The Relationship of Executive Functions to Performance in a Driving Simulator in Healthy Older Adults

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Abstract

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The Relationship of Executive Functions to Performance in a Driving Simulator in Healthy Older Adults

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Driving safety among older adults is an issue of increasing public concern, given the continued aging of the general US population. A growing number of studies in recent years have focused on identifying cognitive predictors of driving performance in healthy older adults, and some researchers have called attention to the importance of executive function in particular for predicting older driver proficiency. The present study utilized a principal component analysis approach in order to test the incremental value of multiple executive components for simulated driving in a sample of community-dwelling adults over the age of 60, in the context of other cognitive measures of visuoperception and memory. Whereas a Shifting/Inhibition Component and a Visual Attentional Control component provided additional predictive validity beyond a measure of visuoconstruction (BD), a Working Memory/Updating component was not significantly related to driving parameters in our sample. Implications for screening, assessment, and training of older drivers are discussed.

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Introduction

Driving and Cognition in Healthy Older Adults

By 2020, over 39 million adults over the age of 65 in the United States will be active drivers (US Census Bureau). Access to transportation has implications for one's sense of independence, and consequently for physical and mental health in older adults in particular (Edwards et al., 2009; Ragland et al., 2005). Nevertheless, in the event of motor vehicle crashes older persons are at a higher risk of morbidity and mortality, due to both fragility and increased crash involvement per mile driven, though the latter is still subject to debate (Li, Braver, & Chen, 2003; see Langford, Methorst, & Hakamies-Blomqvist, 2006). Whereas crashes with younger at-fault drivers are more likely to be related to driving violations and risky behaviors, perceptual and cognitive errors are more often implicated when older drivers are at fault (McGwin & Brown, 1999). In a study featuring a closed-off driving course with older and middle-aged adults, researchers showed that older drivers committed approximately 29% more safety driving errors related to cognition as compared to their younger counterparts, and each 10%-decrease in cognitive battery score accounted for an approximate 10% increase in older drivers' safety errors (Dawson, Uc, Anderson, Johnson, and Rizzo, 2010).

Driving is a complex activity that requires the rapid coordination of sensory, motor, and cognitive abilities. Given that normative aging is shown to bring on declines in processing speed, fluid intelligence, and executive abilities, among others (Salthouse, 2010), it is important to identify the role of age-related changes in cognition for driving ability in older adults (Bieliauskas, 2005). Better understanding of which cognitive factors may be involved in driving safety can have a two-fold benefit: a) allowing for the implementation of efficacious cognitive screening measures to distinguish between safe and unsafe older drivers and b) designing interventions and adaptive devices to allow healthy older drivers with selective, rather than global cognitive deficits to safely remain active.

Much headway has been made into examining the significance of decrements in cognition for driving proficiency in older adults (Mathias & Lucas, 2009). Select findings are highlighted below, but the reader is directed to Table 21 (Appendix A) for a more comprehensive review of investigations to date. Mounting evidence points to the importance of intact visual scanning/visuospatial function (De Raedt & Ponjaert-Kristoffersen, 2001), selective and divided attention (Adrian, Postal, Moessinger, Rascle, & Charles, 2011; Daigneault, Joly, & Frigon, 2002), and speed of information processing (Shanmugaratnam, Kass, & Arruda, 2010; Stutts, Stewart, & Martell, 1998) in older drivers. Whereas earlier studies examined the now established link between global cognitive function and driving proficiency in neurologically compromised individuals (such as in dementia or Mild Cognitive Impairment (MCI)) (see Iverson, Gronseth, Reger, Classen, Dubinsky, & Rizzo, 2010), more recent research has shifted its focus to individual differences present in community-dwelling older adults. Cognitive tests have been shown to be more effective at identifying unsafe elderly drivers relative to age or sensory measures alone (Munro et al., 2010; Stav, Justiss, McCarthy, Mann, & Lanford, 2008), and have demonstrated good sensitivity and specificity in predicting crash history and outcomes of on-road driving tests.

Batteries of cognitive tests have also successfully distinguished between safe and unsafe older drivers in discriminant analyses. Driving safety or proficiency is operationalized in a variety of ways, including presence of at-fault crashes, performance in an on-road driving test, as well as performance in a driving simulator (Anstey, Wood, Lord, & Walker, 2005), with the latter design represented in relatively fewer investigations to date. In one such study, a combination of visuoconstructive and memory measures successfully distinguished between crash-involved older drivers (aged 65 and above) and matched controls with a hit rate of 74% (Lundberg, Hakamies-Blomqvist, Almkvist, & Johansson, 1998). In another, De Raedt and Ponjaert-Kristoffersen (2001) successfully predicted the outcome of an on-road test in older drivers (age range 65-94) with an overall hit ratio of 83% based on performance on a brief cognitive battery.

Although the above classification rates are promising, the inconsistency that exists across studies with regard to specific cognitive measures and findings is of concern (Zook, Bennett, & Lane, 2009). Indeed, a recent meta-analysis of driving and cognition in older adults (Mathias & Lucas, 2009) determined that an assortment of 75 different cognitive tests and subtests were used across 21 separate investigations, with many tests used in only one of the studies. Not surprisingly, this broad assortment of measures varied greatly in their ability to predict driving outcomes, regardless of how it was operationalized (Cohen's *d*-s from 0.04 to 2.14). Furthermore, when separated by type of outcome criterion (i.e., on-road test, history of crashes or performance in a simulator), separate cognitive measures emerged as best predictors. The only instrument utilized across all outcome variable modalities was the Useful Field of View (Visual Awareness Research Group, 2009), likely due to its predictive ability independent of outcome measures. For more detail on specific findings in studies using driving history and on-road tests, please refer to Appendix A. Across the three studies utilizing a driving simulator, there was no overlap amongst the administered cognitive tests, but most significant findings were documented with executive function, visual attention and processing speed assessments (Useful Field of View Divided and Selective Attention, Driver Scan) and visuoperceptual/visuoconstruction skills (Benton Line Orientation Test, Clock Drawing Test). Overall, several *domains* showed medium to large effect sizes and have been replicated in other investigations of driving fitness and cognition in aging individuals, to include attention functions (Baldock et al., 2007; Richardson & Marotolli, 2003), visuoperceptual abilities (De Raedt & Ponjaert-Kristoffersen, 2001; Zook et al., 2009), and processing speed (Shanmugaratnam et al., 2010; Stutts et al., 1998), with memory remaining a tenuous predictive variable. This may be due to the fact that memory was most often assessed in individuals with suspected or known cognitive impairment and dementia (Anstey et al., 2005). Given that not all prior research has controlled for pre-existing MCI or dementia and has sometimes used screeners with poor sensitivity (i.e., the Mini Mental State Examination; Folstein, Folstein, & McHugh, 1975), the significance of memory abilities in healthy older adults remains to be determined.

Executive Function and Driving Proficiency in Older Adults

Although prior studies have revealed significant relationships between other cognitive abilities and driving performance in older adults, a considerable portion of the variance in driving proficiency in this population remains unexplained. Therefore, recent research has called for further investigation of EF as a component that may add to the predictive capacity of a cognitive screening in older drivers (e.g., Diagneault et al., 2002; Zook et al., 2009) and that has been identified as vulnerable to the effects of normal and abnormal aging (Salthouse, Atkinson, & Berish, 2003). In addition, though a few driving studies have attempted to delineate the relative importance of certain EF subdomains (e.g., Adrian, Postal, Moessinger, Rascle, & Charles, 2011; Backs, Tuttle, Conley, & Cassavaugh, 2012), most contemporary investigations only include a single measure of EF. Even so, the preliminary findings are promising.

Executive abilities are comprised of a system of interrelated functions, which are responsible for goal-directed behavior, and have been historically characterized as a "central executive," which controls, organizes, and directs cognitive activity, emotional responses and behavior (Baddeley, 1986). Although multiple theoretical models of EF exist with regard to its comprising components, certain facets can be traced across models, including: (1) inhibition or resistance to interference; (2) working memory; (3) mental flexibility and set-shifting; and (4) attentional control, among others (Fournier-Vicente, Larigauderie, & Gaonach, 2008; Royall et al., 2002).

Furthermore, researchers have suggested that executive control is instrumental in helping carry out other cognitive process in that it is involved in organizing, coordinating, and scheduling cognitive operations, as well as for dividing, shifting, and inhibiting attention (Miyake et al., 2000; Stuss, Shallice, Alexander, & Picton, 1995). Some have criticized the existing body of literature in that if the former postulate were true, executive measures should relate to each other more strongly than to individual cognitive abilities, but that insufficient empirical evidence exists in support of this hypothesis (Salthouse 2003, 2005). One set of findings refuting Salthouse's argument concern the relative sizes of relationships of EF with measures of intelligence relative to the size of relationships of EF with other EF components. Miyake et al. (2000) reported factor loadings among the shifting, inhibition, and working memory components, ranging from .42 to .63, suggesting consistency within the multifaceted construct of EF. In contrast, a different research team found correlations between executive tests and visuoconstructive or processing speed subtests from contemporary intelligence measures ranging from .00 to .37 (Ardila, Pineda, & Rosseli, 2000). Therefore, it is reasonable to suggest that EF accounts for additional variance in driving, beyond that accounted for by visuoperceptual and processing speed measures.

Thus, given its complex and multifaceted nature, EF is thought to facilitate one's adaptation to a changing environment or circumstances. At the same time, the nature of driving errors in older individuals suggest that they may arise from difficulties in tracking and anticipating moment-to-moment changes and responding appropriately, due to perceptual or executive/attentional changes (Shanmugaratnam et al., 2010). Further, driving errors made by older individuals are said to be distinct from those seen in their younger counterparts in that they are not attributable to risk-taking or to inexperience, but rather, related to decrements in executive control. This is suggested by the nature and circumstances under which such errors occur, often leading to at-fault motor vehicle crashes. Common environmental conditions associated with at-fault crashes for older drivers include in busy intersections, when required to yield the right-of-way, when making judgments about gap acceptance in heavy traffic, and during unprotected left turns (McGwin & Brown, 1999), all situations that place demands on EF, among other cognitive functions. For example, Anstey and Wood (2005) demonstrated that older drivers tended to make errors associated with speeded selective attention, task switching, inhibition of responses, and visual discrimination. Stinchcombe, Gagmon, Zhang, Mentembeault, and Bedard (2011) found that in a simulated environment, older individuals exhibited the greatest amount of attentional demand in response to more challenging driving situations, relative to all other age groups, even after controlling for baseline reaction time. In addition, older drivers made more errors as evaluated by trained observers who examined the simulator footage. One can thus conclude that older drivers' cognitive resources are disproportionately taxed by complex environmental demands and it is under such circumstances when EF may serve a critical role in allowing older adults to compensate for declining processing speed and other cognitive abilities. Therefore, EF bears further study as a predictor of driving performance in healthy older adult populations (Bieliauskas, 2005).

Executive skills are also among those cognitive functions that decline substantially in normative aging, thus becoming more relevant to aging drivers. Specifically, it is suggested that changes occur both in white and grey matter within frontal areas, which are more susceptible to decline than other portions of the neocortex (Bartzokis, 2004; Raz et al., 1997). Corresponding functional declines in executive processes have been documented in planning, inhibition, and set-shifting, among others (for review, see Drag & Bieliauskas, 2009).

Finally, the "aging" of EF is associated with instrumental functional decline in older adults with respect to activities such as household tasks, medication management, and financial management. Classic findings confirmed that amongst a set of other cognitive skills, including memory and visuospatial abilities, executive functions were most strongly associated with functional abilities and remained significant predictors even after controlling for sex, age, and education in community-dwelling samples (Bell-

McGinty, Podell, Franzen, Baird & Williams, 2002; Johnson, Lui, & Yaffe, 2007). Most recently, longitudinal changes in executive skills were also shown to mirror changes in daily functional status among a group of older adults with varying levels of cognitive functioning followed for an average of 5 years (Tomaszewski- Farias et al., 2009). These findings suggest that executive abilities may be relevant to additional complex real-word abilities, such as driving.

One of the theoretical models of EF suggested to best capture the potential executive components important for driving proficiency in older adults (Bieliauskas, 2005; Diagneault et al., 2002) is the Supervisory Attention System (SAS; Norman & Shallice, 1986), responsible for governing effortful/controlled as opposed to automated behaviors (Cooper & Shallice, 2000). An expanded SAS model accounts for multiple independent supervisory processes, which parallel facets often derived in the literature, such as inhibition, working memory, and set shifting and was described as including the funciton of attentional control (Stuss, Shallice, Alexander, & Picton, 1995). Similarly to SAS, hierarchical driving theories in the ergonomic literature are based on consideration of the distinction between automated and effortful processes in driving behavior and include three levels of driving behaviors, namely a) strategic, b) tactical/maneuvering, and c) operational (i.e., vehicle control), with the tactical/maneuvering level being the closest parallel to controlled or effortful executive processing (Michon, 1985). Both the SAS and hierarchical cognitive models of driving behavior also base the distinction between levels of processing on the level of complexity, novelty or hazard associated with the driving environment. Of note, these characteristics may vary depending on the age and experience of the individual driver.

To date, few investigations have included a comprehensive evaluation of EF as a predictor of older individuals' driving abilities (e.g., Daigneault et al., 2002; de Raedt & Ponjaert-Kristoffersen, 2001; Zook et al., 2009), with most studies including a single EF component within a larger cognitive battery. Similarly to investigations of other cognitive skills, the EF measures used vary broadly across studies, partly due to lack of firm theoretical guidance. The most commonly used instruments in the Mathias and Lucas' meta-analysis were the Trail Making Test B, which is thought to tap working memory and set shifting (Strauss, Sherman, & Spreen, 2006) (*d*-s ranged from 0.14 to 1.18) and the Useful Field of View, Selective and Divided Attention (2 and 3) subtests, measures of visual attentional control, which fall in the domain of some operationalizations of EF (Stuss & Alexander, 2000; Stuss, Shallice, Alexander, & Picton, 1995) (*d*-s ranged from 0.08 to 1.76). Other classic executive measures, such as the Stroop Word Color Test (d = 1.01) and the Wisconsin Card Sort Test (d = 0.52) were represented less often.

Few driving studies represent systematic examinations of multiple executive components, such as in the case of de Raedt and Ponjaert-Kristoffersen (2000, 2001). The authors report significant corrected bivariate correlations between executive test performance and driving ability on an on-road test, including working memory (r=0.42), selective (r=-0.44) and divided attention (r=-0.39), cognitive flexibility (shifting) (r=-0.55) and inhibition (r=-0.36) tasks; further, working memory (r= -0.33), selective and divided attention (Useful Field of View; r=0.32), and cognitive flexibility (shifting) (r= 0.36) were also related to history of motor vehicle crashes. In another study regarding EF and driving performance, Mantyla, Karlsson, and Marklund (2009) administered a selection of EF measures to a sample of younger, novice drivers (ages 16-19) and used principal component analysis to extract 3 theoretically-guided components, namely Inhibition, Shifting, and Working Memory Updating. The Updating component emerged as the only predictor of driving performance in their teenage – young adult sample. In contrast, Adrian and colleagues (2011) investigated the contribution of executive ability to on-road test performance in healthy drivers older than 60 years. Within their sample, driving performance was associated with the Shifting (Trail Making Test B minus A, r = 0.27 and a Plus-minus task, r = 0.26), and Updating (Operation span task, r = 0.30) components.

Notably, recent investigations have called for incorporating a more detailed level of analysis with respect to the precise role of certain components of EF in older driver safety (Cuenen et al., 2012; Daigneault et al., 2002; Shanmugaratnam et al., 2010; Zook et al., 2009). This is necessary given the heterogeneous neuroanatomical correlates of separate executive components and proposed corresponding differences in the rate of age-related changes, though a more detailed discussion is outside of the scope of the present paper (see Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004 for a review). In addition, a more precise analysis may be beneficial in creating screening measures with greater sensitivity and specificity among healthy older drivers, as well as allowing for targeted interventions for older drivers with selective impairments (Lees, Cosman, Lee, Fricke, & Rizzo, 2010). A clear understanding of the relative contribution of EF as compared to other cognitive abilities will further be beneficial in designing the most efficacious driving remediation and accommodations for older adults with focal deficits.

The Present Study

In light of the literature reviewed above, the purpose of the present study was to offer an investigation of specific cognitive predictors of driving performance, with a particular focus on EF as an under-explored, but promising set of predictors. Utilizing measure selection by balancing representation of theoretical EF components with individual instruments with best empirical findings, in addition to other empirically supported non-EF neuropsychological measures, we examined specific effects of cognition on driving performance within a high- fidelity driving simulator. Finally, we explored in more detail which specific driving parameters may be best predicted by cognitive and executive variables (Cuenen et al., 2012).

The present study improved upon prior research by: 1) introducing multiple executive measures thought to tap distinct executive components; 2) utilizing a theoretically driven data reduction method for EF; 3) testing the incremental validity of EF as a predictor of driving functioning beyond other cognitive domains; 4) screening out individuals with suspected dementia; and 5) assessing driving ability in a high-fidelity simulator allowing for improved control over the demands of the driving environment.

First, we hypothesized that better performance on measures of cognitive abilities, including visuospatial/constructional skills, speed of information processing, and visual memory would be associated with superior driving ability measured within the simulator, consistent with previous findings in the literature. Secondly, we hypothesized that better performance across EF components extracted via a principal component analysis would be associated with better driving performance in healthy older adults, above and beyond other cognitive skills, such as visuoperceptual skills and visual memory.

In addition to these hypotheses, we explored whether specific measures of visuospatial/constructional skills would be associated with particular driving parameters requiring mostly automated processing (Norman & Shallice, 1986) versus skill-based/tactical driving behaviors (Rasmussen, 1987), including lane deviation and speed maintenance, and whether measures of EF would be most associated with specific controlled driving abilities, consistent with demands on higher order cognitive processes and controlled processing (Norman & Shallice, 1986), including lane changing performance, successful navigation of freeway entry and exit, management of unanticipated driving conditions (e.g., road work), and successful navigation of turns.

Method

Participants

Participants were healthy, community-dwelling, older adults residing in a small Midwestern town and its surrounding area. A portion of these individuals were recruited from a pool of participants in previous studies at the neuropsychology laboratory at a Midwestern. The remaining participants were recruited into the study based on response to fliers distributed within the community, via word of mouth, and ads placed in a local newspaper (see copy of newspaper ad used in Appendix B). The final sample included 111 individuals (65 female, 46 male), between 60 and 88 years old (M = 68.41, SD = 7.06). Participants self-identified predominantly as Caucasian (n=105), with few representatives of other ethnic backgrounds, including African American (n = 1) and Asian (n = 1); four participants chose not to report their race/ethnic background. The sample was well-educated, with only two individuals reporting less than 12 years of education (M = 16.43, SD = 3.28). With regard to driving history, individuals who provided full background driving data (79 of the 111) were experienced drivers (M of total years driving = 50.7, SD = 7.5; min = 39, max = 72). All were active drivers in the past two years at the time of their participation in the study. More specifically, 88% reported driving daily, 9.1% stated they were weekly drivers, and less than 2% drove monthly or less frequently. When asked whether they have modified their driving, 55.6% reported using some type of restrictions, most often comprised of limiting their driving at night. Participants reported driving in a variety of settings, including city roads, rural roads, highways and freeways and limited exposure was noted only in the case of long trips with 31.6% indicating that they never or rarely drove on trips that took longer than

2.5 hours in one direction. The majority of the sample reported no driving incidents (including crashes) or violations in the last year (62.8%), with 5% indicating that they were involved in a motor vehicle crash in the past year, 28% describing near-misses, and 10% admitting to having backed into an object in the past year. Only 6.4% self-reported a traffic violation.

