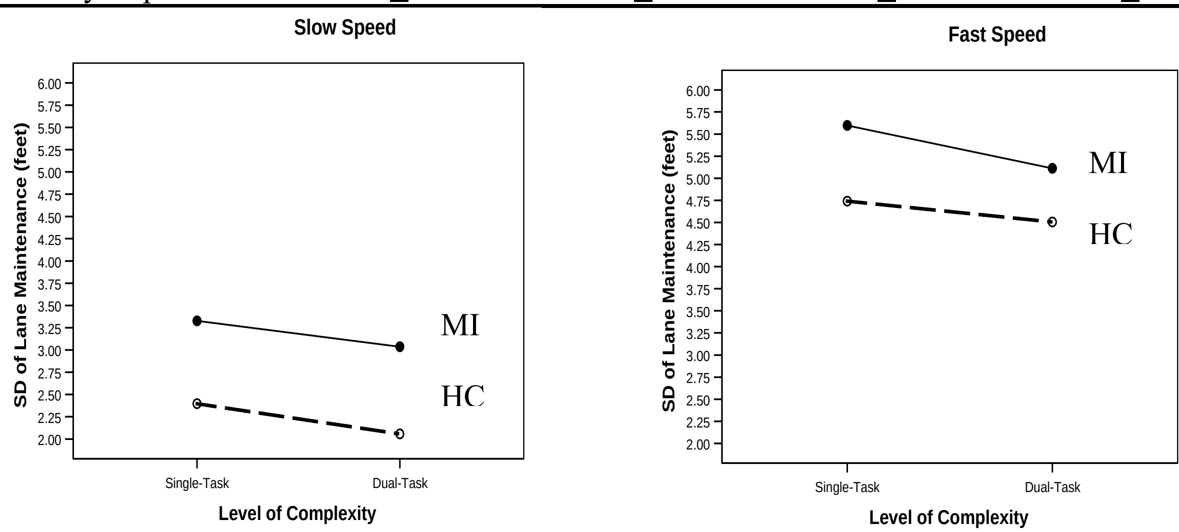

Figure 4-2. Line graphs of level of difficulty and level of complexity by impairment status for standard deviation of lane maintenance (feet). Memory impaired (MI) participants show more variability in lane maintenance than healthy controls (HC), and participants showed more variability at fast speeds than at slow speeds. However, under dual-task conditions, participants showed marginally less variability when a secondary memory task was added.

Mean Time Spent in Lane

The third analysis was also a 2 X 2 X 2 RM-ANOVA design using the same two levels of within-person task difficulty (Slow and Fast) crossed with two levels of task complexity (Single and Dual) and with two levels of the between-person factor of impairment group (healthy control vs. memory impaired) to examine their effect on the mean time spent in lane. A similar pattern of findings was found for this dependent variable as was for the preceding two dependent variables (which was not so surprising because all three variables constitute different linear recombinations of the same moment-by-moment lane maintenance information). Means of task difficulty (speed) show that there was more lane maintenance at the slower speed ($M \pm SE = 0.94 \pm 0.01$) than at the faster speed ($M \pm SE = 0.77 \pm 0.02$). This observation was supported by a main effect of task difficulty, $F(1,54) = 171.99$, $p < 0.01$, $\eta^2 = 0.76$. Again, counterintuitively, means of task complexity showed that there was less lane maintenance in the single task ($M \pm SE = 0.85 \pm 0.02$) than in the dual-task ($M \pm SE = 0.86 \pm 0.02$). This was supported by a main effect of task complexity, $F(1,54) = 6.61$, $p = 0.01$, $\eta^2 = 0.11$. Means of impairment group revealed that the memory impaired group had less lane maintenance ($M \pm SE = 0.82 \pm 0.03$) than the healthy control group ($M \pm SE = 0.89 \pm 0.02$). This finding was supported a significant main effect of impairment, $F(1,54) = 4.55$, $p = 0.04$, $\eta^2 = 0.08$.

The task difficulty by impairment group interaction was non-significant, $F(1,54) = 0.05$, $p = 0.94$, $\eta^2 = 0.01$. There was also no interaction found for task complexity by impairment group, $F(1,54) = 1.07$, $p = 0.31$, $\eta^2 = 0.02$. The task difficulty by task complexity interaction was significant, $F(1,54) = 4.19$, $p = 0.05$, $\eta^2 = 0.07$. The three-way interaction between task difficulty, task complexity, and impairment group showed preliminary evidence of a trend, $F(1,54) = 2.62$, $p = 0.11$, $\eta^2 = 0.05$. Table 4-6 displays the means for this three-way interaction, while Figure 4-3 graphically shows these findings.

Table 4-6. Means ± standard errors of three-way interaction for mean time spent in lane.

	Task Difficulty- Slow		Task Difficulty- Fast	
Impairment Group	Single Task	Dual-task	Single Task	Dual-task
Healthy Control	0.97 ± 0.01	0.98 ± 0.01	0.79 ± 0.02	0.81 ± 0.02
Memory Impaired	0.92 ± 0.02	0.91 ± 0.02	0.71 ± 0.04	0.77 ± 0.04

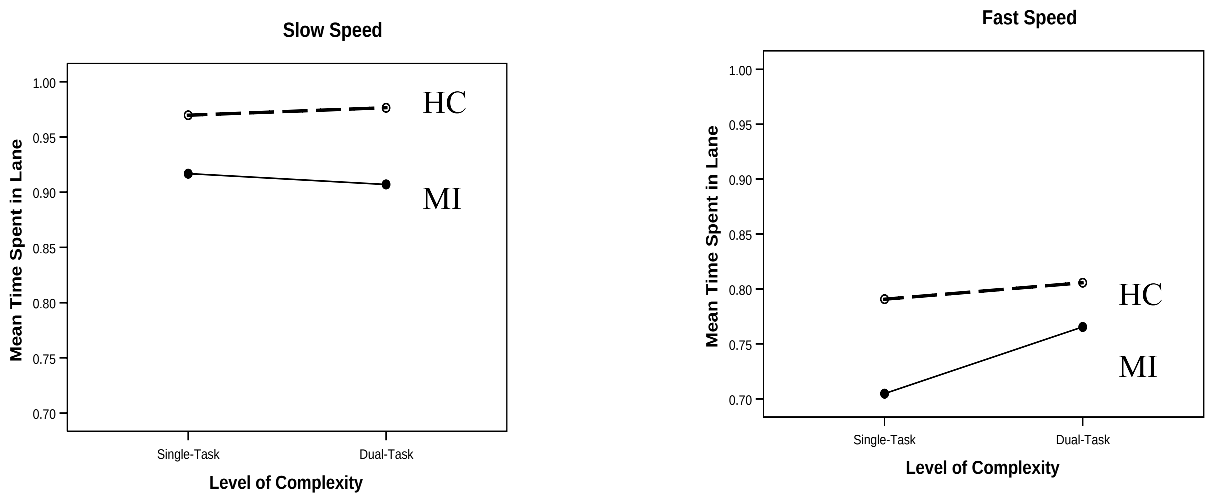

Figure 4-3. Line graphs of level of difficulty and level of complexity by impairment status for mean time spent in lane. Memory impaired (MI) participants show less time in lane than healthy controls (HC), and participants showed less time in lane at fast speeds than at slow speeds. However, under dual-task conditions, participants showed marginally more time in lane when a secondary memory task was added.

Additional Analyses

Practice Effects

As noted above, for all three dependent variables, the results revealed less lane deviation in the dual-task condition than in the single task condition. Throughout the study, single tasks (driving without distraction) always preceded dual-tasks (driving while remembering), in an alternating sequence, for a total of six trials. The specific sequence was:

(1a. single slow) + (1b. dual slow) + (2a. single fast) + (2b. dual fast) + (3a. single slow) + (3b. dual slow) + (break) + (4a. single fast) + (4b. dual fast) + (5a. single slow) + (5b. dual slow) + (6a. single fast) + (6b. dual fast)

The study then examined trends of lane navigation across the six single (three slow, three fast) and six dual-task (three slow, three fast) trials, to see whether there was any evidence of a practice-related reduction in lane deviation over time. Since the slow condition of driving always came first, there was a possibility that participants were more experienced with the driving task under fast task conditions, and this resulted in more competence in staying in lane. The data were divided into six trials, with each trial containing a single and dual-task condition. For all participants, Trials 1, 3 and 5 consisted of driving at 30 mph; the first part of each trial was driving alone; the second part of each trial was driving while remembering. Trials 2, 4 and 6 were similarly organized, but were driven at 60 mph. In order to be sure that the driving task was measuring the same construct across trials, a correlation analysis of all trials was completed with mean time spent as lane as the dependent variable. Results indicated that Trial 1 was significantly related to Trial 2 ($p = 0.01$), but not related to any other trials (p values ranged from 0.07 - 0.78). Trials 2 - 6 were all significantly related to each other.