A total of 111 individuals comprised the final study sample[1]. Inclusion criteria were as follows: 1) 60 years of age or older; 2) possession of a valid driver's license; and 3) active driver within the last 2 years. Exclusionary criteria were: 1) recent history or current presence of any major neurological/medical conditions that may significantly compromise cognitive functioning or 2) diagnosis or currently met criteria for dementia, based on their total score on a dementia screening measure, Repeatable Battery for Neuropsychological Status (RBANS). Inclusion and exclusion criteria were determined based on initial telephone screening and participants' responses to the Demographics and History Questionnaire administered at the start of testing sessions. Participants received a remuneration of $40.00 toward the cost of transportation and for the time invested in the study. If desired, study participants were provided with clinical feedback on their overall cognitive performance.

Comparisons were conducted between participants who completed all driving scenarios (n = 71), and those who only completed a portion or none of the three scenarios, mostly due to experiencing simulator sickness (n = 39), regarding demographics and cognitive performance. Completers did not differ from non-completers

[1] The initial 27 participants were administered cognitive measures prior to the driving simulation, but order of administration was then reversed for the remaining 84 participants to attempt to minimize simulator sickness.

with respect to age, educational attainment, the three extracted components of EF, and select measures of memory (List Recall) and visuospatial skills (RBANS Line Orientation). However, the percentage of women among the non-completers was higher as compared to the completers, $\chi 2$ (1, N = 111) = 6.97, p= .008.

Participants who completed cognitive testing first did not differ from those completing driving simulation first with regard to level of education. Those who underwent neuropsychological testing initially (M = 70.63, SD = 6.85) were older than those who completed the driving simulation first (M = 67.58, SD = 7.00), t (109) = 2.05, p= .04, and were comprised of a larger portion of women relative to the second group, $\chi 2$ (1, N = 111) = 7.79, p= .005. Performance on extracted EF components was not significantly different by order of testing. There were no differences noted on an aggregates of driving performance for routine, i.e., operational or skill-based lane deviation, speed maintenance during routine driving or for controlled/tactical driving.

Procedure

For all participants, the order of neuropsychological instruments within the cognitive assessment portion of the evaluations remained the same, as fatigue has not shown to significantly impact cognitive performance in the population of interest in order to warrant counterbalancing of measures (see Uttl, Graf, & Cosentino, 2000). Neuropsychological assessments were conducted by trained graduate students or by trained undergraduate assistants, under direct supervision by graduate students. The driving assessment portion of the study session consisted of 4 components and was conducted in a separate laboratory space from the cognitive assessments. Descriptions of the components of the driving evaluation follow below.

Driving scenarios.

The driving component of the study was executed in a high-fidelity driving simulator. Participants were instructed to drive as they typically do on the road, and to observe all traffic laws and regulations, including speed limits and traffic signs. Brief, 5-minute breaks were offered between driving scenarios or at the participants' request. Similarly to other studies measuring performance in custom-designed driving simulator tests (e.g., Shanmugaratnam, Kass, & Arruda, 2010), the driving tasks in the proposed study were administered in order from simpler to more complex and challenging. Initially, participants engaged in a 15-minute adaptation scenario, and were provided with the opportunity to practice driving straight ahead, stopping at an intersection, maintaining their lane, changing lanes with and without other traffic present, and turning. The adaptation session was followed by three components beginning with the Basic Scenario: driving straight in a rural setting with several pre-programmed hazards – for example, a deer crossing the road unexpectedly. The Freeway Scenario involved merging on and off the freeway, navigating a freeway section with heavy traffic, following detours, changing lanes, driving through an urban district, and executing an unprotected left turn. The final, Complex Scenario involved driving on a two-lane straight roadway and a 5-lane straight suburban section in inclement weather at night, and navigating through a section with road work. For full descriptions of all three scenarios, as well as driving tasks contained therein, see Appendix B.

Measures

The instruments and variables utilized in the current study are described below. See Appendix B for more detailed information regarding the tests' psychometric properties and copies of materials that are not copyrighted. In preparing data for analyses, variables with positive skew were transformed using the Log 10 of the originals. Negatively skewed scores were transformed by reversing the scores first (i.e., adding 2 to the largest value in the distribution and subtracting the original score from this sum), followed by calculating Log 10 for each of the reversed scores. For range, skew and kurtosis of cognitive variables of interest in the present study, see Table 1.

Demographics, covariates, and exclusion/inclusion criteria.

Demographics and history questionnaire. Participants completed a brief, semi-structured interview assessing demographic information, occupational and medical history (including neurological illness), psychiatric history, current driving status and frequency of driving, as well as driving restriction. A dichotomous variable representing presence or absence of any self-reported driving restrictions was used in exploratory analyses as a predictor of driving parameters within the simulator and of cognitive performance.

Driving history questionnaire. This questionnaire was introduced later in the course of the study, and thus was only completed by 79 participants. Questions were aimed at gathering information about number of years driving, types of driving (e.g., residential vs. freeway), , history of incidents (e.g., crashes, near-misses) or traffic violations over the past year, and additional driving education or courses, among others. A dichotomous variable derived from the measure to represent presence or absence of any reported history of driving-related incidents in the past year was used in exploratory analyses as a predictor of simulator driving parameters and of cognitive test performance.

Repeatable Battery for the Assessment of Neuropsychological Status (RBANS). A brief measure of cognitive functioning was used to screen for dementia and mild cognitive impairment. In order to minimize practice effects, participants recruited from the pool of prior studies were tested using Form B, whereas newly recruited participants were administered the functionally equivalent Form A. Construct validity and reliability has been established in community-dwelling older adults and in patients with Alzheimer's dementia (Duff et al., 2003, 2004). Duff and colleagues (2008) demonstrated an optimal cut-off for distinguishing between healthy individuals and those with dementia of 1.5 SD below the mean for the demographically adjusted total score. In the present study no participants fit this criterion. The Line Orientation and the Coding subtests were also utilized in the present study, as described below.

Variables of interest: visuoperceptual measures.

Line Orientation. The transformed raw score for Line Orientation from the Repeatable Battery for the Assessment of Neuropsychological Status was used as one of the visuospatial correlates of driving performance (transformation was performed for a negatively skewed score distribution). Test-retest reliability within a community-dwelling elderly has been calculated at 0.59 for Line Orientation and 0.62 for the entire visuospatial/constructional index, with a 54-week interval (Duff et al., 2005). Construct validity of Line Orientation is established by correlations with other visuospatial/constructional tests, namely the Judgment of Line Orientation Test and with the Rey Complex Figure test, copy condition total score, which were r=0.62 and r=0.79, respectively (Randolph, 1998).

Block Design (Wechsler Adult Intelligence Scale – IV). The Block Design subtest was administered as a well-validated measure of visual perception and visuoconstructional skills. The test is internally consistent, with alphas ranging from .80 to .89 in older adults (Wechsler, 2008b). Test–retest reliability over a mean of 22 days was .80. The Block Design subtest shows moderate to strong correlations with other measures of visual reasoning, visuoperceptual skills, and visuoconstructional ability (Wechsler, 2008a). Block Design has also been shown to be a good predictor of driving problems in older adults (Mathias & Lucas, 2009). The raw total score on this subtest, which ranged from 20 to 59, was used in the present study.

Hooper Visual Organization Test (HVOT). The Hooper Visual Organization Test (Western Psychological Services, 1983) is a brief instrument designed to measure one's ability to organize visual stimuli. Split-half reliability, as established by Hooper (1948) in a sample of college students was r=0.82. Similar values have been recorded in populations with neurological problems (r=0.80; Gerson, 1974). Hooper Visual Organization Test scores are strongly related to other perceptual organizational abilities (Johsntone & Wilhelm, 1997; Merten, 2005). Participants' raw scores in the present study were of a restricted range (16.5-30), negatively skewed, and thus were transformed accordingly.

Variables of interest: Executive function (EF). A summary of cognitive measures organized by domains is contained in Table 2.

RBANS Coding. The Coding total correct raw score from the RBANS was used as a measure of working memory updating and/or set-shifting. The test-retest reliability for Coding, as reported by an independent study was r = 0.83 (Duff, Beglinger, Schoenberg, Patton, Mold, Scott, & Adams, 2005). Construct validity, as represented by concurrent validity with other measures of executive skills, was reported via correlations of the attention index with the Arithmetic subtest of the WAIS-R – another measure which requires working memory – recorded at r=0.52. Raw correct scores can range between 0 and 89. Scores within the present sample ranged between 26 and 68, representing a restricted range.

Trail Making Test Parts A and B (TMT A & B). The TMT (Reitan & Wolfson, 1985) was used to assess the Working Memory and Set-Shifting components of EF. The time (in seconds) to complete the TMT A was subtracted from time to complete Part B, in order to derive a purer measure of EF, as suggested by Sanchez-Cubillo et. al. (2009). Consensus from clinical and research communities has identified TMT A as a measure of information processing speed factors and visuoperceptual skills (Sanchez-Cubillo et al., 2009), whereas TMT B is considered a classic test of EF, and more specifically set-shifting or cognitive flexibility, with some studies documenting loadings onto a working memory/updating factor (Arbuthnott & Frank, 2000; Perianez et. al., 2007). Criterion validity has been established through the measure's ability to distinguish between groups of patients with frontal damage and individuals without brain injury and with brain injuries in other areas (Stuss, Bisschop, Alexander, Levine, Katz, & Izukawa, 2001). Convergent construct validity has been documented by Arbuthnott and Frank (2000) via associations between TMT B: TMT A ratio and an alternating switch task (r=0.45). Three outlying scores > 3 SD were identified and removed. The transformed TMT A time for completion total score (transformation performed for positive skew) was used as a measure of processing speed.

Useful Field of View (UFOV). The UFOV test (Visual Awareness Research Group, 2009) is a software-based instrument administered on a personal computer with a Windows operating system that is designed to measure visual attention. Three subtests, 1 through 3, assess visual attention and speed, divided visual attention, and selective visual attention, respectively. Scores are generated individually for each subtest in milliseconds (range: 0 - 500 msec). Test-retest reliability over 14-18 days ranged between 0.72 and 0.88, depending on subtest or composite category (Visual Awareness, 1998). Criterion validity is provided through empirical studies of retrospective and prospective vehicular crash rates by the authors, and scores have been shown to predict performance on an on-road driving test (Ball et al., 1993; Owsley et al., 1998). In the present study, raw scores in msec for UFOV 2 and 3 were hypothesized to represent an attentional control and/or set shifting factors. UFOV 1 scores greater than 350 were used as a check for severe central vision loss and/or severe processing speed deficits; no participants scored in that range. Ranges for UFOV 2 and 3 in the present sample were 17-330 msec. and 40-484 msec, respectively.

Delis-Kaplan EF System (DKEFS) – Word-Color Interference Test (WCIT). The WCIT from the DKEFS (Delis, Kaplan, & Kramer, 2001) is a Stroop-type measure with 4 conditions (Color Reading, Word Reading, Interference, and Switching) (Stroop, 1935), designed to measure the executive inhibition function (Interference condition) and inhibition with an added shifting component (Switching condition). Scores were denoted by time for task completion. Internal consistency reliability for the WCIT for individuals between 60 and 89 is reported between r=0.77 and r=0.81. Studies support the ecological validity of the Delis-Kaplan EF System in relation to everyday functioning (Jefferson, Paul, Ozonoff, & Cohen, 2006) and its sensitivity to frontal lobe dysfunction (Delis, Squire, Bihrle, & Massman, 1992). Time for completion of the Interference condition was entered in the PCA analysis to be reduced into EF components.

N-Back task. Computer-administered auditory 1- and 2-Back tasks were utilized as measures of the working memory component of EF. N-Back tasks are considered a classic measure of working memory in healthy and neurologically impaired individuals (Owen, McMillan, Laird, & Bullmore, 2005), with adequate 1-week reliability of accuracy scores ($r = 0.54$; Hockey & Geffen, 2004). Their association with prefrontal brain region activity has been established by functional neuroimaging studies and is consistent with other working memory and executive tasks (e.g., Tsuchida & Fellows, 2009). Furthermore, N-Back type tasks have been found to detect age changes in the effects of cognitive load (Jaeggi, Schmid, Buschkuehl, & Perrig, 2009). In the present study, the percentage of correctly identified items on the 2-Back task was entered into the PCA to generate EF components.

Variables of interest: Driving assessment.

Driving simulator. The driving evaluation was conducted in a DS-600c Research Simulator (DriveSafety), a high-performance, high-fidelity simulator. It provides a 180-degree wraparound projector display and a full-width automobile cab (2004 Ford Focus), including a windshield, driver and passenger seat, center console, dash and instrumentation, as well as real-time motion simulation. The cab includes visual channel computers that provide outputs to display screens in side and rear-view mirrors and is mounted on a Q-motion platform that provides hybrid internal cues combining 2.5 degree pitch and 5-inch (12.7 cm) longitudinal motion. The simulator system includes advanced scenario authoring tools with an extensive library of roads, intersections, vehicle, traffic patterns and landscapes. The simulator includes several standard data collection measurements and allows for up to 25 additional user defined measurements. All data collection measurements are collected approximately every 0.03 seconds.

Driving parameters. As no singular standard criterion of driving performance has been established in the literature on cognitive predictors of driving (see Bedard, Parkkari, Weaver, Riendeau, & Dahlquist, 2010; Lee, Drake, & Cameron, 2002; Mathias & Lucas, 2009; Rizzo, Reinach, McGehee, & Dawson, 1997), in addition to reviewing relevant empirical reports that relate performance in a simulator to cognitive measures, theoretical models (e.g., Michon, 1985) and findings regarding on-road driving safety risks for older adults (US Department of Transportation, National Highway Traffic Safety Administration, 2009) were used for guidance in the selection and operationalization of variables. In addition, the scenario during which driving parameters are measured indicates different levels of driving skills, with the *Basic* scenario being simpler than the *Freeway* scenario, for instance. See Appendix B for a discussion of past research utilized for guidance in choosing driving parameters. Of note, number of crashes in the simulator was not used as a global measure of driving ability, as originally planned due to very few crashes within our sample.

Similarly to prior research, two sets of driving variables were recorded and entered into analyses to reflect a) driving performance that requires controlled or tactical driving and b) driving performance that may be more routine or operational. Lane deviation, operationalized as maximum departures to the right and left of the center-line of the driver's lane for any given stretch of the scenario, and speed maintenance, operationalized as the average velocity maintained during the respective portion of the scenario, were chosen as they have been shown to be most related to overall driving performance in older adults, after hazardous errors (those that would require interference from a driving instructor) (Dobbs, Heller, & Schopflocher, 1998). Maximum lane deviation in this case is considered to be a proxy of swerving, which is associated with potentially dangerous driving behavior. Although the type of parameters (i.e., lane deviation or speed maintenance) were similar across automated and controlled driving variables, the controlled vs. automated distinction was made based on the portion of the scenarios during which each parameter was measured. For a detailed list of driving parameters with matching scenario sections, see Table 3. Calculations and units of measurement for driving parameters can be found in Table 4. Further details regarding the driving scenarios and coding for the type of skill/maneuver within each driving section are in Appendix B.

For analyses, three composite driving variables were calculated to represent: 1) aggregate lane deviation for operational or routine driving situations (3 items, $\alpha = .61$); 2) average speed maintained across operational/routine driving situations (4 items, $\alpha = .75$); and 3) average speed maintained across controlled/tactical driving situations (9 items, $\alpha = .83$). Of note, a composite variable to estimate aggregate lane deviation for tactical driving was not used in the analyses due to low internal consistency reliability (9 items, $\alpha = .23$). This reflected low correlations between lane deviations in diverse situations that require controlled or tactical driving, such as an unprotected left turn, navigating moderate to heavy traffic on a freeway, freeway entry, and lane changing. Therefore, for tests of analyses using tactical driving lane deviation, we examined correlations with individual, rather than aggregated lane deviation parameters for controlled/tactical driving tasks, such as changing lanes, merging onto a freeway, navigating moderate to heavy traffic while driving on the freeway, executing an unprotected left turn at an intersection, and merging into one lane with other traffic due to road work, as reviewed under hypotheses 3 and 4.

Results

Missing Values, Outliers, and Normality of Neuropsychological Variable Distributions

Data were entered into the Statistical Package for the Social Sciences (SPSS, 2012). Missing values were examined for the EF measures to be included in the principal component analysis. A missing value analysis revealed that the extent of missing data ranged from 0.9% (Coding) to 4.5% (Selective Attention). The data were found to be missing completely at random (Little's MCAR test: $\chi^2_{(26)} = 29.94$, $p = .27$) and thus the Expectation Maximization method was used to impute the missing data for measures of EF (Howell, 2008). Missing data from the driving parameter variables obtained in the driving simulator scenarios was determined to not be missing completely at random, likely most related to patterns of drop-out due to simulator sickness, and in fewer cases, mechanical issues (Little's MCAR test: $\chi^2_{(1157)} = 1254.74$, $p = .02$) and was therefore not imputed. Missing data in driving parameter ranged from 16.4 (Lane Deviation 4 in the Basic Scenario) to 47.3 percent (Lane Deviation during a Left Turn in the Freeway Scenario) depending on the particular section and scenario. In previously proposed analyses featuring variables derived in the driving simulator, cases were excluded in a listwise fashion. Our findings regarding cognitive performance in the two groups (with and without simulator sickness) were consistent with Muller, Weaver, Riendeau, Morrison and Bedard (2010), who empirically demonstrated that in healthy older adults, drop-outs due to simulator sickness were not significantly different from completers with respect to driving performance in an on-road test or regarding scores on Useful Field of

View, the Trail Making Test A, and a measure of attention. In all exploratory analyses and correlational tables, cases were excluded pair-wise to maximize power.

Given that the principal component method is sensitive to outliers (Field, 2005), all proposed EF variables were examined for outliers using box plots and standardized values through the Explore and Charts options in SPSS. Outliers were identified based on the criterion of $|z| \geq 3.29$ and were removed as follows: 1) 3 outliers were removed from TMT Part B – TMT Part A; 2) 1 outlier was removed from DKEFS Color-Word Interference. Z-scores for additional outliers were < 3.29 and were therefore retained in the data set. Additionally, among the remaining visuospatial and visual memory cognitive variables to be featured in the regressions, 2 outliers were removed for RBANS Figure Recall and 1 was removed for RBANS Line Orientation. Driving variables only registered one outlier, which was removed due to excessive speeds in sections of the *Complex* scenario.