Practice Effects: Absolute Mean Lane Deviation

The above dependent variables were examined with a 6 X 2 RM-ANOVA with six within-person trial levels crossed with the between-person factor of impairment group on the effect of absolute mean lane deviation. Because none of the experimental conditions interacted with one another, for this analysis the single- and dual-task conditions were collapsed. The means of each trial were as expected; the participants showed fewer lane deviation in slow conditions (Slow/Trial 1: $M \pm SE = 1.63 \pm 0.21$; Slow/Trial 3: $M \pm SE = 1.88 \pm 0.18$; Slow/Trial 5: $M \pm SE = 1.80 \pm 0.11$) than in fast conditions (Fast/Trial 2: $M \pm SE = 4.16 \pm 0.25$; Fast/Trial 4: $M \pm SE = 3.33 \pm 0.16$; Fast/Trial 6: $M \pm SE = 4.09 \pm 0.41$). However only one pair of trials of the same difficulty level had a significant difference (Trial 2 and Trial 4, $p = < 0.01$, Bonferroni corrected for multiple comparisons). While Trial 4 did, in fact, show less lane deviation than Trial 2, by

Trial 6, lane deviation had increased again (perhaps due to fatigue). Thus, there was no consistent linear practice effect. The main effect of trial was significant, $F(5,38) = 40.91$, $p < 0.01$, $\eta^2 = 0.47$. The means for the impairment levels illustrate that the healthy control group had more lane deviation (M$\pm$SE = 2.91 $\pm$ 0.15) than the memory impaired group (M$\pm$SE = 2.72 $\pm$ 0.29), however the main effect of impairment was not significant, $F(1,42) = 0.33$, $p = 0.57$, $\eta^2 = 0.01$. The interaction of trial by impairment group was also not significant, $F(5,38) = 0.48$, $p = 0.79$, $\eta^2 = 0.01$. Table 4-7 displays the means for this two-way interaction. Figure 4-4 graphically displays the findings.

Table 4-7. Means $\pm$ standard error of two-way interaction of trial by impairment for absolute mean lane deviation.

	Slow Speed			Fast Speed		
Impairment Group	Trial 1	Trial 3	Trial 5	Trial 2	Trial 4	Trial 6
Healthy Control	1.73 + 0.19	2.05 $\pm$ 0.17	1.87 $\pm$ 0.10	4.10 $\pm$ 0.23	3.38 $\pm$ 0.14	4.30 $\pm$ 0.37
Memory Impaired	1.54 + 0.38	1.70 $\pm$ 0.33	1.73 $\pm$ 0.19	4.22 $\pm$ 0.45	3.27 $\pm$ 0.28	3.88 $\pm$ 0.72

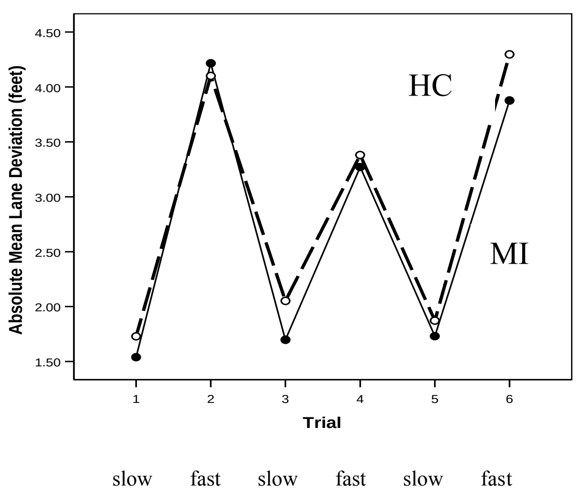

Figure 4-4. Line graph for each trial by impairment status for absolute mean lane deviation. These deviations collapse across single- and dual-task driving. Trials 1, 3 and 5 represent slow (30 mph) driving; trials 2, 4 and 6 represent fast (60 mph) driving. There was a 5-minute break between trials 3 and 4. MI = memory impaired; HC = healthy controls.

Practice Effects: Standard Deviation of Lane Deviation

The second dependent variable of deviation of lane maintenance was examined with the same 6 X 2 RM-ANOVA with six within-person trial levels by the between-person factor of impairment group. A pattern similar to that seen in Absolute Mean Lane Deviation was found. The means of each trial were as expected; the participants showed less lane deviation in slow conditions (Slow/Trial 1: M±SE = 1.83 ± 0.22; Slow/Trial 3: M±SE = 2.20 ± 0.23; Slow/Trial 5: M±SE = 2.11 ± 0.12) than fast conditions (Fast/Trial 2: M±SE = 4.95 ± 0.31; Fast/Trial 4: M±SE = 4.01 ± 0.15; Fast/Trial 6: M±SE = 4.90 ± 0.44). However, as in the Absolute Mean Lane Deviation analysis, only one pair of trials of the same difficulty level had a significant difference (Trial 2 and Trial 4, p = < 0.01, Bonferroni corrected). Again, the main effect of trial was significant, $F(5,38) = 50.31$, $p < 0.01$, $\eta^2 = 0.53$. The means for the impairment levels illustrate that the normal group had more deviation in lane maintenance (M±SE = 3.41 ± 0.17) than the impaired group (M±SE = 3.25 ± 0.33), however the main effect of impairment was not significant, $F(1,42) = 0.19$, $p = 0.19$, $\eta^2 = 0.01$. The interaction of trial by impairment group was also not significant, $F(5,38) = 0.44$, $p = 0.82$, $\eta^2 = 0.0501$. Table 4-8 displays the means for this two-way interaction and Figure 4-5 graphically displays the findings of the analysis.

Table 4-8. Means ± standard error of two-way interaction of trial by impairment for deviation of lane maintenance.

	Slow Speed			Fast Speed		
Impairment Group	Trial 1	Trial 3	Trial 5	Trial 2	Trial 4	Trial 6
Healthy Control	1.97 + 0.20	2.45 ± 0.20	2.22 ± 0.11	4.84 ± 0.28	4.02 ± 0.14	4.97 ± 0.40
Memory Impaired	1.69 + 0.40	1.95 ± 0.40	1.99 ± 0.21	5.05 ± 0.55	3.99 ± 0.27	4.82 ± 0.79

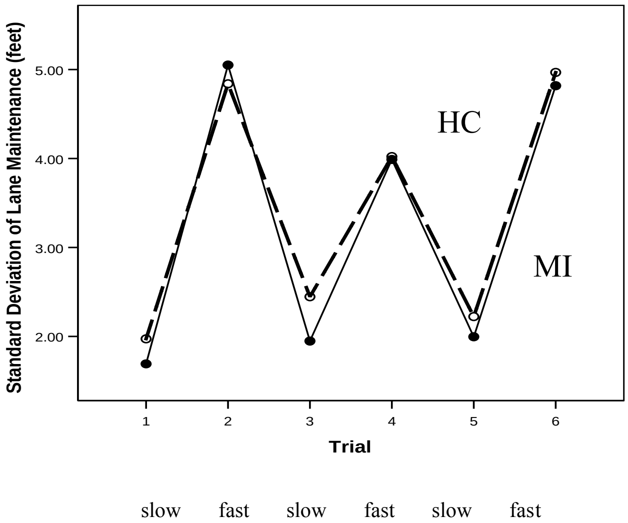

Figure 4-5. Line graph for each trial by impairment status for standard deviation of lane maintenance (feet). MI = memory impaired; HC = healthy controls.

Practice Effects: Mean Time Spent in Lane

The third analysis examined with the same 6 X 2 RM-ANOVA with six within-person trial levels by the between-person factor of impairment group on the effect of mean time spent in lane. A similar pattern was found. The means of each trial were as expected; the participants more time in lane during slow conditions (Slow/Trial 1: M$\pm$SE = 0.98 $\pm$ 0.01; Slow/Trial 3: M$\pm$SE = 0.97 $\pm$ 0.01; Slow/Trial 5: M$\pm$SE = 0.98 $\pm$ 0.01) than fast conditions (Fast/Trial 2: M$\pm$SE = 0.77 $\pm$ 0.02; Fast/Trial 4: M$\pm$SE = 85 $\pm$ 0.02; Fast/Trial 6: M$\pm$SE = 0.78 $\pm$ 0.03). However, as in previous analyses, only one pair of trials of the same difficulty level had a significant difference, and this pair was the same described earlier (Trial 2 and Trial 4, p = < 0.01, Bonferroni corrected). Again, the main effect of trial was significant, $F(5,38) = 25.49$, $p < 0.01$, $\eta^2 = 0.25$. The means for the impairment levels wass almost identical (Normal: M$\pm$SE = 0.88 $\pm$ 0.01, Impaired: M$\pm$SE = 0.89 $\pm$ 0.02) and the main effect of impairment was not significant, $F(1,42) = 0.05$, $p = 0.82$, $\eta^2 = 0.01$. The interaction of trial by impairment group was also not significant, $F(5,38) = 0.31$, $p = 0.91$, $\eta^2 = 0.01$. Table 4-9 displays the means for this two-way interaction. Figure 4-6 shows the findings graphically.

Table 4-9. Means ± standard error of two-way interaction of trial by impairment for mean time in lane.

	Slow Speed			Fast Speed		
Impairment Group	Trial 1	Trial 3	Trial 5	Trial 2	Trial 4	Trial 6
Healthy Control	0.97 + 0.01	0.96 ± 0.01	0.98 ± 0.01	0.78 ± 0.02	0.84 ± 0.02	0.77 ± 0.02
Memory Impaired	0.98 + 0.02	0.98 ± 0.02	0.98 ± 0.01	0.76 ± 0.04	0.85 ± 0.03	0.79 ± 0.05

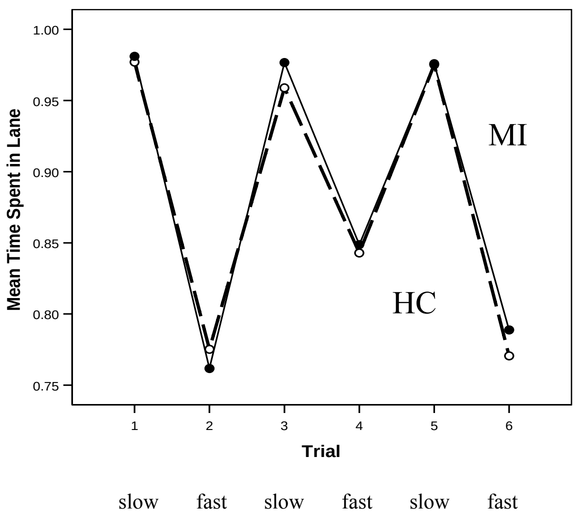

Figure 4-6. Line graph for each trial by impairment status for time spent in lane. MI = memory impaired; HC = healthy controls.

Effect of Memory Phase

The preceding analyses treated the secondary task (remembering) as a unitary construct. In fact, the single and dual-task conditions surrounding a particular paragraph could better be described as a sequence of five steps in each of the six experimental trials: 1. Single-task driving, 2. Listening, 3. Rehearsal, 4. Free recall, 5. Post-recall single-task driving. Participants would then begin the next trial. In order to examine if there were differential effects on driving based on the type of memory phase engaged in, the driving task was divided into these five parts: single task only, listening to story, rehearsing story, recalling story, and post-recall. Since dual-task effects did not interact with either impairment group or driving speed, for this analysis, slow and fast speeds were collapsed, to examine whether there were overall effects of where participants were in the remembering process. The same three dependent variables were tested with these factors.

Memory Phase: Absolute Mean Lane Deviation

The first analysis was a 5 X 2 RM-ANOVA with five within-person memory phase levels (single, listening, rehearsal, recall, post-recall) crossed with the between-person factor of impairment group on the effect of absolute mean lane deviation. The means of each condition showed that the participants had less lane deviation under dual-task conditions (Single task: $M \pm SE = 3.05 \pm 0.24$; Listening: $M \pm SE = 3.22 \pm 0.19$; Rehearsing: $M \pm SE = 2.87 \pm 0.28$; Recalling: $M \pm SE = 3.59 \pm 0.34$; Post-recall: $M \pm SE = 4.90 \pm 0.43$). For the main effect of memory condition, several pairs of memory conditions showed (Bonferroni corrected) significant difference (Single task and Rehearsing, $p < 0.01$; Single task and Post-recall, $p < 0.01$; Listening and Post-recall, $p < 0.01$; Rehearsing and Post-recall, $p < 0.01$; and Recall and Post-recall, $p < 0.01$). The main effect of memory condition was significant, $F(4,52) = 12.42$, $p < 0.01$, $\eta^2 = 0.23$. Summarizing, there was more deviation in the single task condition than in all subsequent memory phases (except for recall), which parallels the broader single-dual-task effects described earlier. Looking within the dual-task conditions, the listening phase showed significantly more deviation than rehearsal, and significantly less deviation than the post-recall phase. The post-recall phase showed significantly larger deviation than all other conditions. The means for the impairment levels illustrate that the healthy control group had less lane deviation ($M \pm SE = 3.37 \pm 0.27$) than the memory impaired group ($M \pm SE = 3.87 \pm 0.47$), however the main effect of impairment was not significant, $F(1,55) = 0.86$, $p = 0.36$, $\eta^2 = 0.01$. The interaction of memory condition by impairment group was also not significant, $F(4,52) = 1.11$, p

= 0.36, $\eta^2 = 0.04$. Table 4-10 displays the means for this two-way interaction. Figure 4-7 graphically displays the findings of this analysis.

Table 4-10. Means $\pm$ standard error of two-way interaction of memory condition by impairment on absolute mean lane deviation.

Impairment Group	Single Task	Listening	Rehearsing	Recalling	Post-Recall
Healthy Control	3.17 $\pm$ 0.23	3.14 $\pm$ 0.19	2.86 $\pm$ 0.28	3.22 $\pm$ 0.34	4.47 $\pm$ 0.42
Memory Impaired	3.83 $\pm$ 0.41	3.31 $\pm$ 0.33	2.88 $\pm$ 0.49	3.96 $\pm$ 0.59	5.35 $\pm$ 0.74

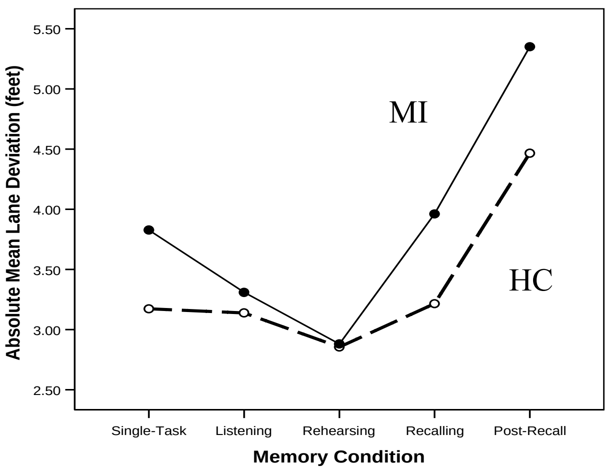

Figure 4-7. Line graph for each memory condition by impairment status for absolute mean lane deviation (feet). MI = memory impaired; HC = healthy controls.

Memory Condition: Standard Deviation of Lane Deviation

The second analysis was the same 5 X 2 RM-ANOVA with five within-person memory condition levels (as listed above) by the between-person factor of impairment group on the effect of deviation of lane maintenance. The means of each condition showed that the participants generally had less lane deviation in under dual-task conditions (Single task: $M \pm SE = 4.57 \pm 0.27$; Listening: $M \pm SE = 4.03 \pm 0.21$; Rehearsing: $M \pm SE = 3.15 \pm 0.27$; Recalling: $M \pm SE = 4.39 \pm 0.37$; Post-recall: $M \pm SE = 5.01 \pm 0.34$). Several pairs of memory conditions showed a (Bonferroni corrected) significant difference like the previous analysis (Single task and Rehearsing, $p < 0.01$; Listening and Rehearsing, $p < 0.01$; Listening and Post-recall, $p < 0.01$; Rehearsing and Recall, $p < 0.01$; and Rehearsing and Post-recall, $p < 0.01$). The pattern of means was identical to the preceding analysis, with the post-recall phase showing the largest variability in lane position. The main effect of memory condition was significant, $F(4,52) = 10.18$, $p < 0.01$, $\eta^2 = 0.08$. The means for the impairment levels illustrate that the healthy control group had less lane deviation (M±SE = 4.01 ± 0.25) than the memory impaired group (M±SE = 4.46 ± 0.44), however the main effect of impairment was not significant, $F(1,55) = 0.79$, $p = 0.38$, $\eta^2 = 0.01$. The interaction of memory condition by impairment group was also not significant, $F(4,52) = 1.75$, $p = 0.15$, $\eta^2 = 0.01$. Table 4-11 and Figure 4-8 display the findings.

Table 4-11. Means ± standard error of two-way interaction of memory condition by impairment on deviation of lane maintenance.

Impairment Group	Single Task	Listening	Rehearsing	Recalling	Post-Recall
Healthy Control	4.08 ± 0.26	3.86 ± 0.21	3.33 ± 0.27	4.13 ± 0.37	4.64 ± 0.34
Memory Impaired	5.06 ± 0.46	4.21 ± 0.36	2.97 ± 0.47	4.66 ± 0.65	5.39 ± 0.59

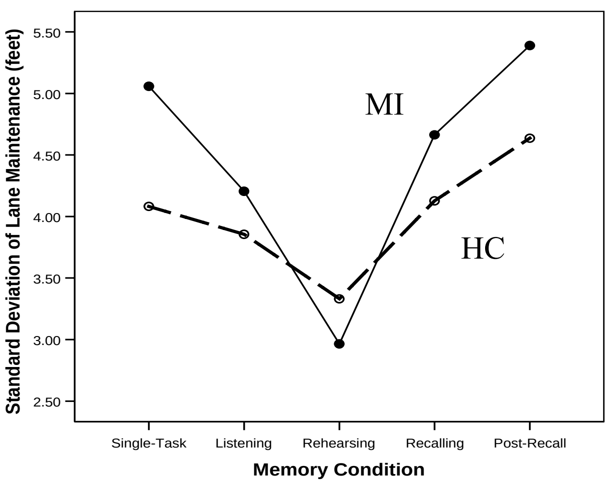

Figure 4-8. Line graph for each memory condition by impairment status for standard deviation of lane maintenance (feet). MI = memory impaired; HC = healthy controls.

Memory Condition: Time Spent in Lane

The third analysis was a 5 X 2 RM-ANOVA with five within-person memory condition levels (as listed above) by the between-person factor of impairment group on the effect of time spent in lane. The means of each condition showed that the participants generally had more time spent in lane under dual-task conditions (Single task: M±SE = 0.83 ± 0.02; Listening: M±SE = 0.84 ± 0.02; Rehearsing: M±SE = 0.88 ± 0.02; Recalling: M±SE = 0.83 ± 0.02; Post-recall:

M±SE = 0.72 ± 0.03). Several pairs of memory conditions showed a (Bonferroni corrected) significant difference (Single task and Rehearsing, $p < 0.01$; Single task and Post-recall, $p = 0.02$; Listening and Rehearsing, $p < 0.01$; Listening and Post-recall, $p = 0.02$; Rehearsing and Recall, $p < 0.01$; Rehearsing and Post-recall, $p < 0.01$; and Recall and Post-recall, $p < 0.01$). Again, the pattern of in-lane time resembled that shown in the preceding two analyses. The main effect of memory condition was significant, $F(4,52) = 19.75$, $p < 0.01$, $\eta^2 = 0.41$. The means for the impairment levels illustrate that the healthy control group had more time spent in lane (M±SE = 0.84 ± 0.02) than the memory impaired group (M±SE = 0.80 ± 0.03), however the main effect of impairment was not significant, $F(1,55) = 0.97$, $p = 0.33$, $\eta^2 = 0.02$. The interaction of memory condition by impairment group was also not significant, $F(4,52) = 0.23$, $p = 0.92$, $\eta^2 = 0.01$. Table 4-12 displays the means for this two-way interaction. Figure 4-9 graphically shows the findings of this analysis.