Considerations of Covariates

In order to determine potential covariates, the relationship between driving simulator variables and participants' education were examined through Pearson's bivariate correlations. Current driving abilities were also compared by sex. Though education was unrelated to any of the driving variables of interest to the study, females' average speed tended to be lower in automated driving situations, t (69) = -3.89, p= .001 and in controlled or tactical driving (p= .016). In addition, participant sex was also related to the Shifting/Inhibition EF component, r = .24, p= .01. Given the significant findings, sex was entered as a covariate where the aggregate speed variables and

Shifting/Inhibition were used together in analyses, as well as for analyses of individual speed parameters with Shifting/Inhibition.

Age of participants was related both to neuropsychological predictors and driving parameters as measured in the simulator, but it was not entered as a covariate in analyses to follow, with two considerations in mind. Firstly, demographic adjustments (equivalent to statistically controlling for age) weaken the predictive ability of cognitive variables when it comes to real-world tasks that require absolute performance, including driving (Silverberg & Millis, 2009; Barrash, Stillman, Anderson, Uc, Dawson, & Rizzo, 2010)

Secondly, given the present study's focus on EFs, which have been shown to decline disproportionately to other cognitive abilities with aging, demographically adjusting the test scores or statistically controlling for age may remove variance from age-related changes in EF, rather than aging itself. The consensus from prior research is that age alone is a poor predictor of driving ability in older adults, and therefore changes seen in driving outcome measures are likely due to other factors, such as cognitive decline (e.g., Ball & Owsley, 2003; Shanmugaratnam, Kass, & Aruda, 2010). Years of driving experience, while related to driving and cognitive parameters, were highly correlated with age (r= .95, p= .001), and were also not entered as a covariate.

Principal Components Analysis (PCA)

The data from select EF measures (Repeatable Battery for the Assessment of Neuropsychological Status-Coding, Trail Making Test B-A, Delis-Kaplan Executive Function System- Interference, Useful Field of View 2 and 3, and 2-Back Computerized Task) were entered into a factor analysis in order to reduce them to linear underlying components. At the outset, the factorability of the measures was examined using several established criteria (Field, 2005), all of which were within appropriate limits: All but one measures correlated at ≥.3 with at least two others (See Table 6); the 2-Back measures correlated at a level ≥.3 with one other measure; “good” Kaiser-Meyer-Olkin measure of sampling adequacy of.73 (Hutcheson & Sofroniou, 1999, p. 224-225); and significant Bartlett’s test of sphericity, $\chi^2_{(15)} = 166.588$, $p = .001$. Taken together, all of the above findings verified that the five chosen measures were appropriate for factor analysis.

Principal component analysis was conducted to extract composites of EF recorded in our sample. Initial extraction indicated that the first 2 components explained 46% and 18% of the variance, with eigenvalues of 2.75 and 1.06, respectively. A third component explained an additional 13% of variance (eigenvalue = .79). Two- and three-component solutions were thus examined. The three-component solution, which explained 77% of the variance, was preferred because of: (1) previous theoretical support for a 3-factor structure of EF (de Frais, Dixon, & Strauss, 2006; Miyake et al., 2000; for a review, see Jurado & Rosseli, 2007); (2) the leveling off of eigenvalues on the scree plot after the third component; and (3) a suggested cut-off of .7 for factor retention as an alternative to the conservative value of 1 (Joliffe, 2002). Both orthogonal and oblique rotations were considered (varimax and oblimin, respectively), as half of the correlations in the component correlation matrix were above a .32 cut-off the other half were lesser than .32 (Tabachnick & Fiddell, 2007). In addition, the two methods of rotation produced similar patterns of clustering. Theoretically, it was important to isolate separate components of EF, rather than overlapping areas, therefore an orthogonal as opposed to oblique rotation was chosen. In addition, orthogonal rotation was preferred in order to limit correlations between the separate components, with the goal of entering respective eigenvalues as variables in regression analyses.

For the final solution, a 3-component extraction with a varimax rotation yielded the best defined factor structure. See Table 7 for the factor loading matrix of this solution and the communalities of each executive measure. Based on prior studies of executive components in younger and older adults (Mantyla, Karlsson, & Marklund, 2009; Miyake et al., 2000), the clustering of executive measures under the present model can be interpreted as follows: The first component, with primary loadings for Useful Field of View 2 and 3 captured measures of *inverse* visual attentional control (higher scores denoted poorer performance), an ability that is closely related with aspects of executive skills, as judging by the moderate correlation with the Shifting/Inhibition component, r = .40, and the more modest correlation with the third component, r = -.20. The second component, with primary loadings for Trail Making Test B – A (positive loading, higher score = worse performance), Coding subtest (negative loading, lower scores = poorer performance), and Color-Word Interference (positive loading, higher scores = poorer performance) resembled the *inverse* of a mixture of the Set Shifting and Inhibition factors in other models. The 2-Back task (positive loading, higher scores = better performance) was the sole measure to primarily load onto the third component, representing the Updating/Working Memory factor from previous studies.

Hypothesis 1: Visuoperception, Visual Memory, and Processing Speed as Predictors of Driving Performance

Pearson's bivariate correlations were conducted to explore the relationships between non-EF cognitive variables and driving parameters prior to further analyses.

Correlational analyses indicated that among visuospatial, memory, and processing speed measures, certain visuoperceptual instruments were related to summary indicators of driving performance. Specifically, there was a positive relationship between Block Design and aggregates of speed maintenance during controlled/tactical driving, as well as with speed maintenance in routine situations, r (71) = .25, one-tailed p= .009 and r (52) = .32, one-tailed p= .02, respectively, indicating that individuals with better visuoconstructive abilities tended to maintain higher speeds in those situations. Block Design was positively associated with aggregate LD during routine driving, r (71) = .20, one-tailed p= .05. In addition, higher scores on Line Orientation were related to higher speeds maintained during controlled/tactical driving, r (52) = .23, one-tailed p= .05, and better visual organization on HVOT was associated with higher speeds during tactical driving, r (52) = .26, one-tailed p= .03. Contrary to hypothesis, visual memory and speed of processing were not significantly related to aggregates of lane deviation across scenario sections requiring routine/operational driving skills or with average speed across routine or controlled driving sections. See Table 8.

Hypothesis 2: Executive Components as Predictors of Driving Performance

In Pearson's bivariate correlations among EF components and aggregate driving variables (i.e., aggregate routine speed, aggregate tactical speed, and aggregate routine lane deviation), a significant relationship emerged between the Shifting/Inhibition component of executive funciton and aggregate routine lane deviation, r (67) = .38, one-tailed p= .001, suggesting that those with poorer shifting/inhibition skills exhibited wider maximum deviations during automated driving. In addition, those with poorer visual attentional control also maintained larger lane deviations during routine driving performance, *r* (67) = .28, one-tailed p= .01 (full correlational data in Table 9).

With regard to the incremental validity of EF measures, a two-block hierarchical regression was conducted focusing on Block Design and Shifting/Inhibition and Visual Attentional Control as predictors of aggregate routine lane deviation (based on the above correlational findings). Block Design scores were entered first and the Shifting/Inhibition and Visual Attentional Control executive components were entered together in the next block. Multivariate and univariate diagnostics did not indicate that any regression assumptions were violated. Multicollinearity diagnostics (i.e., VIF and Tolerance) were within acceptable limits, and review of Mahalonobis distance scores revealed no multivariate outliers. Independence of the errors was also retained (*Durbin-Watson* = 1.97).

In the regression, Block Design accounted for 5% of the variance univariately, F (1,65) = 4.30, p= .04. When added to the model, Shifting/Inhibition with Visual Attentional Control explained an additional 13% of the variation in lane deviation under routine driving conditions, with significant change in R^2, F (1,63) = 6.15, p= .004. In the full model, only the EF components, Shifting/Inhibition (β= .34, p= .006) and Visual Attentional Control (β= .23, p= .05) accounted for significant portions of the variance in driving performance multivariately. This finding was consistent with the second hypothesis, reflective of the role of EF components above and beyond visuoperceptual measures in predicting driving performance during daytime on a straight route. See Table 10 for coefficients and other statistics.

Hypothesis 3: Exploration of Visuoperceptual Measures as Predictors of Routine Driving Abilities

Bivariate correlations among visuoperceptual measures and individual routine driving parameters were examined. Individuals with better visuoconstructional and visuoperceptual skills on Block Design and on Line Orientation maintained higher speeds during separate sections of routine nighttime driving, r (76) = .28, one-tailed p= .007 and r (74) = .28, one-tailed p= .009, respectively. In addition, relationships of better performance on Block Design with lane deviation during another portion of nighttime driving and with driving straight ahead during daytime were marginally significant (p-s= .04 and .02, respectively; see Table 13). See Appendix C for further information on additional findings that were outside of the scope of the hypotheses.

Hypothesis 4: Exploration of Executive Components as Predictors of Controlled or Tactical Driving skills

In exploratory correlational analyses between EF components and individual (i.e. non-aggregated driving parameters) Visual Attentional Control was associated with one speed parameter during freeway driving with moderate to heavy traffic, r (68) = -.38, p= .001, and approached significance in association with another, r (69) = -.29, p= .02, indicating that those with better visual attentional control maintained higher speeds during certain tactical portions of the driving scenarios. Shifting/Inhibition approached significance in predicting higher speed during freeway driving with moderate traffic, r (49) = -.24, p= .04, after controlling for sex. No significant relationships were observed between speed maintenance and Working Memory/Updating. Individual *controlled/tactical* lane deviation parameters were not significantly associated with any of the EF components. Correlations can be reviewed in Tables 15 through 20. In all exploratory analyses, correlations were conducted using the pair-wise method in order to maximize sample size and hence, power. Supplemental analyses can be found in Appendix C.

Discussion

The present study was designed to investigate the relationship of cognitive abilities, such as visuospatial skills and processing speed to driving performance in healthy community-dwelling older adults, as measured in a high-fidelity simulator. Further, we set out to examine the role of EF components as a predictor of driving proficiency in older adults, above and beyond that of other cognitive skills. We hypothesized that, similarly to prior research, driving parameters would be associated with performance on measures of visuoperception, processing speed, and visual memory within our sample. Given the importance of executive skills for a variety of instrumental activities of daily living, including household maintenance, financial abilities and medication management, as well as the earlier decline in such skills that accompanies normative aging, it was expected that they would be predictive of older adults' driving skills, in addition to more established predictors, such as visuospatial skills and processing speed (see Mathias & Lucas, 2009). In light of the multifaceted nature of EF, another goal of the present study was to explore whether or not certain components of EF are more predictive of driving performance than others. To our knowledge, the current study is one of few conducting a theoretically driven examination of specific executive components in healthy older adults and is among a small but growing number of investigations utilizing a high-fidelity driving simulator to measure driving performance.

Extraction of EF Components

Though this was not the primary aim of the study, principal components analysis was conducted using six EF measures and was reduced to individual EF components. Similarly to other factor analytic studies (Mantyla, Karlsson, & Marklund, 2009; Miyake et. al, 2000), our data clustered into 3 primary components, Shifting/Inhibition (loadings of Trail Making Test B-A, Coding and The Color Word Interference Test), Visual Attentional Control (Useful Field of View 2 and 3), and Working Memory/Updating (2-Back), capturing 77% of the variance in executive skills assessed. Our reasoning for including Useful Field of View 2 and 3 in the analysis was that conceptually they relate to the Supervisory Attention System model of executive abilities proposed as an attentional control model (Norman & Shallice, 1986; Stuss et al., 2002. In addition, attentional control may be of specific importance in older adults, as it may underlie some of the other declines in EF seen in this population (see Royall et al., 2002).

Visuoperceptual Abilities, Memory and Processing Speed as Predictors of Driving Performance

Consistent with the first hypothesis, better visuoconstructional ability on Block Design was related to higher speeds maintained during both routine operational and controlled driving, with medium and small effect sizes, respectively. Other visuoperceptual measures (Hooper Visual Organization Test and Line Orientation) were associated with higher maintained speed during certain controlled/tactical driving sections (small effect sizes). At the same time, an association emerged between higher Block Design scores and lower lane deviation during routine driving portions of the scenarios (small effect size). Among individual correlations for separate tactical/controlled lane deviation parameters, those with higher Line Orientation scores were less likely to deviate or swerve when changing lanes and when executing an unprotected left turn (small effect sizes). Contrary to predictions, other measures of visuoperceptual and visuoconstructive skills (Line Orientation and Hooper Visual

Organization Test) were not significantly associated with any of the lane deviation parameters.

Given that the present study's sample engaged in relatively safe driving (only two of 111 participants were involved in a simulator crash; there were only two occasions of running a stop sign or failure to stop at a traffic signal; and only one participant exceeded the speed limit in any section by more than 10 mph), it can be surmised that individuals with better visuoconstructive abilities may have maintained higher speeds due to superior comfort with driving and less need for compensatory driving strategies (i.e., speed reduction), and may have driven more skillfully with fewer instances of swerving. These findings are consistent with previous research that also identified significant relationships of visuoperceptual skills to high driving proficiency and lower risk of motor vehicle crashes, using Block Design and the Judgment of Line Orientation test (e.g., Hoffman et al., 2005; Szylk et al., 2002), and are well aligned with results from Mathias and Lucas' meta-analysis, though they reported a large effect size. Of note, the Szylk et al., Hoffman et al., and Mathias and Lucas studies included participants with suspected dementia, in addition to healthy community-dwelling older adults, which may have accounted for the somewhat larger effect sizes observed in their investigations. Thus, the discrepancies in effect size magnitude between our findings and those in other research could be due to the heterogeneity of used measures, as well as the populations sampled.

Contrary to a-priori hypotheses, processing speed on the Trail Making Test A and visual memory on the Benton Visual Retention Test were unrelated to any of the aggregate driving parameters in our sample. Although both of these domains emerged as predictors of driving performance in prior research examining crash rates and on-road driving test performance, they were not significant predictors in most investigations using a driving simulator (e.g., Mathias & Lucas, 2009). Of those studies that only included dementia-free community-dwelling participants, Shanmugaratnam et al. (2010) observed an association of choice reaction time with what may have been more sensitive driving performance measures, such as crashes and violations. Differences between the present study and other investigations with significant findings included the purposeful recruitment of a healthy community-dwelling sample, the lower sample size due to drop outs secondary to simulator sickness and the potential low sensitivity of the simulation scenarios. Furthermore, many of the other measures utilized in the study and which showed significant relationships to driving simulator outcomes (e.g., Block Design, Coding, and Useful Field of View) are timed, thus including an element of psychomotor processing speed. An alternative explanation is that within a healthy community-dwelling sample such as ours, processing speed may be important for driving performance only when other cognitive abilities are being taxed simultaneously, rather than within a relatively simpler paradigm, such as with Trail Making Test A.

Executive Function as an Incremental Predictor of Driving Parameters

As hypothesized, two components of EF, Shifting/Inhibition and Visual Attentional Control were found to be related to driving (medium and small effect sizes, respectively) and to add incremental predictive validity above and beyond visuoconstructional abilities (measured by Block Design) in explaining the variability in lane deviation in routine/operational driving. Shifting/Inhibition and Visual Attentional Control accounted for an additional 13% of the variance, for a total of 18% explained by Block Design and the two EF components. What is more, in the multivariate model, only the executive component remained significantly related to lane deviation. Although a number of prior studies have provided support for the role of executive skills in older driver safety (e.g., Diagneault et al., 2002; Shanmugaratnam et al., 2010; Zook et al., 2009), to our knowledge this is the first investigation of EF as adding to the predictive ability of more established cognitive variables in the driving literature, such as visuoperception and attention on its own (see studies by the Ball et al. research group, and Hoffman et al., 2005). Individual associations between tactical driving lane deviation parameters and executive components were not significant, though to our knowledge other studies have not studied differential effects of EF on tactical versus routine driving performance, so a comparison could not be drawn. The present findings extend the existing literature utilizing simulated driving performance measurement in healthy older adults.

Interestingly, our findings differed from those of Mantyla et al (2009), who documented a significant relationship between younger, novice driver performance in a simulator and a Working Memory Updating executive factor. One potential explanation for the divergence in findings is the difference in outcome variables (lane changing ability in Mantyla et al., and lane deviation in routine driving in the present study). An alternative explanation is that executive skills play different roles in predicting driving performance at different ages and levels of experience, as suggested by the theoretical literature on EF (Jurado & Rosselli, 2007). Moreover, our findings were similar to those by Adrian et al. (2011) who found Trail Making Test B – A (included as a measure of Shifting/Inhibition) to be related to overall driving performance with a small effect size.

Another measure of set shifting also accounted for a significant portion of the variance (Plus-Minus Task), whereas measures of other executive components did not.

In addition, the present study's findings regarding the role of the Visual Attentional Control Component, which contained loadings for one of the most replicated predictors of driving performance in older adults (the Useful Field of View), were in the small to moderate range for effect sizes. In contrast, prior research has documented moderate to large effect sizes for total Useful Field of View scores or for certain subtests in predicting driving performance in older adults (see Clay, Wadley, Edwards, Roth, Roenker & Ball, 2005 for a meta-analysis). Though a strong predictor, not all studies have found evidence for the validity of Useful Field of View in predicting driving outcomes, and different studies used different scores, ranging from a total score across the three subtests to individual scores on 1, 2, or 3. Staplin, Lococo, Gish, & Joyce (2012) failed to document relationships between most subtests of the Useful Field of View and a variety of driving performance indicators. In addition, the reduction in sample size due to simulator sickness and the limited range of attentional control scores (i.e., few individuals in the at-risk category) may have adversely impacted our findings.

Though somewhat variable, the present findings lend support for the potential role of EF as a factor in individual variance in driving performance among older adults. The large inconsistencies across individual predictors and outcome variables used suggest that future studies may benefit from a more unified approach with regard to choice of independent and dependent variables. In addition, given the divergent findings based on the age group of the participants (Mantyla et al., versus Adrian et al.), further studies investigating the role of executive factors for driving proficiency across multiple age groups is also warranted.