Table 4-12. Means ± standard error of two-way interaction of memory condition by impairment on time spent in lane.

Impairment Group	Single Task	Listening	Rehearsing	Recalling	Post-Recall
Healthy Control	0.86 ± 0.02	0.86 ± 0.02	0.90 ± 0.02	0.86 ± 0.02	0.73 ± 0.03
Memory Impaired	0.81 ± 0.03	0.82 ± 0.03	0.87 ± 0.04	0.80 ± 0.04	0.71 ± 0.05

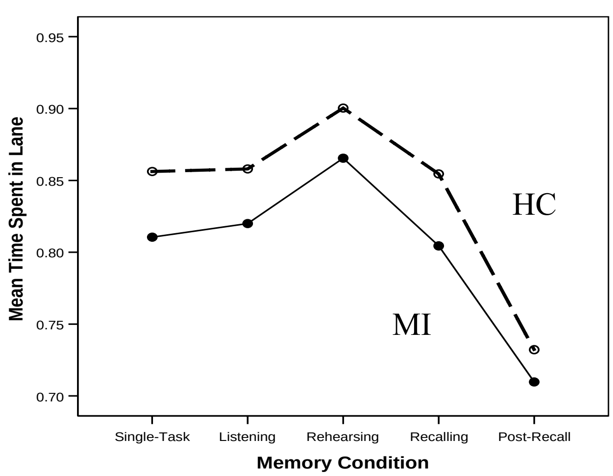

Figure 4-9. Line graph for each memory condition by impairment status for mean time spent in lane. MI = memory impaired; HC = healthy controls.

Dual-task Analysis of Secondary Task: Story Recall

An analysis of the secondary task, how well people remembered the presented paragraphs, was conducted. First, correlations were computed to determine the relationship between the mean time spent in lane and the participants' scores on the story recall task. Table 4-13 displays the findings. The secondary task can shed light on whether, for example, individuals may have prioritized the driving task at the cost of memory (i.e., did we not see the expected dual-task effects because drivers became more vigilant in their steering and less prone to lane deviation?). Was there evidence that participants sacrificed the secondary task (i.e., let memory performance suffer disproportionately under dual-task conditions) to preserve or even enhance the primary task (lane navigation).

Table 4-13. Correlations between mean time spent in lane and story recall scores.

	Single-Task	Slow Speed (Dual- Task)	Fast Speed (Dual- Task)
Slow-Single	0.42**	0.36**	0.21
Slow-Dual	0.48**	0.48**	0.28*
Fast- Single	0.35**	0.25	0.18
Fast-Dual	0.25	0.04	0.25

Note: * = $p < 0.05$; ** = $p < 0.01$

This hypothesis was investigated with a 3 X 2 RM-ANOVA with three levels of within-person story recall (total score during single task, slow conditions, fast conditions) and the between-person factor of impairment group. The means of the stories recalled under each condition revealed that participants remembered more details under single task ($M \pm SE = 7.71 \pm 0.39$) than under the slow conditions ($M \pm SE = 6.36 \pm 0.39$) and fast conditions ($M \pm SE = 5.89 \pm 0.43$). A Bonferroni corrected comparison of the conditions showed that single-task was significantly different from both the slow condition ($p < 0.01$) and the fast condition ($p < 0.01$). There was not a significant difference between slow condition and fast condition ($p = 0.21$). However, the main effect of experimental condition was significant, $F(2,102) = 13.77$, $p < 0.01$,

$\eta^2 = 0.21$. The means by impairment group showed that the healthy control group performed better (M±SE = 8.04 ± 0.33) than the memory impaired group (M±SE = 5.26 ± 0.60) on average. The main effect of impairment was significant, $F(1,51) = 16.38$, $p < 0.01$, $\eta^2 = 0.24$. However, the interaction between experimental condition and impairment was not significant, $F(2,102) = 0.74$, $p = 0.47$, $\eta^2 = 0.01$, likely because there was a low effect size for the interaction. Table 4-14 shows the means for this two-way interaction and Figure 4-10 displays the findings.

Table 4-14. Means ± standard error of two-way interaction of story recall by impairment.

Impairment Group	Single Task	Slow Speed (Dual-Task)	Fast Speed (Dual-Task)
Healthy Control	9.13 ± 0.37	7.51 ± 0.37	7.48 ± 0.41
Memory Impaired	6.30 ± 0.68	5.20 ± 0.69	4.29 ± 0.75

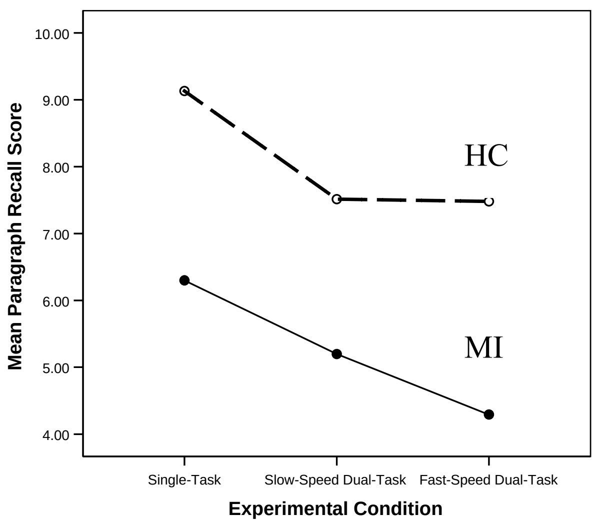

Figure 4-10. Line graph for each experimental condition by impairment status for paragraph recall score. MI = memory impaired; HC = healthy controls.

Tradeoff Analysis

To examine correlated dual task costs, change scores were calculated for the mean time spent in lane (i.e., slow/single-task minus slow/dual-task and fast/single-task minus fast/dual-task). Change scores were also calculated for story recall (i.e., single-task only minus slow/dual-task, single-task only minus fast/dual-task, and slow/dual-task minus fast/dual-task). Table 4.15 shows the results of the correlation analysis. There was no significant relationship between the lane navigation change scores and the story recall change scores. However, there was a significant relationship between the two lane navigation change scores and significant relationships between the story recall change scores, suggesting that within a task, dual task costs were correlated across conditions.

Table 4-15. Correlation of change scores to examine tradeoff.

	Story Recall		
Mean Time in Lane	Single - Slow/Dual	Single – Fast/Dual	Slow/Dual – Fast/ Dual
Slow/Single – Slow/Dual	0.18	-0.10	-0.14
Fast/Single – Fast/Dual	-0.13	0.17	0.11

Possible Correlates

Correlations were examined to determine what cognitive measures may have correlated with the three different lane navigation variables explored above. The hypothesis was that attentional variables would be particularly predictive of driving under dual-task conditions since dual-task should demand more attentional resources. Table 4-16, 4-17, and 4-18 show these correlations. Additionally, Table 4-19 shows the correlations between the story scores under single and dual-task conditions with the cognitive variables. Lastly, Table 4-20 examines the correlations between the change scores derived above and the cognitive correlates to understand how they might be able to predict dual-task costs.

Overall, the driving variables were particularly related to several indicators of *accuracy* on a number cancellation task (Ruff) and to the main three subtests of the UFOV that measures visual attention ability. These results suggest that the more accurate the participants were at the number cancellation task, the more accurate they were in the lane navigation task (i.e., less lane deviation, less variability in lane deviation, and more time spent in lane). The UFOV finding suggests that the participants with more lane deviation, more variability, and less time in lane also required longer amounts of time to correctly identify targets and divide their attention in the visual processing task. Interestingly, some of the correlations were no longer significant in the dual-task fast condition, so that there was little evidence that dual-task performance was more related to indicators of attention than single task performance. A similar pattern was true when we examined the correlates of memory across the single and dual-task conditions; there was little evidence that any of the selected covariates were more related to dual-task performance than to single task performance.

For the correlations of the change scores, significant relationships appeared mainly for the lane navigation task rather than the story recall change scores. The UFOV processing speed and selective attention subtests were significantly related in that those who performed the worst on UFOV (because higher scores mean slower attention speeds) also displayed the most difficulty under dual task conditions. The N-back task, specifically 1- and 2-back, also displayed significant negative correlations with the mean time spent in lane change scores.

Table 4-16. Cognitive correlates of absolute mean lane deviation.

	Slow Speed		Fast Speed	
	Single-Task	Dual-Task	Single-Task	Dual-Task
UFOV Processing Speed	0.36**	0.55**	0.38**	0.09
UFOV Divided Attention	0.41**	0.46**	0.13	0.28*
UFOV Selective Attention	0.24	0.24	0.05	0.34*
UFOV Experimental Subtest	0.17	0.18	0.11	0.09
Ruff Automatic Speed	-0.33*	-0.37**	-0.20	-0.25
Ruff Automatic Accuracy	-0.23	-0.19	-0.27*	-0.56**
Ruff Controlled Speed	-0.26	-0.28*	-0.10	-0.12
Ruff Controlled Accuracy	-0.37**	-0.33*	-0.34**	-0.53**
Ruff Total Speed	-0.31*	-0.33*	-0.18	-0.24
Ruff Total Accuracy	-0.40**	-0.38**	-0.45**	-0.55**
1-Back Accuracy	0.02	-0.26	-0.04	-0.13
2-Back Accuracy	-0.12	-0.30*	-0.19	-0.07
3-Back Accuracy	-0.10	-0.06	0.04	0.05
Vision score	-0.02	0.17	0.07	0.16
Hearing Item	0.22	0.19	0.20	0.09
Driving Habit Difficulty Score	0.13	0.12	0.17	-0.32*
Driving Habits Avoidance Score	-0.05	0.04	0.04	0.03
Driving Habits Maneuvers Done	-0.18	-0.22	-0.35*	0.17
Everyday Attention Screener	-0.08	-0.09	-0.03	-0.09

Note: * = $p < 0.05$, ** = $p < 0.01$

Table 4-17. Cognitive correlates of standard deviation of lane deviation.

	Slow Speed		Fast Speed	
	Single-Task	Dual-Task	Single-Task	Dual-Task
UFOV Processing Speed	0.19	0.40**	0.35**	0.13
UFOV Divided Attention	0.48**	0.57**	0.21	0.43**
UFOV Selective Attention	0.30*	0.31*	0.10	0.41**
UFOV Experimental Subtest	0.19	0.21	0.18	0.24
Ruff Automatic Speed	-0.38*	-0.42**	-0.28*	-0.38**
Ruff Automatic Accuracy	-0.32*	-0.22	-0.33*	-0.61**
Ruff Controlled Speed	-0.30*	-0.32*	-0.13	-0.19
Ruff Controlled Accuracy	-0.40**	-0.31*	-0.39**	-0.58**
Ruff Total Speed	-0.37**	-0.39**	-0.24	-0.33*
Ruff Total Accuracy	-0.40**	-0.34**	-0.47**	-0.49**
1-Back Accuracy	-0.04	-0.28*	-0.11	-0.16
2-Back Accuracy	-0.11	-0.25	-0.25	-0.16
3-Back Accuracy	-0.25	-0.12	0.01	0.01
Vision score	0.07	0.19	0.12	0.20
Hearing Item	0.12	0.13	0.09	-0.01
Driving Habit Difficulty Score	-0.01	0.01	0.17	-0.22
Driving Habits Avoidance Score	0.05	0.08	0.14	0.14
Driving Habits Maneuvers Done	-0.17	-0.15	-0.38**	-0.25
Everyday Attention Screener	-0.01	-0.08	0.05	0.06

Note: * = $p < 0.05$, ** = $p < 0.01$

Table 4-18. Cognitive correlates of mean time spent in lane.

	Slow Speed		Fast Speed	
	Single-Task	Dual-Task	Single-Task	Dual-Task
UFOV Processing Speed	-0.42**	-0.55**	-0.29*	-0.09
UFOV Divided Attention	-0.27*	-0.30*	-0.10	-0.21
UFOV Selective Attention	-0.14	-0.13	-0.03	-0.29*
UFOV Experimental Subtest	-0.15	-0.20	-0.08	-0.09
Ruff Automatic Speed	0.25	0.29	0.18	0.22
Ruff Automatic Accuracy	0.22	0.19	0.29*	0.43**
Ruff Controlled Speed	0.19	0.23	0.07	0.09
Ruff Controlled Accuracy	0.37**	0.33*	0.33*	0.38**
Ruff Total Speed	0.22	0.26	0.17	0.22
Ruff Total Accuracy	0.43**	0.41**	0.45**	0.51**
1-Back Accuracy	-0.01	0.22	0.02	0.14
2-Back Accuracy	0.13	0.28*	0.13	0.06
3-Back Accuracy	0.08	0.07	-0.06	-0.03
Vision score	0.02	-0.14	-0.07	-0.20
Hearing Item	-0.23	-0.19	-0.20	-0.16
Driving Habit Difficulty Score	-0.17	-0.18	-0.14	0.23
Driving Habits Avoidance Score	0.04	-0.01	-0.04	-0.03
Driving Habits Maneuvers Done	0.24	0.26	0.32*	0.20
Everyday Attention Screener	0.11	0.10	-0.01	0.08

Note: * = $p < 0.05$, ** = $p < 0.01$

Table 4-19. Correlations between paragraph recall scores and cognitive measures.

	Single Task	Slow Speed (Dual-Task)	Fast Speed (Dual-Task)
UFOV Processing Speed	-0.28*	-0.35**	-0.22
UFOV Divided Attention	-0.48**	-0.36**	-0.35*
UFOV Selective Attention	-0.27*	-0.17	-0.28*
UFOV Experimental Subtest	-0.28*	-0.15	0.20
Ruff Automatic Speed	0.34**	0.26	0.38**
Ruff Automatic Accuracy	0.38**	0.28*	0.27*
Ruff Controlled Speed	0.31*	0.23	0.26
Ruff Controlled Accuracy	0.36**	0.32*	0.30*
Ruff Total Speed	0.27*	0.21	0.33*
Ruff Total Accuracy	0.40**	0.36**	0.34*
1-Back Accuracy	0.18	0.23	0.26
2-Back Accuracy	0.31*	0.35**	0.43**
3-Back Accuracy	0.02	0.17	0.08
Driving Habit Difficulty Score	-0.14	-0.07	0.11
Driving Habits Avoidance Score	-0.05	-0.16	-0.15
Driving Habits Maneuvers Done	0.18	0.08	-0.01
Everyday Attention Screener	-0.09	-0.08	-0.13

Note: * = $p < 0.05$, ** = $p < 0.01$

Table 4-20. Correlations between change scores and cognitive measures.

	Mean Time in Lane		Story Recall		
	Slow Single-Dual	Fast Single- Dual	Single- Slow Dual	Single- Fast Dual	Slow Dual- Fast Dual
UFOV Processing Speed	0.39**	0.03	0.08	0.06	0.01
UFOV Divided Attention	0.12	0.19	-0.22	-0.04	0.07
UFOV Selective Attention	0.01	0.40**	-0.15	0.08	0.16
UFOV Exp. Subtest	0.14	0.10	-0.19	0.03	0.20
Ruff Automatic Speed	-0.15	-0.09	0.16	-0.16	-0.30
Ruff Automatic Accuracy	0.05	-0.10	0.20	0.15	0.02
Ruff Controlled Speed	-0.13	-0.07	0.18	-0.02	-0.15
Ruff Controlled Accuracy	0.05	-0.11	0.17	0.06	-0.04
Ruff Total Speed	-0.13	-0.08	0.16	-0.16	-0.29*
Ruff Total Accuracy	-0.04	-0.04	0.15	0.07	-0.01
1-Back Accuracy	-0.52**	-0.13	-0.03	-0.04	-0.03
2-Back Accuracy	-0.39**	0.02	0.01	-0.13	-0.17
3-Back Accuracy	0.03	-0.07	-0.08	0.04	0.11
Driving Habit Difficulty	0.05	-0.28*	0.02	-0.05	-0.01
Driving Habits Avoidance	0.13	-0.07	0.14	0.08	-0.01
Driving Habits Maneuvers	-0.11	0.12	0.05	0.09	0.01
Everyday Attention Screen	0.01	-0.17	-0.14	-0.08	0.05

CHAPTER 5
DISCUSSION

Review of Findings

In this study, we examined the influence of three variables, separately and in interaction, on simulated lane navigation in older adults. Cognitive status (specifically, memory impaired versus healthy control) was the chief between-person variable. Cognitive load (i.e., single vs. dual-task, or whether participants did the driving task with or without a concurrent task in which they tried to recall a brief paragraph) and level of driving difficulty (i.e., whether participants maintained lane at 30 mph or 60 mph) were two experimental variables that were varied within person. Three dependent variables (mean absolute lane deviation, standard deviation of lane deviation, and proportion of time spent in lane) were considered.

Preliminary analyses first examined whether the healthy control and memory impaired groups were, in fact, cognitively different from one another. These analyses revealed that the healthy control and memory impaired group significantly differed on most of the neuropsychological measures, especially the memory tests, which was expected due to the nature of cognitive impairments seen in mild cognitive impairment and early Alzheimer's disease, which made up the memory impaired group. The classifications were further corroborated with significant dependence between cognitive impairment status and CDR score, a measure of ability in everyday contexts.

There was also a significant dependency between cognitive impairment status and the use of cognitive enhancing medication, which suggests that these participants have likely had prior complaints about their memory to their physicians. The use of these medications was not universal, however, in that 10 memory impaired participants were not taking these medications (and one healthy control participant was). Interpretively, the heterogeneous use of these medications raises a challenge: It could be that those on such a medication performed better than those who were not on the medication (if the medications did, in fact, enhance cognition). Alternatively, it could have been that medication use signaled greater severity of impairment, and would therefore have been associated with poorer performance. While this potential problem was known prior to the study, the use of this type of medication was not an exclusion criterion because of the high number of memory impaired participants taking these medications in the population. It was felt that if we excluded participants using them, recruitment targets would be even more difficult to meet. Future work should investigate if taking this medication alters the findings by adding it as a covariate in the analyses.