Exploratory Findings in Visuoperceptual and Executive Predictors of Individual Driving Parameters

Exploratory findings using individual driving parameters (i.e, lane deviation and speed maintenance during separate 3-minutes sections of each scenario) suggested that individuals with higher levels of visuospatial and executive skills in our sample had a tendency toward maintaining higher speeds in both routine and more challenging (controlled/tactical) sections of the scenarios. In addition, individuals with better visuoperception as measured by Block Design and Line Orientation swerved less during routine and tactical driving (medium effect sizes). Amongst the executive components, Visual Attentional Control was significantly related to higher, but not unsafe speeds during effortful driving on the freeway with moderate to heavy traffic (moderate effect size), which is likely reflective of better driving skills. Unfortunately, individual analyses were not sufficiently powered to fully explore whether executive abilities are more predictive of controlled/tactical driving skills relative to automated driving. Future studies may advance the current state of knowledge by employing more individual executive tests to be reduced into components and further recruiting larger sample sizes in order to counteract the effects of simulation sickness. The potential role of demand characteristics is also worth noting here. All participants were reassured during the consent process that their driving scores in the simulator would no consequence for their real-world drivers' licenses, but nevertheless, the sense of being evaluated may have caused heightened attention and observance of traffic regulations within our sample, which would have in turn impacted the findings. Another possibility is that the driving scenarios failed to sufficiently challenge this sample of healthy, experienced, active drivers, as can be judged by the low frequency of crashes, violations, and other hazardous errors. Given that this is the first study with an older population using this particular simulator in our lab, it is possible that further calibration

Self-Restrictions and Self-Reported Driving History

In keeping with past studies, we attempted to investigate whether any correspondence existed between older drivers' reports of modification (i.e., compensation) in driving practices and actual driving performance. There were no significant group differences in sex, age, education or cognitive abilities. Nevertheless, those who reported modifying their driving were more likely to experience larger lane deviations across routine driving situations, as measured by an aggregate variable. Within our sample, changes in driving performance for those who self-restricted appeared to precede cognitive changes, and were not explained by other demographic variables. In addition, in our sample individuals reporting some incident or violation history were more likely to experience swerving during routine nighttime driving. These data may suggest that among older drivers who are willing to report on past incident history, nighttime driving may be of particular concern. This is particularly reassuring, given that among the individuals who modified their driving, limiting nighttime driving was one of the most common self-imposed restrictions.

Limitations, Implications and Future Directions

Although the intended sample size for the project was sufficient to power the first two main hypotheses, we incurred higher-than-expected rates of drop outs and data loss among our participants due to technical difficulties and simulator sickness. The sample sizes for individual analyses ranged from 51 to 108, with lowest number in analyses featuring parameters from the *Freeway* scenario, which unfortunately contained highest amount of maneuvers and driving situations of interest to the study. Given this percentage of reduced data due to simulator sickness, the study likely suffered a decrement in power. In addition, to the extent that simulator sickness was present, but did not cause drivers to discontinue participation in the remainder of the scenarios, the ecological validity of driving performance during these scenarios may have been inadvertently impacted. Although we took precautions to minimize simulator sickness in our participants, such as offering breaks in-between each driving scenario, many participants declined to take a break. Anecdotally, participants who opted for breaks reported lower levels of simulation sickness. Future studies may consider including mandatory breaks in-between driving stretches, using other strategies for minimizing simulator sickness in older participants, and recruiting larger than necessary samples of participants in order to account for drop-outs. Ethical considerations with regard to the level of discomfort associated with simulator sickness are also warranted.

Another consideration in the present study are the limited ranges for a number of the cognitive, as well as driving variables of interest, which likely further diminished the power of analyses. As previously discussed, much of this is likely due to the nature of the population of study, including healthy, community-dwelling adults, without indications of dementia. Few crashes and hazardous errors were observed within the sample, allowing for limited assessment with regard to driving difficulties. The present findings highlight the importance of employing the most sensitive measures to detect selective deficits in future studies.

Whereas aggregate measures of speed and lane deviation during routine driving were obtained, this type of aggregation may not always be possible across more diverse, challenging driving scenarios, as was the case in the present study. Given the nature of the challenging sections (i.e., unprotected left turn at a traffic light, right turn at a T-intersection), a low internal consistency in lane deviation is to be expected. Although use of individual stretches of the scenario allowed for testing hypotheses regarding controlled driving performance, the increased number of correlations inherent in this method can inflate the chance of Type I errors. In light of these difficulties, future research should aim to identify and utilize simulator driving parameters with optimal sensitivity to cognitive deficits, thus limiting the number of comparisons/analyses to be conducted. Previous studies offer a paucity of examples on how best to approach this issue, thus warranting further validation of existing driving evaluation methods and development of new ones in order to continue using this technology.

Due to the nature of our sample and due to the use of a driving simulator, the results from the present study have limited generalizability and ecological validity. The findings may only apply to individuals similar to our sample, including mostly Caucasian, well-educated (reflective of good cognitive reserve), and predominantly female community-dwelling persons, who were slightly younger than those in most other studies in the literature − a mean age of 68.4 as compared to means ≥70 years in other research (see Appendix A). In addition, there was an inadvertent lack of consistency in the order of driving simulator evaluation relative to the cognitive test administration, and although no significant differences were evident in cognitive or driving performance between the groups, other unanticipated confound variables may have influenced the findings. Some have questioned the ability of driving simulator data to accurately reflect real-world driving abilities (e.g., level of fidelity, different behavior due to being observed). Nevertheless, mounting evidence is available for the correspondence between driving simulators and on-road driving tests, which are the gold standard of driving assessment. Schechtman, Classen, Awadzi, and Mann (2009) documented no significant differences between errors made in a high-fidelity simulator and those made on the road by groups of younger (25-45) and older individuals (65-85). Lee (2002) found that an index of simulated driving performance explained two-thirds of the variance in an index of on-road performance in 129 community-dwelling adults (ages 60-90).

Though findings from the present study were somewhat limited, it made several important contributions to existing literature. Specifically, we demonstrated that the use of PCA for reduction in multifaceted cognitive data, such as in the case of EF has a viable application in driving proficiency studies with older adults and raised further questions about the relative importance of different executive function components for this population. In addition, the role of EF, and more specifically, a mixture of shifting and inhibition components, as a predictor of aspects of driving performance was highlighted. Aside from limitations with regard to power, the presence of relatively smaller effect sizes for cognitive factors with regard to driving abilities in our healthy, community-dwelling older adult sample can be reassuring in that it is possible that the normative aging of cognition is not significantly associated with decrements in driving performance, and it is only in neurologically compromised individuals (e.g., those with dementia) that cognition plays an important role. Certainly, further research comparing healthy controls to older adults with MCI and early dementia is needed to better evaluate this conclusion. Finally, the present findings contribute to the larger body of literature in working toward identifying and designing ways to efficiently screen for and intervene with driving deficits in healthy older adults, a burgeoning concern given the growth of the older adult population within the US and other Western nations.

Table 1

Cognitive Variables: Descriptive Statistics

Variable	Mean	SD	Skew	Kurtosis	Possible Range	Study Range[1]
LO*	0.57	0.22	0.90	-2.4	0-20	11-20
BD	38.22	10.01	0.66	-2.17	0-66	20-59
HVOT*	0.79	0.17	-0.38	0.23	0-30	16.5-30
Coding	46.19	8.72	-1.36	-0.89	0-89	26-66
TMT A*	1.53	0.15	2.09	1.05	0-300	15-99
TMT B-A	37.83	22.80	0.14	4.63	-300-300	-46-98
UFOV 2	83.1	80.5	5.91	2.53	0-500	17-330
UFOV 3	196.85	96.19	3.17	0.10	0-500	40-484
WCIT	61.28	15.41	1.25	1.85	0- --	20-106
2-Back	68.39	18.75	-1.12	-0.74	0-100	20-100

Note. Study range based on untransformed scores. Abbreviations: BD = Wechsler Test of Adult Intelligence – Block Design subtest; Coding = Repeatable Battery for the Assessment of Neuropsychological Status – Coding subtest; HVOT = Hooper Visual Organization Test; LO = Repeatable Battery for the Assessment of Neuropsychological Status – Line Orientation subtest; UFOV = Useful Field of View; TMT – Trail Making Test; WCIT = Delis-Kaplan Executive Function System Word-Color Interference Test. * Denotes transformed variables

Table 2

Variables of Interest – Cognitive Variables by Domain

Domain/ Measures	Dementia Screen	Visual Memory	Speed of Information Processing	Visuospatial/ Constructional	Executive Functions
	Total Score (RBANS)	Benton Visual Retention Test	Trail Making Test A	Line Orientation (RBANS)	Trail Making Test Part B
				Block Design (WAIS-IV[3])	2-Back Task
				Hooper Visual Organization Test	D-KEFS[2] Color-Word Interference Test
					Useful Field of View – Divided Attention
					Useful Field of View – Selective Attention
					Coding (RBANS)

Note. [1]RBANS – Repeatable Battery for the Assessment of Neuropsychological Status. [2]Delis-Kaplan Executive Function System. [3]Wechsler Adult Intelligence Scale – Fourth Edition

Table 3

Variable Descriptions – Driving Simulator

Variable	Driving section description	Duration/Speed limit
Basic Scenario: Approximately 14 minutes at 55 MPH speed limit		
LD[1]-3 Speed-3	2-mile straight roadway in rural setting	2.2 minutes at 55 MPH speed limit
LD-4 Speed[2]-4	3-mile straight roadway with passing and no-passing section; participant must navigate around vehicle moving at 25 MPH[3]; eventually other vehicle turns into driveway	3.3 minutes at speed limit to 7.2 minutes at 25 MPH
LD-5a LD-5b LD-5c LD-5d Speed-5a, 5b, 5c, 5d	1-mile straight section with deer entering at right side, crossing road, and crossing back through from the left.	1 minute
LD-7 Speed-7	Right turn at a 4-way stop T-intersection	0.5 minute
Freeway Scenario: Approximately 13 minutes at 25 to 65 MPH speed limits		
LD-11	Entering and merging onto 2-lane freeway from the right; speed limit: 65 MPH	1 minute at 65 MPH
Speed-11	Average speed on entry ramp	
LD-12 Speed-12	Merging onto 2-lane freeway from the right Average speed while merging onto freeway	0.5 minute at 65 MPH
LD-14a Speed-14a	2 freeways merging into one; exit entrance ramp along 3-mile straight freeway section with moderate to heavy traffic volumes	1 minute at 65 MPH
LD-16a	0.5-mile straight section in city with traffic signals every ½ miles. Pedestrian enters roadway between two parked vehicles on side of road	1.2 minutes at 25 MPH speed limit
LD-16b	0.5-mile straight city section with moderate traffic continues;	1.2 minutes at 25 MPH speed limit
LD-17	Unprotected left turn after detour signal; participant proceeds to park near sign on the right side of road	1 minute at 25 MPH

Table 3 Continued

Complex Scenario: Approximately 14 minutes at 45 to 55 MPH speed limits		
LD-2a_3 Speed-2a	2-mile straight section of 2-lane straight roadway; nighttime clear conditions	2.2 minutes at 55 MPH speed limit
Speed-3	2-mile straight section of 2-lane roadway; nighttime	2.2 minutes at 55 MPH speed limit
LD-2b_11a Speed-2b Speed-11a	Transition to a 5-lane straight suburban section	2.7 minutes at 45 MPH speed limit
LD-18 Speed-18	Work zone begins after posted notification; both lanes in direction of travel closed with open lane in two-way-left-turn lane under light to moderate traffic conditions	1.3 minutes at 45 MPH speed limit
LD-19 Speed-19	Continue in two-way left-turn lane used as main lane due to closed remaining lanes; light to moderate traffic ; nighttime	1.3 minutes at 45 MPH speed limit
LD-20a Speed-20a	Continue in two-way left-turn lane used as main lane; light rain begins; nighttime; light to moderate traffic volumes	1.5 minutes at 45 MPH speed limit
LD-20b_21 Speed-20b	Work zone ends; two-mile section of 5-lane roadway through horizontal curves with heavy rain	2.7 minutes at 45 MPH speed limit

Table 4

Calculation of Driving Simulation Variables

Variable Name	Meaning/Formula	Units of Measurement
Lane Deviation (LD)	Maximum deviation to the left of lane center + maximum deviation to the right of lane center	Meters
Speed	Average velocity for the respective stretch of the route = distance travelled/travel time	Miles Per Hour (MPH)
Aggregate Variables		
Ave LD - Routine Driving	[LD-3 (B) + LD-2a_3 (C) + LD-21_20b (C)]/4	Meters
Speed Maintenance – Routine Driving	[Speed -3 (B) + Speed-3 (C) + Speed-2a (C) + Speed-20b (C)]/4	Miles Per Hour (MPH)
Speed Maintenance – Controlled Driving	[Speed-7 (B) +Speed-11 (F) + Speed-12 (F) + Speed-14a (F) + Speed-14b (F) + Speed-14c (F) + Speed-17 + Speed-11a (C) + Speed-11b (C)]/9	Miles Per Hour (MPH)

Note. B = Basic Scenario, F = Freeway Scenario, C = Complex Scenario

Table 5

Executive Measures Correlation Matrix

	RBANS Cod	DKEFSI nt	UFOV2	UFOV3	2Back%	TMT B – TMT A
RBANSCod	1					
DKEFSInt	-.47**	1				
UFOV2	-.46**	.19*	1			
UFOV3	-.50**	.28**	.73**	1		
2BackPerc	.31**	-.20*	-.18	-.15**	1	
TMTB – TMTA	-.36**	.32**	.26**	.28**	-.24*	1

Note. N=111. Abbreviations: RBANSCod= Repeatable Battery for the Assessment of Neuropsychological Status – Coding Subtest; DKEFSInt= Delis-Kaplan Executive Function System – Color-Word Interference; UFOV2= Useful Field of View-Divided Attention; UFOV3= Useful Field of View – Selective Attention; 2BackPerc = 2-Back Task Percentage Correct; TMT B – TMT A= Trail Making Test B – Trail Making Test A. **Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Table 6

Bivariate Correlations Between EF and Other Cognitive Abilities

	TMT A	BVRT	BD	LO	HVOT	Vis. Attn. Contr.	Inv. Shift /Inhib
TMT A	1 *(108)*						
BVRT	-.17 *(108)*	1 *(109)*					
BD	-.32** *(108)*	.37** *(109)*	1 *(109)*				
LO	.08 *(107)*	-.34** *(108)*	-.44** *(108)*	1 *(108)*			
HVOT	.09 *(107)*	-.22* *(108)*	-.42** *(108)*	.22* *(107)*	1 *(108)*		
Vis. Attn. Control	.28** *(103)*	-.21* *(103)*	-.23* *(103)*	.15 *(102)*	.37** *(103)*	1 *(103)*	
Inv. Shift/Inh	.03 *(103)*	-.19 *(103)*	-.22* *(103)*	.03 *(102)*	.03 *(103)*	.00 *(103)*	1 *(103)*
WM Upd.	-.01 *(103)*	.23* *(103)*	.27** *(103)*	-.28** *(102)*	-.04 *(103)*	.00 *(103)*	.00 *(103)*

Note. Abbreviations: BD = Wechsler Test of Adult Intelligence – Block Design subtest; BVRT = Benton Visual Retention Test; HVOT = Hooper Visual Organization Test; LO = Repeatable Battery for the Assessment of Neuropsychological Status – Line Orientation subtest; TMT A– Trail Making Test, Part A ** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed).

Table 7

Factor loadings and communalities based on a principal components analysis of executive function measures

	Visual Attentional Control	Shifting/ Inhibition	Working Memory/Updating	Communality
TMTB – TMTA	.12	**.69**	-.20	.53
RBANSCod	-.45	**-.63**	.22	.65
DKEFSInt	.13	**.85**	.02	.73
UFOV2	**.91**	.14	-.09	.86
UFOV3	**.90**	.22	-.01	.86
2-BackPerc	-.07	-.17	**.97**	.98

Note. N=111. Rotation method: Varimax. Abbreviations: RBANSCod= Repeatable Battery for the Assessment of Neuropsychological Status – Coding Subtest; DKEFSInt= Delis-Kaplan Executive Function System – Color-Word Interference; UFOV2= Useful Field of View-Divided Attention; UFOV3= Useful Field of View – Selective Attention; 2BackPerc = 2-Back Task Percentage Correct; TMT B – TMT A= Trail Making Test B – Trail Making Test A.

Table 8

Bivariate Correlations of Visuoperceptual, Processing Speed, and Visual Memory with Driving Parameters

	BD	BVRT	TMTA	RBANS LO	HVOT	Aggr. Speed (Routine)	Aggr. Speed (Tactical)	Aggr. LD (Routine)
BD	1							
(n)	*(109)*							
BVRT	**.37*****	1						
(n)	*(109)*	*(109)*						
TMTA[1]	**-.32****	-.17*	1					
(n)	*(108)*	*(108)*	*(108)*					
RBANS LO[1]	**-.44*****	**-.34*****	.08	1				
(n)	*(108)*	*(108)*	*(107)*	*(108)*				
HVOT[1]	**-.42****	**-.22****	.09	**.22****	1			
(n)	*(108)*	*(108)*	*(107)*	*(107)*	*(108)*			
Aggr. Speed	.25*	-.05	-.14	-.01	.04	1		
(Routine)*(n)*	*71*	*71*	*70*	*70*	*71*	*71*		
Aggr Speed (Tactical)	**.32****	.03	-.03	-.23*	-.26*	**.73*****	1	
(n)	*(52)*	*(52)*	*(51)*	*(52)*	*(52)*	*(52)*	*(52)*	
Aggr LD (Routine)	-.20*	-.11	.08	.03	.17	.10	-.12	1
(n)	*(70)*	*(70)*	*(69)*	*(69)*	*(70)*	*(67)*	*(50)*	*(70)*

Note. BD = Wechsler Adult Intelligence Scale-Fourth Edition Block Design; BVRT = Benton Visual Retention Test; RBANS LO=Repeatable Battery for Assessment of Neuropsychological Status – Line Orientation; HVOT = Hooper Visual Organization Test. LD=Lane Deviation. Italicized values represent sample size.

**Correlation is significant at the 0.01 level (1-tailed).

* Correlation is significant at the 0.05 level (1-tailed).

Table 9

Bivariate Correlations of EF Components with Aggregated Driving Parameters

	Aggr. Speed (Routine)	Aggr. Speed (Controlled)	Aggr. LD (Routine)	Visual Attentional Control	Shifting/Inhibition	Working Memory Updating
Aggr. Speed (Routine)	1					
(n)	*(71)*					
Aggr. Speed (Controlled) *(n)*	**.73***** *52*	1 *52*				
Aggr. LD (Routine)	.10	-.12	1			
(n)	*(67)*	*(50)*	*(70)*			
Visual Attentional Control	-.14	-.16	**.28****	1		
(n)	*(68)*	*(50)*	*(67)*	*(103)*		
Shifting/Inhibition	-.10	-.03	**.38****	.00	1	
(n)	*(68)*	*(50)*	*(67)*	*(103)*	*(103)*	
Working Memory Updating	-.003	.01	-.03	.00	.00	1
(n)	*(68)*	*(50)*	*(67)*	*(103)*	*(103)*	*(103)*

Note. Italicized values represent sample size. **Correlation is significant at the 0.01 level (1-tailed). * Correlation is significant at the 0.05 level (1-tailed).