A common problem with driving simulator studies is "simulator sickness" (Kennedy et al; 1993). Simulator sickness results from a disconnect between kinesthetic/vestibular senses and visual stimulation and causes motion sickness-type physical symptoms (i.e., nausea, dizziness, pallor, increased sweating). While there was some difficulty with simulator sickness in our sample, it was not unlike other driving simulation studies (e.g., Kubose et al., 2006, where 17% of college-aged participants could not complete the driving simulator task due to sickness). Unfortunately, a greater proportion of older adults from the memory impaired group were unable to complete the entire task compared to the healthy control older adults, however this difference was not significant. This may have resulted for several reasons. There is some evidence to suggest that older adults with cognitive impairment have more challenges with balance and gait (Pettersson, Olsson & Wahlund, 2005), which from a vestibular standpoint may have played a role in having difficulty with the motion of the simulated task. Additionally, if the memory impaired participants were self-judging their performance, it is possible that they complained more about the motion and the task itself because of a feeling of failure or inadequacy with the task. The data showed that there was a significant difference in driving performance between those who completed the driving task and those who did not, which supports this idea that they may have been self-judging. Lastly, examiner bias may also have played a role in this as well. At the time that the driving simulator task was administered, the examiners had already administered the neuropsychological tests. It could be that the examiners, who were not blind to cognitive test scores, made "protective" pre-judgments about the cognitive ability of the participants and therefore were more sympathetic of the participants' complaints or felt that the participant was too frail to continue with the entire task.

In the remainder of this chapter, the findings regarding the study's three specific aims will be summarized. Next, the larger theoretical and practical considerations raised by the study will be considered. Then the additional analyses and possible correlates will be considered. Limitations of the study, and future directions for this research are considered in the final sections of this chapter.

Review of Study Findings

Aim 1

Aim 1 of this study was to verify that under low difficulty conditions, persons with memory impairment show few deficits in lane navigation. It was hypothesized that there would be small-to-null differences between groups. The analyses revealed that the main effect of impairment was only significant when the dependent variable was mean time spent in lane. The impairment main effects for other two dependent variables, absolute mean lane deviation and standard deviation of lane maintenance, were both marginally significant. Follow-up independent samples t-tests (not presented in the Results section due to the lack of significant main effects) of the three dependent variables in the slow difficulty (speed) and low complexity (single-task, no memory task) conditions showed no significant differences between impairment groups. This is likely due to the low overall difficulty of the task and suggests that under short time periods, older adults with memory impairment are able to sustain their attention to complete the task. Of course, although effect sizes were uniformly low, the low sample size in this study also reduced sensitivity to cognitive status effects.

Aim 2

Aim 2 of this study was to confirm that there would be within-person reductions in performance on the lane navigation task as task difficulty (speed) was increased. It was hypothesized that there would be significant differences in performance on the two difficulty levels of the driving-only task. The results supported this hypothesis; there were significant main effects of task difficulty, such that lane deviation was greater and more variable at faster speeds, for each of the three dependent variables, absolute lane deviation, variability in lane deviation, and mean time spent in lane.

Aim 3

Aim 3 of this study was to investigate whether increases in complexity, via dual-task conditions, disproportionately decreased lane navigation ability (i.e., increased lane deviation) in memory impaired individuals; this would have taken the form of dual-task by cognitive impairment interactions. It was hypothesized that all participants would experience reductions in lane navigation ability when under the dual-task conditions, that memory impaired individuals will perform more poorly on the secondary memory task, and that lane navigation performance will be particularly reduced in memory impaired participants. The results revealed that while there were significant main effects of task complexity (single-versus dual-task) for each of the dependent variables under study; the direction of this finding was not as anticipated. Specifically, the participants showed *less* lane deviation in the dual-task condition than in the single-task condition. Furthermore, the interactions for each of the dependent variables were not significant, suggesting that the memory impaired group was not disproportionately impacted by the task complexity.

Theoretical and Practical Considerations

Less lane deviation under dual-task conditions

While the finding that drivers had less deviation under dual-task conditions seemed surprising and could be a paradoxical effect, past research has previously suggested similar effects. Kubose and colleagues (2006) conducted a study examining the differential effects of speech comprehension and speech production on simulated driving. They found that when the secondary task involved speech production, maintenance of lane position was better under the dual-task condition than under the single-task (drive only) condition. However, this finding was not found when the secondary task involved speech comprehension. They concluded that this was the result of the "drivers" recognizing that the driving task was more demanding and therefore allocated more resources to perform the task. Engstrom et al. (2005) report about a meta-analysis conducted on the effect of cognitive load on lane-keeping ability. They indicated that one study (Brookhuis, de Vries, & de Ward, 1991) also found increased lane navigation performance during a mobile-phone conversation. Engstrom et al. (2005) argued that drivers become consciously aware of the increased risk of a concurrent task and subsequently compensate by lowering performance on the secondary task in order to maintain an acceptable level of risk during driving. Correspondingly, we did observe lower memory performance under dual-task conditions, although there was little evidence that memory was progressively reduced with increasing driving challenge (e.g., as participants moved from slow to fast driving). However, a key challenge in most dual-task research, including this study, is that we did not systematically vary the attentional allocation ratios of participants; thus, there may have been individual differences in the proportion of attention allocated to the driving and memory tasks.

This therefore emerged as a possible source of heterogeneity between participants, and may further have added ambiguity to the findings.

As a second possibility about the paradoxical increase in lane navigation proficiency under dual-task conditions, the level of arousal in the participants may also have lead to the finding of increased performance under dual-task conditions. Many studies have confirmed that the level of physical arousal increases with cognitive workload during driving. For example, skin conductance response (SCR) has been related to the traffic environment, such that there have been reports of an increase in SCR amplitude with an increase in traffic density (Michaels, 1962) and increases in the number of traffic lanes (Brown & Huffman, 1972). Furthermore, Zeier (1979) measured SCR with electrodes positioned on the inner side of the left foot (since it is not used in acceleration/deceleration). He compared the effect of three conditions on psychophysiological measures: driving a car with manual transmission, with automatic transmission or being a passenger in a car. Not surprisingly, SCR was greatest while driving the car with manual transmission due to the increased workload. There is one caveat though; in mental workload research, SCR might be useful to assess overall sympathetic nervous system activation level, but movement artifacts are a possible source of noise. This is particularly relevant in car driving where SCR generally is measured on the palm of the hand, while both hands have to be used in steering (De Waard, 1996).

Similar to SCR, arousal effects of mental load have been found for heart rate measures. Zeier (1979) measured heart rate in heavy city traffic while participants drove a car with manual transmission, a car with automatic transmission or were just passengers. Average heart rate differed significantly between the manual-transmission condition and the other two conditions while driving with automatic transmission or riding as a passenger did not lead to a significant difference in heart rate. Fairclough and colleagues (1991) found an effect on HR of car-phone use. Average heart rate while performing a secondary task presented through a hands-free phone was found to be higher compared with the same task presented by an experimenter that accompanied the driver in the passenger seat. The authors give two possible explanations for the effect: either additional effort is required in the phone condition due to lack of cues in conversation, or unfamiliarity with cellular mobile phones aroused the participants. Furthermore, van Winsum et al. (1989) found an effect of mental load on average HR, with driver navigation based on a paper map to be more effortful than navigation by vocal messages by a passenger. Despite the effects of increased workload, studies have shown that the physical demands of different activities of driving are not central to the distraction, but rather it's the increase in mental workload associated with the activities (e.g., talking on phone; Haigney, Taylor & Westerman, 2000; Strayer & Johnston, 2001).

Since research has suggested increased HR and SCR during driving under high workload conditions, it is possible that this increased arousal heightened the participants' awareness of the tasks at hand and became more vigilant to the task of driving. Research has shown that a high level of arousal increases the proportion of resources allocated to the higher priority task in a dual-task paradigm (Matthews & Margetts, 1991). Therefore, if the participants were under heightened arousal during the dual-task condition and considered the driving task to be priority, they allocated all possible resources to performing that task at the expense of the remembering task.

Why were dual-task and driving difficulty effects not greater in the cognitively impaired?

Throughout the analyses in this study, cognitive status essentially never interacted with any of the other study variables. Despite consistent hypotheses that persons with memory impairment would be disproportionately affected by distraction and increased task difficulty, the study did not support this expectation. While there was generally a main effect of impairment (such that amnestic participants performed more poorly, meaning they were less adept at lane navigation), this did not appear to interact with any other factors. One potential explanation for the lack of interaction effect is that the two tasks in the dual-task condition required different (i.e., non-competing) cognitive resources. While the secondary task was chosen to be heavily memory-based, in order to maximize cognitive load in the domain on which amnestic individuals are most impaired (and the results corroborated that the impaired group performed worse on the paragraph recall task than the normal group), the lack of interaction could be due to low interference the secondary task placed on the primary driving task. First, the attention needed to support driving (visuospatial) may have represented a different set of cognitive resources from the attention needed to support memory (verbal/acoustic). Second, the level of challenge in either or both of the driving and memory tasks may not have been adequate to truly challenge the attention allocation system of either healthy control or memory impaired elders.

Warnings about the need to recognize a multiple attention system have a long history. Baddeley (1986) suggested that in dual-task studies, the two tasks should draw upon the same cognitive resources in order to provide the most dual-task interference. Studies have found that the dual-task costs are reduced significantly when using two relatively simple tasks that are processed via different perceptual modalities, nonetheless one study has shown significant dual-task costs differences between cognitively healthy and impaired older adults when using tasks processed with separate resources (visual-manual and auditory-verbal; Holtzer, Burright, & Donovick, 2004). This finding led this research group to believe that “the ability to execute concomitantly two competing tasks may be sensitive to subtle changes in cognitive status in aging,” (Holtzer, Burright, & Donovick, 2004, pp. 236). Lindenberger, Marsiske & Baltes

(2000) also reported that when walking and simple list recall were done concurrently, both tasks interfered with one another (walking was slowed, and memory performance was reduced), and that this effect was disproportionately greater in older adults than in younger adults. There is a rapidly growing literature on dual-task effects in posture/locomotion and many different cognitive tests (e.g., Kerr, Condon, & McDonald, 1985; Woollacott & Shumway-Cook, 2002; Maylor & Wing, 1996; Weeks et al., 2003), which suggest that cross-modality dual-task effects may often occur. Indeed, the growing literature on the effects of cell phones on driving (Engstrom, Johansson, & Ostlund, 2005) strongly suggested to us that we would find negative dual-task effects in this study. The counterintuitive effects obtained (lane navigation was better with divided attention) suggests that the specific tasks chosen for this study, and their specific levels of difficulty, may need to have been better calibrated for this population. On the more positive side, the absence of strong negative dual-task effects and disproportionately negative effects for the memory impaired lends further credence to the literature that suggests that memory impairment, at least in its early stages, may not be a strong risk factor for driving (Withaar, Brouwer, & van Zomeren, 2000; Reger et al., 2004).

Another possible reason for the lack of interaction effects, such that memory impaired individuals were not disproportionately worsened in lane navigation by increases in speed or dual-task load, might have been due to the increased level of participant partial-completion in the memory impaired group (i.e., discontinuation of performance due simulator sickness or unwillingness to continue). This means that the aggregate reliability of the dual-task data may have been poorer for the memory impaired participants. Because of partial completion, the data for one-third of the memory impaired group was based on fewer trials (usually three instead of six dual-task trials), and likely had lower reliability. It is important to note though that 23% of the healthy control group also did not complete the full dual-task protocol, but given the larger numbers of participants, means for this group were more reliably estimated. As an attenuating factor, since the number of behavioral samples was extremely large (10 datapoints per second), the psychometric reliability of the means in each condition was likely very large.

Still another explanation for the lack of disproportionately poorer performance (under dual-task or faster driving conditions) for the memory impaired participants may relate to the *focal* nature of early cognitive impairment. The amnestically impaired group could still be expected to have relatively spared attentional abilities, and the secondary task may not have been optimal to reveal any subtle changes in attentional capacity during the driving lane maintenance task. It may be that despite the poorer memory performance of the impaired participants, the "limiting variable" in the dual-task condition was attention, and this was still quite intact in most memory impaired participants. As mentioned in the introduction, mild cognitive impairment, which represented a significant portion of the memory impaired group, usually involves mild focal impairments, yet with attention being spared until later points of progression in cognitive status, such as developing dementia. While there are changes in attention with normal aging, it would be expected that all of the participants would have had some decline in attention ability from earlier in life; however, this relatively general cognitive loss would not predict disproportionately poorer performance in our amnestically impaired participants.

Was the superior lane navigation under dual-task conditions a practice effect?

The results of the analyses examining possible practice effects in the driving task revealed that there were not significant practice effects. Specifically, lane navigation was poorer in fast conditions, better in slow conditions, and this was true across the duration of the study. The only major factor that seemed to predict better lane navigation was the trial that occurred after a five minute break. This trial (which was under fast conditions) showed significantly better lane navigation that the other 60 mph trials in the study.

Of course, this post-hoc analysis highlights a larger challenge in the study design: the dual-task always came after the single-task. This was a pragmatic decision, made in the service of having participants be comfortable in the primary task (driving) before the secondary task was introduced. We were trying to avoid spurious “dual-task” effects that were really the effect of task novelty (e.g., suddenly being asked to drive and remember without any prior exposure to either of the subtasks).

Looking more closely at each of the six study trials (Trials 1, 3 and 5 represented 30 mph trials, where the first half was spent in single-task driving and the second half was spent in dual-task driving; Trials 2, 4 and 6 represented 60 mph trials, where the first half was spent in single-task driving and the second half was spent in dual-task driving), pairwise comparisons were conducted between each of the pairs of trials within slow or fast driving conditions. Examining these pairwise comparisons revealed that the only pair of trials of the same difficulty level with significant differences was the fast speed Trials 2 and 4. Trial 4 showed less deviation than Trial 2, but again by Trial 6 the deviation was increased.

When participants dropped out due to simulator sickness or fatigue (and this was mainly the impaired participants), they typically dropped out after Trial 3 (which was followed by a break). Thus, the data for Trials 4-6 were disproportionately provided by healthy control older adults. Perhaps those that could tolerate the task were also better at the task than those who had difficulties with the motion. Another explanation of the finding is that Trial 4 always came after a scheduled five-minute break. The significant improvement in lane navigation in Trial 4 may then have reflected the benefits of “rested” performance.

Effect of type of memory phase on driving

We also examined whether the effect of a concurrent memory task on driving varied with the phase of the memory task (e.g., listening, rehearsal, recall). The analyses examining the effect on driving during different memory conditions showed again that participants had less deviation in the dual-task conditions than in single-task. Of note is that the most deviation in both groups took place post-recall (i.e., return to a single task condition after the recall task has been completed). It could be that this reflects a “release from heightened arousal” that had occurred during the memory task, and with this release came a general relaxation/inattention/loss of vigilance, which yielded its effects in poorer lane navigation. Another potential explanation for the V-shaped finding in the memory phase analyses could be that the early phases (where driving got better) was a “practice” effect, whereas the later phases (where driving got worse) was a “fatigue” effect.

Consistently, participants also showed the least amount of deviation in their lane navigation performance during the rehearsal phase (after they had heard the story, but before they had to remember it, a period of about 35 seconds) than the recalling phase. During this phase, participants were both trying to rehearse and consolidate story details, as well as anticipate the forthcoming recall trial. This finding was unexpected because previous research suggests that encoding is more susceptible to interference by a secondary task than retrieval (Kubose et al., 2006). There was no way to determine whether participants were, in fact, rehearsing during the silent driving period after the paragraph had been presented. One question was whether participants should have been asked to rehearse out loud. A concern, however, is that if participants were asked for vocal rehearsal, it might have confounded rehearsal costs with speech production costs. On the other hand, there was little evidence that speech production actually had costs for driving. In the recall phase, when participants had to produce their recalled paragraphs, there was no evidence of worsened lane navigation.

One caveat concerning the finding that the most deviation occurred post-recall must also be noted: The post-recall condition usually required substantially less time (often 20 seconds) than the driving task (usually 120 seconds) and therefore the post-recall mean is based on fewer datapoints than in the other conditions in the analysis. Thus, the post-recall phase may have had less reliable data.

Story Recall Performance

We also examined dual-task effects on the secondary (paragraph recall) task. We compared experimental condition (single-task, no driving; dual-task, 30 mph; dual-task, 60 mph), and we compared memory impaired and healthy control participant groups. The effect on story recall of study conditions was as expected. The participants remembered the most under the single-task condition than under slow speed and fast speed dual-task conditions. Also, there was a main effect of impairment with the memory impaired group performing worse than the healthy control group. This finding was as expected and believed to be a possible explanation for why participants performed the lane navigation task better under dual-task: they likely disregarded the recall task in an effort to maintain their driving ability.

Correlation analysis examining if the lane navigation task and story recall task were competing for the same attentional resources indicated that there was no significant relationship between change scores of the two tasks. This finding could mean several things. First, there could be no tradeoff because the tasks were cross modality and therefore not competing for the same resources or the tasks could not have been challenging enough to cause interference. Second, this finding could mean that there were individual differences in tradeoff. In other words, some participants delegated more of their attention to the lane navigation task while others allocated their resources to the story recall task. The finding that the lane navigation difference scores were related to each other and the story recall difference scores were also only related to each other supports this hypothesis. There was within-person systematicity in the difference scores. The last potential explanation for the lack of relationship between difference scores could be that there was not enough power to adequately detect a tradeoff due to the low reliability of difference scores.

The use of other types of memory tasks might have resulted in different findings. A visual memory task, which would have been within the same modality as the driving task might have resulted in stronger dual-task costs. For example, while completing the lane navigation task, participants could have been instructed to view "billboards" displayed on the side of the road and have been asked to remember their contents for later recall. As another possibility, recall of target objects in the roadside scenes could have been another kind of visual recall task. This type of task, as well as the lane navigation, would have both required visual attention and thus may have provided more interference than the listening task the participants engaged in during the present study. However, one concern with using a visual secondary task is that then both tasks would have competed for both visual (perceptual) resources and visual attentional resources, so it would have been less clear where the locus of interference was. Moreover, the growing body of cell phone research suggests that even when one task is verbal (cell phone) and one is visuospatial (driving), there is dual task interference. Thus, we continue to believe that insufficient levels of challenge in the lane navigation and/or memory task are probably the principal basis for the lack of expected findings in this study.