Table 10

Summary of Hierarchical Regression Analysis for EF as Predictors of Aggregate Routine LD

	LD during Routine/Operational Driving (n= 51)		
	B	*SE B*	β
Model 1			
Constant	3.09	.24	
BD	-.01	.01	-.25*
Model 2			
Constant	2.77	.24	
BD	-.01	.01	-.09
Shifting/Inhibition	.18	.06	.34**
Visual Attentional Control	.12	.06	.23*
R^2(Model 1)	.06		
F for change in R^2(Model 1)	4.30*		
R^2 (Model 2)	.18		
F for change in R^2 (Model 2)	6.15**		

Note. * < .05. **<.01. 1-tailed. LD=Lane Deviation.

Table 11

Bivariate Correlations of Visuoperceptual Measures to Routine Speed Maintenance.

	Basic- 3	Com - 2a	Com - 2b	Com - 20b	Block Design	RBANS LO	HVOT
Basic- 3	1						
(n)	*(91)*						
Com - 2a	**.61****	1					
(n)	*(71)*	*(76)*					
Com - 2b	**.52****	**.38****	1				
(n)	*(70)*	*(75)*	*(75)*				
Com - 20b	**.47****	**.32****	**.60****	1			
(n)	*(70)*	*(75)*	*(74)*	*(75)*			
Block Design	.22*	**.28****	.20*	.14	1		
(n)	*(90)*	*(76)*	*(75)*	*(75)*	*(109)*		
RBANS LO[1]	-.10	-.01	-.28*	-.16	**-.44****	1	
(n)	*(89)*	*(75)*	*(74)*	*(74)*	*(108)*	*(108)*	
HVOT[1]	-.16	-.06	.04	.02	**-.42****	.22*	1
(n)	*(9)*	*(76)*	*(75)*	*(75)*	*(108)*	*(107)*	*(108)*

Note. RBANS LO = Repeatable Battery for the Assessment of Neuropsychological Status – Line Orientation; HVOT = Hooper Visual Organization Test. [1]Transformed variables. *Italicized values represent sample size.* * Correlation significant at the .05 level ** Correlation significant at the .01 level (1-tailed).

Table 12

Bivariate Correlations of Visuoperceptual Measures to Controlled/Tactical Speed Maintenance.

	BD	RBANS LO	HVOT	Bas-7	Fre-11	Fre-12	Fre-14a	Fre-14b	Fre-14c	Fre-17
BD	*1*									
(n)	*(109)*									
RBANS LO	**-.44****	1								
(n)	*(109)*	*(108)*								
HVOT	**-.42****	.22*	1							
(n)	*(108)*	*(107)*	*(108)*							
Bas-7	.15	-.15	-.15	1						
(n)	*(86)*	*(86)*	*(86)*	*(86)*						
Fre-11	**.30****	-.20*	-.05	.11	1					
(n)	*(73)*	*(72)*	*(73)*	*(70)*	*(73)*					
Fre-12	**.33****	-.25*	-.22*	.24*	**.95****	1				
(n)	*(73)*	*(72)*	*(73)*	*(70)*	*(73)*	*(73)*				
Fre-14a	.08	-.06	-.13	**.40****	**.32****	**.32****	1			
(n)	*(72)*	*(71)*	*(72)*	*(69)*	*(72)*	*(72)*	*(72)*			
Fre-14b	.14	-.10	-.18	.25*	**.42****	**.43****	**.73****	1		
(n)	*(71)*	*(70)*	*(71)*	*(68)*	*(71)*	*(71)*	*(71)*	*(71)*		
Fre-14c	.02	-.22*	-.08	.16	.20*	.20*	.26*	**.50****	1	
(n)	*(71)*	*(70)*	*(71)*	*(68)*	*(71)*	*(71)*	*(71)*	*(71)*	*(71)*	
Fre-17	.25*	-.24*	-.17	.08	**.32****	.27*	.09	.15	.16	1
(n)	*(59)*	*(59)*	*(59)*	*(57)*	*(59)*	*(59)*	*(59)*	*(58)*	*(58)*	*(59)*
Com-11b	.12	-.20*	-.12	**.33****	.16	.23	**.29****	**.30****	.11	.21
	(75)	*(74)*	*(75)*	*(69)*	*(65)*	*(65)*	*(65)*	*(64)*	*(64)*	*(56)*

Note. RBANS LO = Repeatable Battery for the Assessment of Neuropsychological Status – Line Orientation; HVOT = Hooper Visual Organization Test. [1]Transformed variables. *Italicized values represent sample size.* * Correlation significant at the .05 level
** Correlation significant at the .01 level (1-tailed).

Table 13

Bivariate Correlations of Visuoperceptual Measures to Routine/Automated Lane Deviation Parameters.

	Bas-3	Com-2a_3	Fre-16b	BD	RBANS LO	HVOT	Com-21_20b
Bas-3	1						
(n)	*(88)*						
Com-2a_3	**.54****	1					
(n)	*(73)*	*(78)*					
Fre-16b	**.35****	.11	1				
(n)	*(60)*	*(60)*	*(64)*				
BD	-.17	-.18	**-.31****	1			
(n)	*(88)*	*(78)*	*(64)*	*(109)*			
RBANS LO	.10	.03	.10	**-.44****	1		
(n)	*(87)*	*(77)*	*(64)*	*(108)*	*(108)*		
HVOT	.18*	.08	.12	**-.42****	**.23****	1	
(n)	*(88)*	*(78)*	*(64)*	*(108)*	*(107)*	*(108)*	
Com-21_20b	.28*	**.43****	.07	-.04	.12	.10	1
(n)	*(70)*	*(75)*	*(59)*	*(75)*	*(74)*	*(75)*	*(75)*

Note. BD = WAIS-IV Block Design; RBANS LO = Repeatable Battery for the Assessment of Neuropsychological Status – Line Orientation; HVOT = Hooper Visual Organization Test.[1]Transformed variables. *Italicized values represent sample size.*
* Correlation significant at the .05 level ** Correlation significant at the .01 level (1-tailed).

Table 14

Bivariate Correlations of Visuoperceptual Measures with Controlled/Tactical Lane Deviation

	BD	RBANS LO	HVOT	Fre-11_12	Fre-12	Fre-14a	Fre-14b	Fre-14c	Fre-17	Com-11b_19	Com-2b_11
BD	1										
(n)	*(109)*										
RBANS LO	**-.44****	1									
(n)	*(108)*	*(108)*									
HVOT	**-.42****	**.22****	1								
(n)	*(108)*	*(107)*	*(108)*								
Fre-11	-.20	**.29****	.21	1							
(n)	*(64)*	*(63)*	*(64)*	*(64)*							
Fre-12	.12	-.10	.24*	.05	1						
(n)	*(71)*	*(70)*	*(71)*	*(63)*	*(71)*						
Fre-14a	-.07	-.10	.19	.10	.12	1					
(n)	*(72)*	*(71)*	*(72)*	*(64)*	*(71)*	*(72)*					
Fre-14b	-.21*	.16	-.06	.18	.02	.13	1				
(n)	*(71)*	*(70)*	*(71)*	*(63)*	*(70)*	*(71)*	*(71)*				
Fre-14c	.04	-.07	.04	-.13	.14	.22*	-.16	1			
(n)	*(70)*	*(69)*	*(70)*	*(62)*	*(69)*	*(70)*	*(70)*	*(70)*			
Fre-17	.19	**-.38****	.02	-.08	.12	.16	-.07	.23*	1		
(n)	*(58)*	*(58)*	*(58)*	*(51)*	*(57)*	*(58)*	*(57)*	*(56)*	*(58)*		
Com-19	.01	.20*	.06	-.14	.10	.13	-.01	.10	-.30*	1	
(n)	*(76)*	*(75)*	*(76)*	*(59)*	*(64)*	*(65)*	*(64)*	*(63)*	*(55)*	*(76)*	
Com-11a	.11	.02	-.11	.08	.04	.12	-.16	.28*	-.05	.13	1
(n)	*(77)*	*(76)*	*(77)*	*(58)*	*(64)*	*(65)*	*(64)*	*(63)*	*(55)*	*(75)*	*(77)*

Table 15

Bivariate correlations of EF components with routine speed maintenance parameters.

	Visual Attentional Control	Working Memory Updating	Bas-3	Com-2a	Com-2b	Com-20b
Visual Attentional Control	1					
(n)	*(103)*					
WM Upd	.00	1				
(n)	*(103)*	*(103)*				
Bas-3	**-.25****	.02	1			
(n)	*(86)*	*(86)*	*(91)*			
Com-2a	**-.31****	-.10	**.61****	1		
(n)	*(73)*	*(73)*	*(72)*	*(76)*		
Com-2b	.02	.03	**.52****	**.38****	1	
(n)	*(73)*	*(73)*	*(71)*	*(75)*	*(75)*	
Com-20b	.03	.03	**.47****	**.32****	**.60****	1
(n)	*(72)*	*(72)*	*(71)*	*(75)*	*(74)*	*(75)*

Note. Italicized values represent sample size. **Correlation is significant at the 0.01 level (1-tailed). * Correlation is significant at the 0.05 level (1-tailed). Sample sizes in parentheses.

Table 16

Partial Correlations of EF Components with Routine Speed Maintenance Parameters, Controlling for Sex.

	Shifting/ Inhibition	Bas-3	Com-2a	Com-2b	Com-20b
Shifting/Inhibition	1				
(n)	(0)				
Bas-3	-.01	1			
(n)	*(64)*	*(0)*			
Com-2a	-.24*	**.54****	1		
(n)	*(65)*	*(65)*	*(0)*		
Com-2b	-.14	.20	**.32****	1	
(n)	*(64)*	*(65)*	*(65)*	*(0)*	
Com-20b	-.01	.30*	.22	**.56****	1
(n)	*(64)*	*(65)*	*(65)*	*(65)*	*(0)*

Note. **Correlation is significant at the 0.01 level (1-tailed). * Correlation is significant at the 0.05 level (1-tailed). Sample sizes in parentheses.

Table 17

Bivariate Correlations of Visual Attentional Control and WM Updating with Tactical/Controlled Speed Maintenance

	Fre-11	Fre-12	Fre-14a	Fre-14b	Fre-14c	Fre-17	Com 11a	Com-11b	V. Attn. Control	WM Updating
Fre-11	1									
(n)	*(73)*									
Fre-12	**.95****	1								
(n)	*(73)*	*(73)*								
Fre-14a	**.32****	**.32****	1							
(n)	*(72)*	*(72)*	*(72)*							
Fre-14b	**.42****	**.43****	**.73****	1						
(n)	*(71)*	*(71)*	*(71)*	*(71)*						
Fre-14c	.20*	.20*	.26*	**.50****	1					
(n)	*(71)*	*(71)*	*(71)*	*(71)*	*(71)*					
Fre-17	**.32****	.27*	.09	.15	.16	1				
(n)	*(59)*	*(59)*	*(59)*	*(58)*	*(58)*	*(59)*				
Com-11a	**.34****	**.38****	**.43****	**.44****	.17	.20	1			
(n)	*(64)*	*(64)*	*(64)*	*(63)*	*(63)*	*(55)*	*(75)*			
Com-11b	.16	.23	.29**	.30**	.11	.21	**.69****	1		
(n)	*(65)*	*(65)*	*(65)*	*(64)*	*(64)*	*(56)*	*(74)*	*(75)*		
V. Attn. Control	-.19	-.20*	**-.29****	**-.38****	-.01	.00	.02	-.03	1	
(n)	*(69)*	*(70)*	*(69)*	*(68)*	*(68)*	*(56)*	*(73)*	*(72)*	*(103)*	
WM Updating	.13	.17	-.05	-.04	-.07	.01	.03	-.06	.00	1
(n)	*(69)*	*(70)*	*(69)*	*(68)*	*(68)*	*(56)*	*(73)*	*(72)*	*(103)*	*(103)*

Note. V. Att. Control = Visual Attention Control. WM Updating = Working

Table 18

Partial Correlations of Shifting/Inhibition with Controlled/Tactical Speed Maintenance Parameters Controlling for Sex.

	Shifting Inhibition	Fre-11	Fre-12	Fre-14a	Fre-14b	Fre-14c	Fre-17	Com-11a	Com-11b
Shifting/ Inhibition	1.000								
Fre-11	-.06	1.000							
Fre-12	-.04	**.95*****	1.000						
Fre-14a	-.08	**.48*****	**.43****	1.000					
Fre-14b	-.24*	**.58*****	**.55****	**.66****	1.000				
Fre-14c	-.02	**.33****	.27*	**.39****	**.65****	1.000			
Fre-17	-.08	**.36****	.28*	.19	.12	.17	1.000		
Com-11a	-.12	**.41****	**.41****	**.45****	**.44****	.28	.18	1.000	
Com- 11b	-.10	**.36****	**.40****	**.38****	**.35****	.17	.22	**.60****	1.000

Note. N=49. *** Correlation significant at the 0.001 level. ** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level (1-tailed).

Table 19

Bivariate Correlations of EF Components with Routine LD Parameters.

	Bas-3	Com-2a_3	Com-21_20b	Vis. Att. Control	Shifting/ Inhibition	WM Updating
Bas-3	1					
(n)	*(88)*					
Com-2a_3	**.54****	1				
(n)	(73)	*(78)*				
Com-21_20b	**.28****	**.43****	1			
(n)	*(70)*	*(75)*	*(75)*			
Vis. Att. Control	.19*	.19	.20*	1		
(n)	*(84)*	*(75)*	*(72)*	*(103)*		
Shifting/ Inhibition	**.28****	**.35****	.10	.00	1	
(n)	*(84)*	*(75)*	*(72)*	*(103)*	*(103)*	
WM Updating	-.01	-.02	-.07	.00	.00	1
(n)	*(84)*	*(75)*	*(72)*	*(103)*	*(103)*	*(103)*

Note. Att. Control = Visual Attention Control. WM Updating = Working Memory Updating. **Correlation is significant at the 0.01 level (1-tailed). * Correlation is significant at the 0.03 level (1-tailed).

Table 20

Bivariate Correlations of EF components with Controlled/Tactical LD Parameters.

	Vis Att. Control	Shifting/Inh.	WM Updating	Fre-11	Fre-12	Fre-14a	Fre-14b	Fre-14c	Fre-17	Com-19	Fre-11a
Vis Att. Control	1										
(n)	*(103)*										
Shifting/ Inhibition	.00	1									
(n)	*(103)*	*(103)*									
WM Updating	.00	.00	1								
(n)	*(103)*	*(103)*	*(103)*								
Fre-11	.06	-.02	.01	1							
(n)	*(61)*	*(61)*	*(61)*	*(64)*							
Fre-12	-.01	.01	.08	.05	1						
(n)	*(68)*	*(68)*	*(68)*	*(63)*	*(71)*						
Fre-14a	.13	.01	-.08	.10	.12	1					
(n)	*(69)*	*(69)*	*(69)*	*(64)*	*(71)*	*(72)*					
Fre-14b	.02	-.19	-.02	.18	.02	.13	1				
(n)	*(68)*	*(68)*	*(68)*	*(63)*	*(70)*	*(71)*	*(71)*				
Fre-14c	.02	.17	.04	-.13	.14	.22	-.16	1			
(n)	*(67)*	*(67)*	*(67)*	*(62)*	*(69)*	*(70)*	*(70)*	*(70)*			
Fre-17	-.10	-.01	.20	-.08	.12	.16	-.07	.23	1		
(n)	*(55)*	*(55)*	*(55)*	*(51)*	*(57)*	*(58)*	*(57)*	*(56)*	*(58)*		
Com-11b_19	.10	-.19	-.12	-.14	.10	.13	-.01	.10	-.30	1	
(n)	*(73)*	*(73)*	*(73)*	*(59)*	*(64)*	*(65)*	*(64)*	*(63)*	*(55)*	*(76)*	
Fre-11a	.01	-.01	-.07	.08	.04	.12	-.16	.28*	-.05	.13	1
(n)	*(75)*	*(75)*	*(75)*	*(58)*	*(64)*	*(65)*	*(64)*	*(63)*	*(55)*	*(75)*	*(77)*

Note. *Correlation significant at the $p \leq .05$ level, 1-tailed.

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Appendix A: Summary of Cognitive Studies

Table 21

Summary of Findings on Cognitive Predictors of Driving Performance.

CITATION	SAMPLE	DRIVING MEASURES	COGNITIVE MEASURES		SIGNIFICANT RESULTS
		Outcome Measure	**Domain**	**Instruments**	
Stutts et al (1998)	Healthy older adults Age: M=73.6 N= 3238	Crashes and convictions 3 yrs retrospectively	♦ EF & processing speed ♦ Reaction Time ♦ Global cognitive functioning ♦ Traffic sign knowledge	• TMT A and B • AARP Reaction Time Test • Short Blessed cognitive scan • NC Traffic Sign Recognition	<u>Poisson regression :</u> • TMTB • AARP Reaction Time • TMTA (maybe) <u>Multivariate Poisson regression (control for age, gender, driving exposure)</u> • TMTA&B
Wadley et al	Clinical – Mild Cognitive Impairment	On-Road Test ○ L turns	♦ Global cognitive functioning	• Dementia Rating Scale	<u>Chi squared tests – MCI</u>

(2009)	and controls Age: 71.3(7.79) N (MCI) = 46 N (Controls)= 59	○ R turns ○ lane control ○ gap judgment ○ steering steadiness ○ maintaining speed ○ Total Score			patients • left turns • lane control • global driving rating • maintaining speed • gap judgment
De Raedt & Ponjaert-Kristofferse n (2001)	Healthy older adults Age: 78.6(6.8) N=84	On-Road Test – TRIP ○ Fit vs. unfit to drive	♦ Vision ♦ Selective attention ♦ Visuo-spatial ♦ Global cognitive	• Ergovision device • TMT A • Clock Drawing • MMSE	Stepwise discriminant function analysis • Ergovision • TMTA • Clock Drawing
Whelihan et al. (2005)	Clinical – questionable dementia (Clinical Dementia Rating= 0.5) and healthy controls Ages: 74.3/78.2; (7.3/9.2)	Rhode Island Driving Evaluation – on road test (RIDE): ○ Pass/fail as judged by examiner ○ RIDE scale score (31 items; total score 0-570)	♦ Global cognitive functioning ♦ Premorbid intelligence ♦ Visual attention	• MMSE • Dementia Rating Scale • American National Adult Reading Test • UFOV • WCST • Action Fluency • TMTA & B	Zero order correlations in Control group with RIDE: • age Hierarchical regression: • TMTB • UFOVI and • Maze Navigation Time