Possible Correlates of Single and Dual-Task Lane Navigation Performance

Correlations were conducted to determine what cognitive and physical measures may have correlated with the lane navigation dependent variables, with the hypothesis that attentional variables would be particularly predictive of driving under dual-task conditions since dual-task should demand more attentional resources. Examination of correlation tables showed that, overall, the lane navigation simulated driving variables were particularly related to accuracy on a number cancellation task, as well as to the main three subtests of the UFOV that measures visual attention ability. These results suggest that the more accurate the participants were at the number cancellation task, the more accurate they were in the lane navigation task as well (i.e., less lane deviation, less variability in lane deviation, and more time spent in lane). The other finding suggests that the participants with more lane deviation, more variability, and less time in lane also required longer amounts of time to correctly identify targets and divide their attention in the visual processing task. This finding may be an extension to prior work, which has suggested that the UFOV task can significantly predict crashes in older adults (Owsley et al, 1991). Interestingly, none of the lane navigation variables were related to participants' self-rated everyday attention ability.

The correlation tables also illustrate that performance in the dual-task conditions of the driving task and performance on attentional measures are lower, and often disappear, than the relationships under single-task conditions. This was somewhat counterintuitive, because we had expected that attention would be a more important predictor of driving under divided attention conditions. This further suggests that Baddeley's (1986) conception of multiple attention systems has some relevance here, and that overly simplistic conceptions of attention as a global resource, predictive of driving under divided attention conditions, are unlikely to be useful. We also cannot rule out that our choice of the measures chosen to represent the various attentional abilities of interest (selective attention, visual divided attention, auditory working memory) may not have been ideal for the criterion tasks in this study. Alternatively, dual-task performance could be subserved by topographically different attentional mechanisms than those of the tasks administered.

Similar patterns were found when examining the correlations of the paragraph recall performance during single task, slow speed dual-task, and high speed dual-task with the same cognitive and physical measures. Greater accuracy in the number cancellation task was associated with higher recall of the paragraphs. Also, higher recall of the paragraphs was related to lower (better) speed on the visual processing task. No relationship was found between the paragraph recall and the participants' self-rated everyday attention ability.

Limitations of this Study

Of course, no study is without limitations, and this applies to the current investigation as well. A number of pragmatic and resource constraints were present in this study, and these may have introduced several alternative explanations for some of the study findings. The first limitation of the present study was the sample itself. The participants were highly selected and consisted mainly of Caucasian, healthy, highly educated elders, which is not representative of the general elder population in the United States. Despite the limitations, the sample in this study is similar to that of most cognitive aging studies in the literature.

It should be noted that 24.6% of the sample was assigned to the memory impaired group, which is higher than the rate of AMCI alone in the general population of this age group (1-2%; Petersen et al., 1999). This likely resulted from the recruitment technique of specifically stating that the study was recruiting older adults with or without memory problems as well as those already with a diagnosis of dementia. It would have been ideal to be able to examine a trichotomy of groups (normal, AMCI, and dementia), which was the original proposal. Due to a lack of resources and infrastructure for the recruitment of memory impaired individuals, and not presumed to be a lack of older adults with these conditions, it was very difficult to recruit older adults with memory complaints and/or memory problems. It would have been ideal to have had longer-standing relationships with several parties (e.g., primary care offices, geriatric practices, continuing care communities, retirement communities, and assisted living facilities) prior to beginning the study to aid in the recruitment of memory impaired older adults rather than try to establish these relationships during the study. We did attempt recruitments in each of these settings, but the rate of consecutive recruitment was too low to provide adequate numbers of impaired persons for this study.

A second limitation of the study is the absence of a medical or neurological examination to rule out other potential causes of memory problems, such as a vitamin B deficiency or untreated hypothyroidism (Petersen et al., 1999). Without such examinations, it cannot be certain that the memory problems displayed by the impaired participants are caused solely by a degenerative brain disorder. While this study did not endeavor to medically diagnose AMCI or dementia, the best possible situation for doing so would have been a neurological examination of frontal release signs and reflexes and a thorough laboratory workup to rule out other potential causes of memory impairment. Thus, to the extent that the memory problems seen in this study might represent more reversible or transitory conditions, this could have attenuated the group differences and be a potential cause for some null findings.

With regard to the driving task, while there was great between-person experimental control, the ecological validity of the task used in the study is questionable. In this task, participants were not able to control speed (thus, they were not able to slow down at curves), and this lack of driver control over speed clearly reduced the ecological validity of the task. Also, given the relatively high proportion of participants who did not complete all six driving trials in this study (especially in the impaired group), the simulated driving task may have been too lengthy for this population. While an effort was made in the design to simulate a sustained attention task, therefore requiring the task to be long enough to measure sustained ability, many participants complained about the length of the task, possibly due to its perceived difficulty. While each participant was given a break between segments to reduce fatigue, it is unclear how fatigue might have affected study results. If, for example, participants in both groups were increasingly fatigued during the study, this could have attenuated some of the expected cognitive status interactions with dual-task and driving difficulty conditions. Given the resources and time, it would have been ideal to pilot the task with several older adults to look at their data and compile their feedback about the task before beginning the study. Also, it may have been helpful, given the funds, to use motion sickness bracelets (an FDA-approved acupressure technique) to reduce the amount of complaints about dizziness so that more participants would have had complete data.

Another limitation of the driving task pertains to the instructions given to participants. The instructions did not include which task, the driving task or the secondary remembering task, should have been prioritized. Therefore, participants used their own judgment about which task to attend to more. There is research in the dual-task literature that suggests that directions given influence task performance (Kramer, Larish & Strayer, 1995). Additional work in the area of dual-task prioritization has shown that task prioritization or goal selection is intact in individuals with mild AD (Rapp, Krampe, & Baltes, 2006). It could be possible that the lack of direction given to participants in the current study resulted in individual difference in resource allocation during the dual-task conditions, thus increasing the amount of noise in the data. Future work should investigate if different task priorities using this study's measures yield different results.

Lastly, there are some questions that have not been answered by this study. No attempt was made to use the neuropsychological tasks as potential predictors or correlates of the driving tasks. This was not done because of the potential circularity of the findings since the neuropsychological task performance was used in the consensus procedure to classify participants. Additionally, none of the neuropsychological tests administered to participants measured susceptibility to interference (e.g., the Stroop task), which might have helped to better understand which participants would be more likely to experience performance losses under the dual-task conditions. Other possible predictors of driving behavior were not explored as well: the average number of miles driven, whether the participants were current drivers (since the exclusion criteria was that the participants had to have driven within the last two years), the number of crashes or times pulled over by police was not systematically collected. The study also did not require participants to give out their drivers' license number to obtain official records from the Department of Motor Vehicles. While some of this data has been collected, it was not a major aim of the study and will be reserved for future work and analyses.

Future Directions

Future work in this area seems necessary due to the aging of the population and the potential for lack of insight into driving ability in those with cognitive impairment. Based on the findings and limitations of this study, future work should endeavor to recruit larger samples of older adults with different memory impairment conditions in order to replicate group differences. It would also be important to explore if there are different types of driving errors or performance decrements with the different degenerative conditions.

Because of the possible lack of interactions due to the tasks using different cognitive resources, future work should investigate dual-task conditions that use the same processing resources (i.e., both involve heavily demanding visual tracking) and/or to manipulate the priority of tasks to better understand competition for attentional resources. A comparison between such same processing resource dual-task with one similar to that of the current study that relied on different processing resources might provide more information about the effects of multi-tasking during driving. However, recent legislation has led to greater standards about completing two manual tasks while driving (e.g., it is illegal to talk on hand-held cell phone in some jurisdictions), so the ecological validity of completing such a study may be in question.

Lastly, it is important to identify the possible benefits of using cognitive-enhancing medications on driving in older adults with cognitive impairment. Since this data has been collected, future analyses are planned to examine this. However, a larger sample of cognitively impaired individuals will likely need recruited in order to increase the power to detect group differences, including a large number not taking such medications. An alternative to this method would be to find older adults with cognitive impairment that are not taking cognitive enhancing medications and conduct a clinical trial to place half of the participants on such a medication to determine their effect on driving ability and dual-task performance.

Conclusion

In conclusion, this study manipulated difficulty (slow versus fast speed) and complexity (single versus dual-task) in a simulated lane navigation driving situation, and investigated whether performance decreases disproportionately in those with memory impairment. The results confirmed our hypothesis that participants' performance would decrease as the difficulty (speed) increased. On the other hand, our hypothesis that increasing task complexity (dual-task) would decrease performance was not supported. The opposite was true; participants' lane navigation performance increased under dual-task conditions. Further analysis showed that the secondary task, a paragraph recall task, did decline under dual-task conditions. Thus, participants became more vigilant to the driving task, possibly due to an increased level of arousal, while compromising their performance on the secondary task. Interestingly, our hypothesis that participants with memory impairment would be disproportionately worse in the dual-task conditions was not supported with an interaction in either the primary driving task or the secondary paragraph recall task. In both cases, while the memory impaired participants generally performed more poorly, they were not disproportionately affected by the addition of a secondary task. The major limitation of the study was a small sample size and limited range of memory impairment, which led to low power to detect group differences.

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BIOGRAPHICAL SKETCH

Sarah Cook graduated from the University of Pittsburgh with a bachelor's degree in psychology. She then spent 2 years working as a research associate at the Alzheimer Disease Research Center at the University of Pittsburgh. Ms. Cook earned a masters degree in clinical and health psychology at the University of Florida in 2004 and then began her doctoral studies in the same program. She concluded her doctoral training with an internship at the James A. Haley Veteran's Medical Center in Tampa, FL. After internship, Ms. Cook plans on pursuing a neuropsychology post-doctoral position.