	N (Clinical) = 23 N (Controls) = 23		♦ Executive ♦ Visuospatial ♦ Language	• Maze Navigation • Ruff Figural Fluency • Brief Visual Memory Test-Revised Copy • Letter Cancellation Test • Visual Form Discrimination Test • COWA • Generative Naming of Animals	Discriminant analysis: • Maze Navigation time – accuracy of 80% to classify patients from controls Zero order correlations in patient group with RIDE score: • TMTB – time • Maze navigation – time • UFOV – Part I • UFOV – Part II • UFOV – Part III
Ball et al. (2006) (longitudinal follow-up	Healthy older adults: driving license renewal Age: 68.55(7.95) N=1910	Occurrence of at-fault MVCs after assessment at MVA field sites (4.18 – 5.13 yrs)	♦ GRIMPS – motor ability ♦ Memory	• Rapid Walk • Foot Tap • Arm Reach • Head/Neck Rotation • Cued and delayed recall • Symbol Scan	t-tests between participants involved in MVCs and not: • UFOV II • MFVPT Series of logistic regressions

of outcome)			♦ Scanning pattern/hemi-neglect ♦ Visuo-spatial ♦ Exec ♦ Speed of processing/visual attention	• Motor Free Visual Perception Test (MFVPT - Visual Closure Subtest) • TMTA&B • UFOV – II	<u>to identify predictors of</u> <u>MVCs:</u> • Annual mileage • Age • Gender • Hx of falling • MFVPT • TMTB • UFOV
Mathias & Lucas (2009) Meta-analysis	Majority of studies recruited general community participants & some recruited participants for driving license renewal Age: 74.9(5.9) N = 5797	On-road test; simulator studies; driving problems	Driving ability	<u>On-road test as outcome measure:</u> • Ergovision movement perception test • UFOV overall • Complex Reaction Time Task • Paper Folding Task • Dot Counting • Wechsler Memory Scale – Visual Reproduction • CVAT <u>Driving simulator assessments:</u> • Benton Line Orientation* • Clock Drawing • Driver Scan	

				• UFOV divided attention • WAIS Picture Arrangement* • MMSE* • UFOV selective attention* <u>Driving problems as outcome:</u> • TMT A&B • Stroop Color Word Test • UFOV – total • WAIS Block Design • Missing Object Subtest – Computerized Automated Psychophysical Test	
Lundberg et al. (1998)	Suspended drivers (traffic violations) with and without prior crashes & Healthy Controls Age = 74.7/75.7(6.15/ 6.57) N(Controls) = 31 N(Suspended) = 37	Crashes and driving violations – confirmed with records	♦ Reasoning ♦ Visuospatial/co nst-ructional ♦ Simple STM ♦ Visuo-constructional ♦ Verbal memory ♦ exec & processing speed ♦ reaction time	• WAIS-R Similarities • WAIS-R Block Design • WAIS-R Digit Symbol • Rey-Osterrieth Complex Figure Test (R-O CFT) • Free & cued recall of word list • Rey Auditory Verbal Learning Test (RAVLT) • TMT A and B	<u>Differences between crash-involved drivers, drivers with other violations, and controls</u> • Block Design • Recall R-O CFT • TMTA • Free recall of word list • RAVLT

			♦ Divided attention	• APT-PC (reaction time) • Continuous performance test (background) + intermittent instructions to press keys (foreground)	
Daigneault et al. (2002)	Healthy drivers with and without crash history (all male) Age= 69.4/80.1(2.3/4.1) N = 180	Self-reported number of accidents from 1992 to 1997; verified against records when possible	♦ Executive skills: inhibition, switching, planning, problem-solving, sequencing	• Stroop • WCST • Tower of London • Color Trails Test	Associations with self-reported crash history – verified for some • Stroop • WCST • Tower of London • Color Trails Test
Hoffman et	Healthy older adults	Performance in a driving	♦ visual attention ♦ visual scanning and attention	• UFOV • Driver Scan	Structural equation models to

al. (2005)	Age= 75.2(4.7) Relatively low mileage drivers N= 155	simulator with variety of components Performance assessed based on: ○ crashes ○ stoplight violations ○ speeding violations ○ lane position variation ○ proportion of missed ○ divided attention tasks	♦ vision	• Visual assessment	predict Driving performance as measured by 6 variables: • UFOV – all three subtests (34% of variance) • Driver Scan (36% of variance When both examined together: • Driver Scan better
Shanmugaratnam, Kass, & Arruda (2010)	Healthy older adults and younger adults Age = 22.20/65.56(13.02/3.79) N=62	Performance in driving simulator ○ driver control ○ maintenance behaviors ○ collisions & violations ○ attention and reaction time	♦ Processing speed ♦ Psychomotor dexterity ♦ Visual tracking ♦ Pattern memory; STM; working	• Choice reaction time task (CRT) • Grooved Pegboard (GP) • Pursuit Tracking Test • Delayed Match to Sample Test (DMS) • Continuous Performance	Diffs between younger and older: • CRT • time on GP • visuospatial DMS • CPT • WCST Correlations between neuropsych

			memory ♦ visual perception ♦ Sustained attention ♦ Exec function: decision making & problem solving; perseverance ♦ Sustained attention ♦ time-dependent accuracy of reasoning	Test (CPT) • WCST • Logical Reasoning Test	<u>perf & simulated driving:</u> • CRT • GP • DMS • WCST Age differences in driving performance: • Failure to stop at red lights (older adults – higher)
McKnight & McKnight (1999)	Older adults with history of incidents and drivers with no history (<u>no dementia screen</u>) N(incident-involved) = 253 N(no incidents) = 154	Structured road test based on one used by California Department of Motor Vehicles	♦ range of attention ♦ selective attention ♦ divided attention ♦ perceptual speed ♦ motion detection ♦ field dependence ♦ information processing ♦ short-term memory	• Automated psychophysical test (APT)	<u>Product-moment correlations with reported driving incidents</u> • All tests were significantly correlated with past report of incidents • Cognitive composite (errors) – r=0.54 • Attentional composite (errors) – r=0.51 • Perceptual composite (errors) – r=0.49 • Psychomotor composite (errors) – r=0.47

	Age = 80.6/75.2(7.39/ 7.78)		♦ delayed memory ♦ simple reaction time ♦ choice reaction time ♦ visual tracking		
Goode et al. (1998)	Older adults with a range of cognitive ability (<u>6 with dementia</u>) N= 239 Age = 70.36 (8.95)	History of crashes: Status as crash (1 or more) or non-crash (0 at-fault crashes) driver based on Department of Public Safety <u>crash records</u>, rated by blind raters for fault of driver	♦ cognitive screening ♦ processing speed ♦ executive functioning ♦ visual memory ♦ visuo-constructional skills ♦ speed of visual processing ♦ divided attention ♦ selective attention	• Mattis Organic Mental Syndrome Screening Examination (MOMSSE) • TMTA • TMTB • Wechsler Memory Scale – Visual Reproduction • Rey-O Complex Figure Test • UFOV	<u>Independent sample t-tests between safe and unsafe drivers:</u> In order of difference ♦ UFOV ♦ TMTA and B ♦ Rey-O immediate recall ♦ WMS-VR ♦ Rey-O Copy ♦ MOMSSE <u>Logistic regression:</u> Model 1: only cognitive variables, without UFOV: TMTA and MOMSSE accounted for 57% of unsafe drivers; sensitivity = 57.3 and specificity= 60.00

					(noncrashers) Model2: cognitive variables plus UFOV – significant; sensitivity = 76.6% and specificity = 78.3% Model3 (UFOV alone): sensitivity = 86.3% and specificity = 84.3%
Zook, Bennett, & Lane (2009)	Healthy older adults N=39 Age=74.03(6.4)	Standardized on-road driving task – BOST ○ Based on Department of Motor Vehicles evaluation ○ With increasing difficulty in driving environments ○ 60-minute driving	♦ cognitive screen ♦ visuospatial constructional ♦ executive functions	• MMSE • WAIS – III: Block Design • Hooper Visual Organization Test • Clock Drawing Test • Picture Completion • WAIS – III: Digit Symbol	1) <u>Significant correlations with driving test:</u> • WAIS III: DS • TMTA&B • WCST-Perseveration • WCST – Total Errors • Stroop • HVLT-Total Recall • IVA – response • IVA-Attention

course		• TMT B • Stroop Color Word Test • Wisconsin Card Sort Test	• CBDI • UFOVII & III 2) <u>Linear regression results :</u> • UFOV alone accounted for 31% of variance in BOST • CBDI alone accounted for 23% of variance in BOST <u>3) Stepwise linear regression</u> <u>results:</u> • IVA Response, Hopkins Total Recall and TMTB = 58% of variance
	♦ visuo-perceptual	• Motor-Free Visual Perception Test	
	♦ speed of processing	• TMT A	
	♦ learning/memory	• Hopkins Verbal-Learning Test – R (HVLT)	
	♦ sustained attention	• Integrated Visual and Auditory Continuous Performance Test (IVA)	
	♦ selective attention	• Ruff 2 & 7 Selective Attention	
	♦ speed of processing, selective attention, divided attention	• UFOV	
	♦ Comprehensive computer-administered cognitive measure: attention,	• Cognitive-Behavioral Driving Inventory (CBDI)	

			concentration, reaction time, rapid decision making, visual scanning, visual alertness, attention to detail, visual-motor coordination, sequencing		
Munro et al. (2010)	Healthy screened (MMSE) older adults N=1080 Age= 78(5.2)	Rate of lane change failure monitored by software installed in participants' cars	• visual ability (visual acuity, contrast sensitivity, and visual field) • cognitive screen • attentional visual field • auditory attention • Processing speed • Verbal learning and Short-Term Memory	• standard vision tests • Mini Mental State Exam • Custom software (not UFOV) • Brief Test of Attention • TMT A • Hopkins Verbal Learning Test-R • Beery Buktenicka Developmental	**1)** Univariate analyses <u>Significant associations with lane changing failures</u>: • Residence (rural over urban) • TMTB • Brief Test of Attention (auditory attention) • Visuo-motor integration (copying figures of increasing difficulty) • Visual attention **2)** Multivariate analyses: • Residence (rural versus urban) • Brief Test of Attention • Visuo-motor integration

		♦ Visuoconstructional ♦ Executive function	Test of Visual-Motor Integration (VMI) • Tower of Hanoi • TMT B	
Ball & Rebok (1994)	Healthy older adults N=294 licensed drivers Age=71(SD not reported)	♦ Cognitive screen ♦ Vision tests ♦ Executive function ♦ Visuospatial/constructional ♦ Visual attention ♦ Visual processing speed; selective attention; divided	• MOMSSE (Mattis Organic Mental Status Syndrome Examination) • Visual acuity, contrast sensitivity; disability glare; stereopsis; color contrast sensitivity • TMT B • WAIS-R Block Design • Rey-Osterrieth Test • Visual Attention Analyzer I, II, III • UFOV	<u>Structural equation modeling:</u> • UFOV and Mental Status accounted for 28% of crash frequency variance • Central and peripheral vision accounted for 30% of UFOV variance • UFOV best at identifying crash-involved drivers by ROC curves

			attention		
Freund, Gravenstein, Ferris, Burke, & Shaheen (2005)	Healthy older adults N=109 Age range: 61-96 (mean and SD not reported)	Performance in a STISIM Drive simulator *Allowed for a 10 minute practice/acclamation period* ○ hazardous errors, ○ traffic violations, ○ rule violations Drivers categorized into: ○ Safe ○ Restricted ○ Unsafe ○ Other/Unknown	♦ Executive and visuoconstructional skills	• The Clock Drawing Test (CDT) with 4 separate scoring methods: ○ Rouleau ○ Mendez ○ Manos ○ Freund	<u>ROC Analysis</u> • All scoring methods for the CDT were correlated with one another (r_s range: 0.75-0.82) • CDT cut-off score of 4 - predictor of unsafe driving status: (sensitivity, 64.2%; specificity, 97.7%)
de Raedt & Ponjaert-Kristofferse n (2001).	Healthy older drivers (some referred for evaluation due to accidents) N=84 Age = 78.6(6.8)	Standardized road test on 35-km course (TRIP): ○ Anticipation ○ Visual behavior/ communication ○ Mechanical operations/reaction ○ Traffic signals perception/reaction	♦ Visuo-perceptual ♦ Visuo-spatial (+WM component)	• Movement Perception subtest (Ergovision) • Paper folding task: has WM component	63% of participants self-reported at-fault accidents in last 12 months <u>Significant correlations:</u> • MVP & Road Test = .73

○ Lateral position on road/steering control ○ Understanding/ perception/quality traffic participation ○ Distance from car in front/adjusting ○ Total score Self-reported at-fault accidents in last 12 months	♦ Visual attention – divided, selective, visual processing speed ♦ Executive: ♦ Cognitive flexibility – *may be similar to N-back* ♦ Mental flexibility – *(similar to Stroop)* ♦ Selective attention ♦ Divided attention	• UFOV • Van Zomeren's Reaction Time device • Zimmermann/Fimm's Incompatibility task – • Brouwer's Tracking Dot-Counting task (reaction time) – visual scan in moving environment	• Paper fold & Accidents = -.33 • Paper fold & Road Test = .42 • UFOV & Accidents = 0.32 • UFOV & Road Test = -.66 • Selective attention & Accidents = .36 • Selective attention & Road Test = -.55 • Dot counting & Road Test = -.44 • Tracking task & Road Test = -.39 • Incompatibility & Road Test = -.36 <u>Planned correlations with specific driving parameters</u> • Paper-folding & anticipation = .47 • UFOV & anticipation = -.66 • MVP & anticipation = .65 • Vis behaviour/ communication & UFOV = -.60 • Vis. behavior/ communication & Dot counting = -.43 • Mechanical operations & Incompatibility = -.37

- Mechanical operations & flexibility = -.45
- Traffic signals & MVP = .59
- Traffic signals & Dot counting = -.37
- Lateral position & Tracking = -.37
- Understanding/perception/quality & paper folding = .44
- Understanding/ perception/quality & UFOV = -.61
- Understanding/perception/quality & MVP = .68
- Distance from car in front & MVP = .70

Regression (number of accidents)

- R^2 = 0.19: Cognitive flexibility & Visuo-spatial

Regression (road test score,

controlling for age)

- R^2 =0.27 (age alone)
- R^2 = 0.67 (age; MVP, UFOV, Cognitive Flexibility, Selective Attention)

De Raedt & Ponjaert-Kristofferse n (2000).	Healthy older drivers (some referred for evaluation due to accidents) N=84 Age = 78.6(6.8)	Standardized road test on 35-km course (TRIP): 3 factors/scales Self-reported at-fault accidents in last 12 months Accidents at crossroads: ○ 1a. Accidents involving traffic coming from the right with right of way while driving straight on ○ 1b. Accident involving traffic coming from the left with right of way and left turns Other accidents: ○ 2a. Rear-end	♦ Visuo-perceptual ♦ Visuo-spatial (+WM component) ♦ Visual attention – divided, selective, visual processing speed ♦ Executive: ♦ Cognitive flexibility – *may be similar to N-back* ♦ Mental flexibility – *(similar to Stroop)* ♦ Selective attention	• Movement Perception subtest (Ergovision) • Paper folding task: has WM component • UFOV • Van Zomeren's Reaction Time device • Zimmermann/Fimm's Incompatibility task – • Brouwer's Tracking Dot-Counting task	<u>Discriminant analyses involving accidents in 1a</u> • UFOV <u>Discriminant analyses involving accidents in 1b</u> • Paper Folding Test <u>Discriminant analyses involving accidents in 2a</u> • Incompatibility Test <u>Discriminant analyses involving accidents in 2b</u> • Tracking test

		collisions and side-swipes ○ 2b. Parking accidents	♦ Divided attention	(reaction time) – visual scan in moving environment	
Lincoln et al (2010).	Older adults with dementia N=65 Age = 75.18(6.79)	The Nottingham Neurological Driving Assessment (on-road test) – categorical overall ratings of definitely unsafe, probably unsafe; probably safe; definitely safe	♦ Cognitive screen ♦ visual scan ♦ immediate and delayed recognition ♦ Executive function	• Mini Mental State Exam (MMSE) • Stroke Drivers Screening Assessment (SDSA) (dot cancellation) • Salford Objective Recognition Test • Stroop color word test • Delis-Kaplan Executive Function System TMT • Behavioral Assessment of Dysexecutive Syndrome	Equation made up of all cognitive measures, excluding Trail Making Test correctly classified 76% of participants as safe or unsafe. Greatest weights in the equation were reserved in order for • VOSP (6.906) • BADS (1.412) • MMSE (4.272) • SORT delayed (3.058)

				(BADS) (key search and rule shift raw scores)	
			⬩ visuospatial perception ⬩ speed of info processing	• The Visual Object and Space Perception Battery (VOSP) • Adult Memory and Information Processing Battery (AMIPB)	
Richardson & Marottoli (2003)	N=35 drivers aged 72 and up (Mean age=80.2) Majority were male	Standardized on-road driving test: ○ 20-mile course; 45-60 min long ○ 36 items with a maximum total Driving score of 72 (no details on items provided)	⬩ cognitive screen ⬩ visual memory ⬩ visuospatial skills ⬩ visual attention ⬩ executive	• MMSE • WMS – Logical Memory & Visual Reproduction Memory • Hooper VOT • Number cancellation task • TMTB • Symbol-Digit	<u>Significant partial correlations (controlling for visual acuity) with Driving score:</u> • Visual attention (number cancellation) (r = 0.43) • Visual memory (WMS Visual Reproduction Memory) (r = 0.40) • TMTB (r = -0.38) <u>Correlations of individual driving variables with 3 cognitive</u>

			function ♦ concentration, rapid decision making, visual-motor speed ♦ simple, choice, complex reaction times	Modalities test • Experimental measures	<u>measures above</u>: • Visual attention correlated with 25 out of 36 items (r_s range: 0.35 – 0.58) • TMT B - speed of entry into highways (r = -0.48)
Adrian et al (2011).	Healthy older adults, screened for dementia N= 42 Age = 66.75(5.46)	TRIP On-road test protocol: 11 variables same as used in de Raedt et al. studies o Total score (range: 65-260)	♦ cognitive screen for dementia ♦ executive function ♦ inhibition ♦ shifting ♦ updating	• ScreenDEM • Stroop; Incompatibility Test; Go/No-Go • Plus-minus task; Number Letter Task; Flexibility test; TMT B • Letter Memory Test (LMT); Operation Span Task; Letter-Number Sequencing	<u>Controlled for age and gender in analyses:</u> • age was associated with TMTA; flexibility test; LNS; TRIP score • gender: men better at LMT & TRIP scores <u>Significant Pearson's Product-Moment Partial correlations</u>

			♦ speed of informaiton processing ♦ visuospatial / constructional	(LNS) • Symbol Search • TMT A • Bourdon-Wiersma test • Coding subtest of WAIS III • Block design test	(controlling for age and gender) (r-values): • TMT B minus A : .27 • Plus-minus task: .26 • Operation span task: .30 • Extraversion trait: -.30 A stepwise linear regression retained only: • age • gender • extraversion
Baldock et al. (2007)	Healthy older adults and clinical: older adults referred by the Driver Assessment Rehabilitation Service N (healthy) =82 N (clinical) = 8 Age = 74(6.2)	Standardized driving test (40 mins – 1 hr.): included multiple difficulty levels: ○ Weighted error score	♦ Depression and anxiety ♦ Visual functioning (acuity and contrast sensitivity) ♦ head-neck mobility	• Geriatric Depression Scale and State Trait Anxiety Inventory • Snellen Static Visual Acuity test; Pelli-Robson Contrast Sensitivity test • Goniometer	Pearson's Product Moment Correlations (p<0.01) with error scores from on-road test, r_s • contrast sensitivity (-0.33) • speed of info processing (-0.32) • visuospatial memory (-0.30) • visual attention (range: 0.30 – 0.46) • age

			♦ mental status ♦ speed of info processing ♦ visuospatial memory (working memory component) ♦ selective and divided attention, as well as Reaction Time	• Modified Mini Mental (3MS) • Symbol-Digit Modalities test • Wechsler spatial span • Computerized Visual Attention Test (modeled after UFOV, but includes moving, rather than static stimuli)	<u>Stepwise linear regression (p=.05), partial R^2s:</u> -controlled for age -model accounted for 34% of variance: • Two types of reaction times (from Computerized Visual Attention Test) (0.21 & 0.05) • Binocular contrast sensitivity (0.04) • Total spatial span (0.04)
Stav et al. (2008).	Healthy older adults N=123 Age =75.3(6.3)	Standardized road test – good psychometrics of validated driving course; included at least 3	♦ Cognitive screen ♦ vision (visual acuity, contrast sensitivity, visual field testing)	• Mini Mental State Exam • Stereo Optical Inc. vision testing machine • Functional Acuity Contrast Test	Regression (Global Rating Score), r_s(all p-s<0.001): • Contrast sensitivity A-E: (0.34 - 0.51) • MMSE total score (0.39) • UFOV rating (-0.58)

		examples of each maneuver at each level of complexity of the course ○ Global Rating Score (0-3) assigned – measure of overall safety	♦ executive skills ♦ working memory ♦ visual scanning ♦ memory span ♦ visual perceptual abilities ♦ visual attention + visual info processing speed	• TMTB • Digit-Symbol Modalities Test (DSMT) • Letter Cancelation • Digit-Span task (WAIS-R) • Motor Free Perceptual test • UFOV	• TMT B (time) (-0.51)
Anderson et al (2005).	Healthy older adults & clinical – older adults with mild dementia N (mild	Driving simulator assessment – Composite Score	♦ verbal memory ♦ visual memory ♦ delayed visual	• Rey Auditory Verbal Learning Test • Benton Visual Retention Test • Delayed Complex Figure Test (CFT)	<u>Neuropsychological composite score Spearman correlation with simulator composite</u>: *r* = 0.34;

dementia)= 70 N (healthy controls) = 132 Age = 71.1 (7.6)		recall (also constructional) ♦ spatial perception ♦ visuomotor/visuo-constructional ♦ processing speed ♦ executive functions ♦ language/executive function	• Judgment of Line Orientation (judgment of LO) • Complex Figure Test • WAIS III Block Design • TMT A • TMT B • COWA	p<.001) <u>Individual cognitive test Spearman correlations with simulator composite</u> • judgment of LO = 39% • Block Design = 32% • TMTB (time) = -28% • AVLT = 28% • BVRT errors = -24% <u>Comparisons between drivers who crashed in simulator and those who did not:</u> • Visuomotor: CFT copy, *p*=.002; Block Design, *p*=.003 • Executive: TMTB, *p*=.001 <u>Associations with subsequent</u>

					state crash records • memory: AVLT, p=.004 • CFT recall, p=.036

Szlyk et al
 	
(2002)
	Participants with suspected dementia (based on Mini Mental State Exam) and healthy controls
	
	N (Clinical) = 8
	N (Controls) = 14
	
	Age=76.5/77(7/6.2)
		Driving simulator test
		
		○ Mean speed
		○ Brake pedal pressure
		○ Number of lance boundary crossings
		○ Braking response time to a stop sign
		○ Slope of the braking response curve
		○ Horizontal and vertical eye movement
		○ Number of times the participant ran stop signs and stop lights
		○ Number of near accidents
		○ Simulator accidents
			♦ Attention
			
			♦ Visual memory
			
			♦ Executive function
			
			♦ Visuospatial/constructional
			♦ Processing speed
				• The Seashore Rhythm Test
				• Digit Span
				• Visual Reproduction I and II (WMS)
				• TMT B
				• Block Design
				
				• Digit Symbol
				
				• TMT A
					Pearson and Spearman correlations (p-s range from 0.5 to 0.001)
					
					• Lane boundary crossings:
					  • Short term verbal memory
					  • Delayed visual memory
					  • Visuospatial/constructional
					  • TMT A & B
					  • Attention
					  • Processing speed
					• Speed:
					  • Verbal memory
					  • Visuospatial/constructional
					  • Executive skills
					• Brake pedal pressure:
					  • Short-term and delayed verbal memory
					  • Attention
					  • Executive skills

Note. Abbreviated measure names: COWA – Controlled Oral Word Association; MMSE – Mini Mental State Exam; TMT A and B – Trail Making Test Parts A and B; WAIS – Wechsler Adult Intelligence Scale (various editions); WCST – Wisconsin Card Sort Test.

Appendix B: Measures and Materials

Ohio University Consent Form

Title of Research: Neuropsychological Predictors of Driving Hazard Perception in Older Adults (Session I)

Researchers: Julie Suhr, Ph.D., & Deb McAvoy, Ph.D.

You are being asked to participate in research. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

Explanation of Study

This study is being done because we are interested in learning more about how changes in cognitive skills associated with aging are related to challenging driving situations. If you agree to participate, you will be asked to complete several measures of thinking and memory skills. Some of these are paper and pencil puzzle type tasks and some are computerized. Then you will take a short stroll over to another building, in which you will get to participate in a driving situation using a simulator. You will be seated in the simulator and have eye tracking equipment placed upon you. Then the controls of the simulator will be explained to you and you will complete a brief training protocol to help you become familiar with the simulator and how it works. Then you will experience three brief driving situations in which you will be exposed to various hazardous driving situations. We will measure your reaction to those hazards (your eye tracking towards them, and your driving response such as braking, etc.). Between each driving situation, you can take a brief break. Your participation in the study will last about 4 hours.

Risks and Discomforts

Risks or discomforts that you might experience are anxiety about your performance on either the cognitive or driving tests, and possible motion sickness during the driving simulator. You will be provided with clinical feedback about your performance on the cognitive tests by Dr. Suhr, a licensed psychologist, which should help to minimize any anxiety you experience about the cognitive tests. The driving simulator tests were specifically designed to be challenging and to increase likelihood of driving errors or crashes and are NOT clinical evaluation of your driving skills.

With regard to your potential for driving sickness, the training protocol described above is designed to acclimate you to the driving scenario and has been shown by Dr. McAvoy to minimize your risk for motion sickness; however, if you experience such symptoms you can take a rest or discontinue participation at any time.

Benefits
This study is important to science/society because results could provide a better understanding of the kinds of cognitive changes that are related to changes in driving skills in aging, and potentially lead to better interventions to minimize these risks. Individually, you may benefit from receipt of feedback about your own cognitive changes.

Confidentiality and Records
Your study information will be kept confidential by creating a unique identifying code for your data. This will consist of: the first letter of your mother's first name, the first letter of your father's first name, the month of your birth, and the actual date of your birth (NOT the year). For example, a participant whose mother's name is Mary and whose father's name was Bill, and whose birthday was on June 5^{th}, would have the code MB0605. Thus, no code key will be kept and the number will not allow you to be identified by your code. In addition, all data from the study will be maintained in locked files or on password protected computers, accessible only to the Study Directors and their research assistants.

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:

* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

Compensation
As compensation for your time/effort, you will receive 40 dollars. If you discontinue the study early, your compensation will be prorated (i.e., you will receive 10 dollars for every completed hour of the 4-hour study).
Please note that, because University funds will be used to compensate you, your name and address will need to be provided to the Finance Office at OU. This does not identify what study you were in or any of your study results, but simply indicates that you received compensation for study participation.

Contact Information
If you have any questions regarding this study, please contact Dr. Julie Suhr, suhr@ohio.edu, 593-1091, or Dr. Deborah McAvoy, mcavoy@ohio.edu, 593-1468.

If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

By signing below, you are agreeing that:

- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- you have been informed of potential risks and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study
- you are 18 years of age or older
- your participation in this research is completely voluntary
- you may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature____ Date___________________

Printed Name____

Demographics and History Questionnaire

INTERVIEW FORM (2011)

ID NUMBER_________________ DATE ________________ ______

(ID is first initial Mom's name, first initial Dad's name, MO of birth, DA of birth (numerical)

Sex M F Age _____ Race/ethnic background ___________ Date of birth: ______________

How many years of education have you completed?

Are you currently employed? If YES, what is your job?

If NO, are you retired? What was your job? How long since you retired?

Have you ever been diagnosed with a learning disability? If so, what type?

Have you ever lost consciousness due to a blow to the head or other head injury? Y N

If yes, for how long did you lose consciousness? _________ Did you see a doctor? _____________Were you hospitalized? ________________ What was your diagnosis, if any? ________________ Did you have any form of treatment?__________________

Have you ever had: (if yes to any, get details about when and what, treatment)
Seizures? Y N (details here: ____)
Brain tumor? Y N (details here: ____)
Stroke? Y N (details here: ____)
Heart attack? Y N (details here: ____)

Do you have any other neurological/medical problems? (please list, and list when diagnosed if known) (write none for none)

What current medications do you take? (please be specific with name, or at least descriptive by what the medication is supposed to treat – antihypertensive medication, for example) (write none for none)
Have you ever seen a mental health professional (psychiatrist, psychologist, counselor?) Y N

If yes, when (including currently) ___________________ For what diagnosis(es)?

____

Do you currently drive? Y N

If no, when did you last drive? (date) _____________________

If yes, how often do you drive? daily weekly monthly less than monthly

Do you restrict your own driving compared to when you were younger? If yes, how?

Driving History Questionnaire

1. Approximately how old were you when you got your driver's license? ________
2. Apart from a standard driver's license, did you ever hold **any other class of license**?

No_____ Yes______
If Yes, what kind? _________________ (e.g., bus, truck, tractor-trailer, etc.)

Using a scale from 0 to 4 answer the following scale, answer questions 3 through 5 below
(0 – never 1 – rarely 2 – occasionally 3 – often 4 – very often)

3. Over the past 2 years, how often have you driven on the following **types of roads?**

___ residential streets
___ main city streets
___ rural roads
___ freeways (e.g., e.g., I-70; 270)
___ highways (e.g.,33, 52,32)

4. Over the past 2 years, how often have you driven in new unfamiliar areas?_____

5. Over the past 2 years, how often have you driven on one-way trips that took 2 hours or longer? _____

6. Have you taken **any driving courses**? ___ No ___ Yes motorcycle course
If so, about **how long ago? ________________________**

7. In the past year, have you had any of these **problems when driving**?

Accidents involving another vehicle?	___ No __ Yes
Near misses (almost an accident)?	___ No __ Yes
Backing into things besides other cars?	___ No __ Yes
Getting lost?	___ No___ Yes
Traffic violations with loss of demerit points?	___ No ___Yes

(Note, this questionnaire was read over the phone to those who already participated, if they are willing to answer the questions. Anyone interviewed over the phone was also asked to re-create their study ID so that their scores can be linked to their already existing data.)

Newspaper Advertisement

Interested in helping us learn more about cognitive changes in aging that are related to driving skills?

We are looking for community-dwelling adults ages 60 and over who have been active drivers in the past 2 years to participate in a driving study, using a driving simulator. Your participation in the first part of the study will take about 4 hours and you will receive 40 dollars for your participation, as well as feedback about your performance on the cognitive tests. It is important for you to note that the driving simulator is NOT a test of your basic driving skills and does not measure your driving ability, and you will not receive feedback about your driving performance in the simulator.

To participate or to ask questions about the study, contact Dr. Julie Suhr at 593-0910 orsuhr@ohio.edu.

Driving Protocols

Neuropsychological Predictors of Driving Performance in Older Adults

Driving Protocols

1. Introduction to simulator

- **a.** Lane Keeping with Speed Control Adaptation
- **b.** Lane Changing Adaptation
- **c.** Lane Changing in Traffic Adaptation
- **d.** Stopping Adaptation
- **e.** Turning Adaptation

2. Basic Driving Scenario (Scenario 1) – Approximately 14 minutes in length, if driving at speed limit

- Begin in a suburban setting in a parallel parked position[1] then transition[2] to 2-lane straight roadway along rolling to flat terrain in a rural setting.
- 55 miles-per-hour speed limit
- Light to moderate traffic volumes

a. 2-mile straight section of roadway[3] (2.2 minutes at speed limit)

b. 3-mile straight section of roadway with passing and no-passing section. Position a very slow moving vehicle in the no-passing section and continues into the passing section[4] – target vehicle traveling approximately 25 mph with minimal opposing traffic slow moving vehicle must turn into driveway before participant transitions to next task. (3.3 minutes at speed limit to 7.2 minutes at 25 miles-per-hour).

c. 1-mile straight section of roadway with deer entering from far side of road – unobstructed view[5] at speed limit of 55 miles-per-hour – deer enters at ¼- ½-mile mark (1 minute at speed limit)

d. ½-mile straight section of roadway with 2-way stop controlled intersection at ¼-mile[6] mark where participant is required to stop and continue straight with moderate traffic flow on road with

e. 1-mile straight section of roadway with deer entering from left side of road – unobstructed view[5] at speed limit of 55 mph – deer enters at ½-mile mark (1 minute)

f. 1-mile straight section of roadway ending at 4-way stop T-intersection[10] where the participant will have been informed prior to beginning the scenario to turn tight[7] and park on the right side of the road8 at a designated sign[9]

3. Freeway Driving Scenario (Scenario 2) – Approximately 13 minutes in length, if driving at speed limit

- Begin in a suburban setting in a parallel parked position[1] along rolling flat terrain.
- 55 miles-per-hour speed limit.
- Light to moderate traffic volumes

a. 1-mile straight section of roadway in suburban setting (1 minute at speed limit)

b. Participant enters 2-lane freeway with speed limit of 65 miles per hour through ramp on right side of roadway[11] and merges onto freeway[12] with moderate traffic volumes (1 minute at speed limit)

c. After 3-mile straight freeway section, participant approaches 3-freeways merging into one with increasingly heavier traffic volumes[13] – at 1-mile increments there are entrance and exit ramps with heavy entering and exiting volumes[14] – participant does not exit at these two ramps (3 minutes at speed limit)

d. Along another 3-mile straight freeway section, changeable message signs will be posted at 1 to ½-mile increments asking the subject[9] to exit at next ramp due to freeway closure caused by a fatal crash[15] (3 minutes at speed limit)

e. Exit ramp terminates at traffic signal in urban district with 25 mile-per-hour speed limit. Participant will travel straight following detour signs associated with freeway crash[9] (1 minute at speed limit)

f. 1-mile straight section with traffic signals at ½-mile increments. Before first signal, pedestrian will enter roadway between two vehicles on right side of road – obstructed view[16] (2.4 minutes at speed limit)

g. At second traffic signal, detour signs posted inform driver to turn left with unprotected left turn phase[17] and then park near the "Park Here" sign on the right side of the road (1 minute)

4. Complex Driving Scenario (Scenario 3) – Approximately 14 minutes in length, if driving at the speed limit.

- Begin in a suburban setting in a parallel parked position[1], then transition[2a] to 2-lane straight roadway along rolling to flat terrain in a rural setting.
- 55 mile-per-hour speed limit
- Light to moderate traffic volumes

a. 2-mile straight section of roadway[3] (2.2 minutes at speed limit)

b. Transition to 5-lane straight suburban section[11a] with 45 mile-per-hour speed limit[2b]

c. 2-mile straight section of roadway with notification of work zone ahead (2.7 minutes at
speed limit)

d. Work zone closes both lanes in direction of travel with open lane in the two-way-left-turn-lane[11b,18,19] under light to moderate traffic volumes – approximately 2-mile straight section (2.7 minutes)

e. 1-mile into work zone moderate rain[20a] begins (1.5 minutes at speed limit)

f. 1-mile after rain begins, the work zone ends (1.5 minutes at speed limit)

g. 2-mila section of 5-lane roadway through horizontal curves[21] with heavy rain[20b] at 45 mile-per-hour speed limit (2.7 minutes at speed limit)

h. After 2-mile section, straight roadway transition, rain ending and thank you note covering entire screen asking participant to stop the vehicle and put it into park.

Evaluation Notes:

1. Ability to leave a parked position.
2. Ability to maintain speed control.
3. Basic vehicular control.
4. Comprehension of no-passing signs and markings. Somewhat of ability to just distance of oncoming vehicles, but there are few oncoming vehicles to make this a worthy evaluation.
5. Reaction to unobstructed and unexpected event on side of roadway.

6. Ability to judge distance and speed of oncoming vehicles to determine if gap is adequate for maneuver.
7. Ability to turn right.
8. Ability to park along side of roadway in parking space. Use of turn signal to park.
9. Ability to follow a route.
10. Comprehension of stop sign.
11. Ability to change lanes.
12. Ability to enter a freeway.
13. Ability to negotiate high traffic volumes.
14. Ability to travel along freeways with entrance and exit ramps under high traffic volumes. Comprehension of signs – changeable message signs noting unexpected event.
15. Reaction to obstructed and unexpected event on side of roadway.
16. Ability to complete an unprotected left turn.
17. Ability to travel along multi-lane roadway.
18. Ability to merge in unexpected condition.
19. Ability to drive during nighttime conditions with inclement weather.
20. Ability of lane keeping with inclement weather.

Measures: Additional Psychometric Information

Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)

The Repeatable Battery for the Assessment of Neuropsychological Status is a relatively brief, but comprehensive screening instrument designed to specifically evaluate dementia, including mild cognitive impairment at the early stages of dementia, which generally takes approximately 30 minutes to administer in its entirety. It yields a Total Score, as well as individual scores on 12 subtests grouped into five neurocognitive indices: Immediate Memory, Visuospatial/ Visuoconstructional, Language, Attention, and Delayed Memory. In order to minimize practice effects, one of two equivalent forms was administered to participants: Individuals recruited from the neuropsychology laboratory participant pool who were likely exposed to the instrument in previous cognitive studies were administered Form B, whereas the remaining participants completed Form A. The RBANS was used as a screening measure to rule out early signs of undiagnosed dementia in the sample. Ranges of raw scores vary by subtest; the standardized total score ranges from 40 to 160. Construct validity and reliability has been established in community-dwelling older adults and in patients with Dementia of the Alzheimer's Type (Duff et al., 2003, 2004, 2005; Patton et al., 2003). Duff and colleagues (2008) demonstrated an optimal cut-off for distinguishing between healthy individuals and those with dementia at 1.5 SD below the mean for the demographically adjusted total score. In the present study total scores falling below this cut-off were used as an exclusionary indicator of possible dementia. In addition to dementia detection, the instrument has demonstrated sound ecological validity through associations of language and immediate memory domain scores with domains scores on the Clinical Dementia

Rating scale among individuals with dementia and mild cognitive impairment (Hobson, Hall, Humphreys-Clark, Schrimsher, & O'Bryant, 2010). Reliability coefficients for Attention and Visuospatial/Constructional Indices for the age group 60-89 range from 0.81 to 0.93; the inter-rater reliability was $r = 0.85$ (Randolph, 1998). The Line Orientation subtest from the Visuospatial/Constructional Index and the Coding subtest from the Attention index were utilized in the present study as described below.

Variables of Interest: Visuoperceptual Measures

RBANS Line Orientation. The Line Orientation total score from the Visuospatial/Constructional Index was used as one of the potential visuospatial predictors of driving performance, as drivers' awareness and understanding of objects in space is thought to be relevant to safe driving (Ranney, 1994; Rizzo & Kellison, 2010), and because Judgment of Line Orientation has been found to significantly predict driving performance in the meta-analysis by Mathias and Lucas (2009). The Line Orientation subtest requires examinees to judge the orientation and angle of two lines and identify their match from an array of 13 equal numbered lines radiating out from a single point and forming a semi-circular fan-like pattern that are pictured above. The examinee is given up to 20 seconds to identify each pair of lines in the 10 trials of the subtest. One point is awarded for each correctly identified line, resulting in a maximum score of 20 points for the entire subtest. Total raw score on Line Orientation were used as an independent variable. An independent study in a community-dwelling sample of older adults recorded a test-retest reliability of 0.59 for Line Orientation and 0.62 for the entire visuospatial/constructional index (Duff et al., 2005). Construct validity of Line Orientation is established by correlations with other visuospatial/constructional tests, namely the Judgment of Line Orientation Test and with the Rey Complex Figure test, copy condition total score, which were r=0.62 and r=0.79, respectively (Randolph, 1998).

Block Design (Wechsler Adult Intelligence Scale – IV). Block Design is a well-validated measure of visual perception and visuoconstructional skills from the Wechsler Adult Intelligence Scale – Fourth Edition (Wechsler, 2008a). The test is internally consistent, with alphas ranging from .80 to .89 in older adults (Wechsler, 2008b). Test–retest reliability over a mean of 22 days was .80. The Block Design subtest shows moderate to strong correlations with other measures of visual reasoning, visuoperceptual skills, and visuoconstructional ability (Wechsler, 2008). The test also has good demonstrated ecological validity. For instance, Block Design performance in 18- to 25-year-olds was moderately correlated to measures of everyday visuospatial skills; a significant amount of the variance in individual test scores on the Standardized Road Map Test of Direction Sense (a measure of spatial left-right discrimination) and the Everyday Spatial Abilities Test (Groth-Marnat & Teal, 2000) was accounted for by Block Design scores. Block Design has also been shown to be a good predictor of driving problems in older adults (Mathias & Lucas, 2009). The score used in the present study was the raw total score on the subtest.

Hooper Visual Organization Test. The Hooper Visual Organization Test (Western Psychological Services, 1983) is a brief instrument designed to measure one's ability to organize visual stimuli. The measure requires participants to view a set of 30 line drawings displaying a common object, such as a truck or a flower, that have been cut up into pieces and scattered on the page in a puzzle-like fashion, and to identify what each object would be if it were put back together. Total raw score was used in the present study. Split-half reliability, as established by Hooper (1948) in a sample of college students was r=0.82. Similar values have been recorded in populations with neurological problems as well (r=0.80; Gerson, 1974). The Hooper Visual Organization Test has been shown to successfully discriminate between groups of healthy, schizophrenic, and neurologically impaired individuals, with the neurologically impaired group having the lowest overall scores (mean = 13.7) and the control group scoring the highest (mean = 25.8) (Hooper, 1952). Construct validity can be determined from findings in healthy controls, as well as individuals with neurologically impaired naming abilities: in both groups, Hooper Visual Organization Test scores were correlated with other perceptual organizational measures (perceptual measures from Wechsler Adult Intelligence Scales - Revised accounted for 44% of the variance in Hooper Visual Organization scores), and no significant differences in performance were evident between those with impaired naming ability and healthy controls.

Variables of interest: Executive Function

RBANS Coding. The Coding total correct raw score from the Attention Index was used as one of the executive function predictors of driving performance, as ability to attend to several stimuli and switch between them is deemed to be an important skill in driving (e.g., Mantyla et al., 2009). During the Coding subtest, the examinee is given a page with rows of boxes with a number from 1 to 9 above each box, and a blank space below the number. At the top of the page is a key with a unique, simple geometric shape beneath each number. The examinee is required to use the key in order to complete a page, filling in the numbers corresponding to printed marks, with a time limit of 90 seconds (Randolph, 1998).

The test-retest reliability for Coding, as reported by an independent study was *r* = 0.83 (Duff, Beglinger, Schoenberg, Patton, Mold, Scott, & Adams, 2005). Construct validity, as represented by concurrent validity with other measures of executive skills, was reported via correlations of the attention index with the Arithmetic subtest of the WAIS-R – another measure which requires working memory – recorded at *r*=0.52.

Trail Making Test Parts A and B. The Trail Making Test (Reitan & Wolfson, 1985) was used as a classic measure of executive function, with a goal of tapping the working memory and set-shifting components specifically. The test is comprised of two Parts – A and B. Part A requires examinees to draw lines in order to sequentially connect 25 encircled numbers that are randomly distributed across a page. The subjects are instructed to draw the lines as quickly as they can. Trail Making Test B, on the other hand, requires the examinee to alternate numbers (1 – 13) and letters (A – L) while connecting them. Scores can be obtained both for the amount of time it takes to complete each task, and for the number of errors participants make. Due to the typical low frequency and variability of error scores in a healthy, community-dwelling population, the time (in seconds) to complete the Trail Making Test A was subtracted from the time to complete Part B, in order to derive a more pure measure of executive function.

Some consensus exists both in the research and clinical communities that Part A of the Trail Making Test loads on information processing speed factors and visuospatial skills (Crowe, 1998; Gonzalez-Blanch et al., 2006; Rios et al., 2004; Sanchez-Cubillo et al., 2009). For instance, in a multiple regression of measures derived from the Trail Making Test A and B, which were designed to isolate individual pure cognitive-perceptual components of the two tasks, Crowe demonstrated that the Trail Making Test A correlated most highly with visual search and speed.

Trail Making Test B score on its own, or in various additional indexes with Trail Making Test A (e.g., B-A or B/A; Arbuthnott & Frank, 2000; Lezak, 1995) has been more strongly associated with executive function, and more specifically task-switching or cognitive flexibility (Arbuthnott & Frank, 2000; Olivera-Souza et al., 2000; Perianez, Rioz-Lago, Rodriguez-Sanchez, Adrover-Roig, Sanchez-Cubillo, Crespo-Facorro, Quemada, & Barcelo, 2007; Rios et al., 2004; Stuss, Bisschop, Alexander, Levine, Katz, & Izukawa, 2001). Sanchez-Cubillo et al (2009) suggest that using a difference score calculated by subtracting TMT-A from TMT-B more accurately captures the pure executive component of this measure. A brain-behavior relationship for Trail Making Test B specifically has been supported by data from Stuss and associates. They were able to record significant differences between patients with damage to frontal regions to those with nonfrontal damage and healthy controls both on time for completion of Trail Making Test, and on errors on the Trail Making Test B. Error scores were further able to discriminate among various types of frontal damage, with participants with dorsolateral frontal damage scoring in the most impaired range. Further construct validity has been documented by Arbuthnott and Frank (2000) via associations between Trail Making Test B: Trail Making Test A ratio and an alternating switch task (r=0.45). The Trail Making Test is chosen for the proposed study due to its documented associations both with driving errors and crash history (e.g., Ball et al., 2006; Richardson & Marotolli, 2003; Stutts et al., 1998), and with performance on road tests (e.g., Adrian et al., 2011; Zook et al., 2009).

Useful Field of View. The Useful Field of View test (Visual Awareness Research Group, 2009) is a software-based instrument administered on a personal computer with a Windows operating system. In order to interact with the test, participants use a computer mouse and left-click on various objects on the screen. Test administration was conducted in accordance with instructions in the Users' Guide Version 6.1.4 (Visual Awareness, 2009). Each subtest administration included an introduction and instructions to the task on screen, and then allowed participants to practice the task for 4 trials, after which the actual subtest is administered. An examiner was present in the room during the administration of this task in order to address any questions or concerns that might arise.

The Useful Field of View is comprised of three subtests (1 through 3), each of which is purported to tap a different set of cognitive skills. The participant's task in each subtest becomes increasingly complex and relies on processing speed and divided and selective attention. The duration of stimulus presentation on the screen is gradually reduced for each subtest until the viewer is unable to respond correctly 75% of the time. Scores are generated individually for each subtest in milliseconds (msec.) with cut-offs indicative of driving risk (range 0-500). In addition, an overall risk category ranging from 1 to 5, where 1 indicates "Very Low Risk" and 5 indicates "High to Very High Risk" is generated. Score interpretation has been validated against retrospective and prospective vehicular crash risk by the authors (Ball et al., 1993; Owsley et al., 1998).

Useful Field of View I, which is designed to measure speed of visual processing, requires participants to identify an object that flashes in a white box in the middle of the screen as a car or a truck. Normal processing speed threshold duration is ≤ 30 msec. Divided attention, the ability to carry out two tasks simultaneously, is tested in the Useful

Field of View II, which requires participants to identify the object in the middle of the screen, and simultaneously determine the position of a second target, located at one of eight radially distributed positions in the screen's periphery. Normal divided attention threshold is ≤ 100 msec. Raw score on this subtest was utilized as a measure of executive function in the proposed study. Selective attention, which is the ability to attend to certain information, while ignoring task-irrelevant stimuli is tested in the Useful Field of View III. In this subtest, participants are asked to perform the same task as in Useful Field of View II; however, this time the peripheral target stimulus on the screen is embedded among a radial arrangement of distracters. The participant is required again to both identify the central object as a car or a truck, and determine the position of the peripheral object. The normal selective attention threshold is ≤ 350 msec. Raw score on the third subtest was used as an executive function variable in the proposed study.

Test-retest reliability, as assessed with a sample of 70 participants aged 65 years and above in an interval between 14 and 18 days ranged between 0.72 and 0.88, depending on subtest or composite category, with the Useful Field of View I having the lowest reliability, followed by Useful Field of View III, Useful Field of View II, and the composite score evincing the highest test-retest reliability (Visual Awareness, 1998). A prospective study of crash risk in 294 drivers (as indicated by state records) established the criterion validity of the Useful Field of View (Owsley, Ball, McGwin, Sloane, Roenker, White, & Overley, 1998). After adjusting for person-miles traveled, older drivers with a 40% or greater impairment in the Useful Field of View were 2.2 times more likely to crash during a 3-year follow-up period. When testing the Useful Field of View 's validity as related to performance on an on-road driving test, a study of 66 individuals referred for evaluations of driving ability determined that the Useful Field of View was significantly related to whether or not a driver passed the on-road test (odds ratio = 22.9). The probability of failing the on-road test was less than 0.10 for individuals scoring at 30% reduction or less, but jumped to 0.73 for 50% reduction or greater, and to 0.94 for those with a 60% reduction or more (Visual Awareness, 1998). Finally, a study in a high fidelity driving simulator found the Useful Field of View to be a sensitive indicator of the presence of dementia of the Alzheimer type (DAT), as well as an excellent predictor of driving performance (Rizzo, Reinach, McGhee, & Dawson, 1997).

Delis-Kaplan Executive Function System – Word-Color Interference Test (WCIT). The Word-Color Interference Test from the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) is a stand-alone Stroop-type measure (Stroop, 1935) designed to measure the executive inhibition function with an added switching component. The Delis-Kaplan Executive Function System Word-Color Interference Test includes two basic naming conditions a traditional interference condition, and a switching condition. In the basic tasks, participants are consecutively presented with a page of color patches and a page of words denoting colors printed in black ink and are instructed to name the targets for each condition as quickly as they can without making mistakes. In the interference condition, the stimulus consists of words denoting colors printed in different color ink, whereby examinees are instructed to name the ink color of each target as quickly as they can without making mistakes. Time for completion of this condition was used as one of the inhibitory executive function variables in the proposed study. In the switching condition, examinees view a page similar to that in the interference condition, but with some words enclosed in a black box. Individuals are then asked to follow the rule from the previous condition for all but the enclosed words – name the ink color; however they are to read the word and not name the ink color for the boxed words, thus requiring them to switch between rules. Scores are generated in the form of time required to complete each condition, as well as number of self-corrected and uncorrected errors. Originally, the intent was to use the time to complete the switching condition of this measure as an additional inhibition or shifting test, but many participants performed better or equally as well on this test, despite the presumed higher level of cognitive load, raising concerns about practice effects. Therefore this variable was not used in the final analyses.

Internal consistency reliability for the Word-Color Interference Test for individuals between 60 and 89 is reported to range between r=0.77 and r=0.81. Test-retest reliability for individuals aged 50 to 89 was between 0.50 and 0.57, depending on the condition. Multiple studies support the ecological validity of the Delis-Kaplan Executive Function System in relation to everyday functioning. For instance, in a sample of 72 community-dwelling individuals with a mean age of 69, out of a number of executive function tests, including those from the Delis-Kaplan System, Color-Word Interference was most predictive of individuals' performance on activities of daily living, as reported by care-takers (Jefferson, Paul, Ozonoff, & Cohen, 2006). The Delis-Kaplan Executive Function System has also been reported to be particularly sensitive to frontal lobe dysfunction, as opposed to other neurological conditions; in a study of patients with a variety of deficits, including some with frontal lobe lesions, The Delis-Kaplan Executive Function System scores were impaired in the individuals with frontal lobe lesions, whereas the remaining patients were performed in the impaired range on only one test of the system that required them to name the rules of sorts performed by themselves and the examiner (Delis, Squire, Bihrle, & Massman, 1992).

N-Back task. N-Back tasks are designed to measure the working memory component of executive function by requiring participants to rehearse and maintain a dynamic set of stimuli, while at the same time deciding whether a concurrently presented stimulus matches the one N items back. The present study utilized a computer-administered auditory letter one- and two-back task, during which the participant is presented with an auditory string of letters (via computer speakers) and is asked to press a key on the keyboard when the letter spoken is the same as the one immediately before it (for trial 1) and the one two letters back (for trial 2). The program generates a score based on the percentage correctly identified items, and the number of omission and commission errors. The variable utilized in the current study was the percentage correct score on the 2-back trial.

N-Back tasks are considered a classic measure of working memory in healthy and neurologically impaired individuals (Owen, McMillan, Laird, & Bullmore, 2005), with good 1-week reliability of accuracy scores (r = 0.54; Hockey & Geffen, 2004). Their association with prefrontal brain region activity has been established by functional neuroimaging studies and is consistent with other working memory and executive tasks (e.g., Tsuchida & Fellows, 2009). Furthermore, N-Back type tasks have been found to detect age changes in the effects of cognitive load (Jaeggi, Schmid, Buschkuehl, & Perrig, 2009).

Variables of Interest: driving assessment.

Driving simulator. The driving evaluation was conducted in a DS-600c Research Simulator (DriveSafety) for the purpose of evaluating driving performance. The DS-600c is a fully integrated, high performance, high fidelity driving simulator. It provides an 180-degree wraparound projector display and a full-width automobile cab (2004 Ford Focus), including a windshield, driver and passenger seat, center console, dash and instrumentation, as well as real-time motion simulation. The cab also includes visual channel computers that provide outputs to display screens in side and rear-view mirrors. The cab is mounted on a Q-motion platform that provides hybrid internal cues combining 2.5 degree pitch and 5-inch (12.7 cm) longitudinal motion. The simulator system includes advanced scenario authoring tools with an extensive library of roads, intersections, vehicle, traffic patterns and landscapes. The scenario building tool allows the ability to script specific actions. The simulator includes several standard data collection measurements and allows for up to 25 additional user defined measurements. All of the data collection measurements are collected approximately every 0.03 seconds.

Driving parameters. A number of driving parameters were recorded during the course of the driving simulator sessions to measure driving performance for each participant. As no singular standard criterion of driving performance has been established in the literature on cognitive predictors of driving (see Bedard, Parkkari, Weaver, Riendeau, & Dahlquist, 2010; Lee, Drake, & Cameron, 2002; Mathias & Lucas, 2009; Rizzo, Reinach, McGehee, & Dawson, 1997), in addition to reviewing relevant empirical reports that relate performance in a simulator to cognitive measures, theoretical models and findings regarding on-road driving safety risks for older adults (US Department of Transportation, National Highway Traffic Safety Administration, 2009) have been used for guidance in the selection and operationalization of variables. In addition, as the driving simulator scenarios have been designed in such a way that their relative difficulty and complexity gradually increases from the first to second and through the third scenario, the scenario during which driving parameters are measured is expected to indicate different driving skills. More details on these distinctions are provided in the discussion below. Consistent with the SAS model of controlled executive functioning and Ramsmussen (1987) and Michon's (1985) cognitive control models, Lee and colleagues conducted an empirical investigation of two sets of driving simulator criteria in healthy older adults – "performance indicators," which were postulated to require exercise of cognitive control in interacting with a dynamic driving environment ("regularly making interactive judgments and rapid decisions") and "operational parameters" requiring mostly automated responses in maneuvering a vehicle (Lee, Drake, & Cameron, 2002, p.140). The performance indicators for their study included speed violations, proper signaling, number of collisions, and the total length of running through the driving simulator scenarios. Automated parameters were related to proper vehicle positioning and trajectory and consisted of curvature error, heading error and steering wheel rate. The performance parameters were found to be associated with the age of the participants in the study, whereas operational parameters were unrelated.

Of note, as previously reviewed literature of motor vehicle crashes and incidents in older adults highlight certain settings and maneuvers that are particularly challenging to older adults and most associated with crashes in the population of interest, such as unprotected left turns, complex intersections where decisions regarding right of way have to be made, and changing lanes or merging onto a highway or freeway (e.g., McGwin &

Brown, 1999). Therefore, it is likely that these situations require controlled or tactical-level driving skills.

Similarly to prior research, two sets of driving variables were recorded and entered into analyses to reflect a) driving performance that requires controlled or tactical driving and b) driving performance that may be more routine or operational. Lane deviation, calculated by adding the maximum deviations to the right and to the left of the center-line of the driver's lane for any given stretch of the scenario, and speed maintenance, operationalized as the average velocity maintained during the respective portion of the scenario, were chosen as they have been shown to be most closely related to crashes based on aggregated large-scale transportation agency data. In addition, in an investigation of 496 older drivers (mean age=71.5) undergoing an on-road driving evaluation, di Stefano and McDonald (2003) found that the majority of errors associated with a pass or fail outcome of the test, termed hazardous errors by Dobbs et al (1997), ccurred when changing lanes, navigating an intersection or merging. Moreover, they also reported that the types of errors most associated with test outcome after hazardous errors included improper lateral lane position, overcautiousness (i.e., driving at too low speeds), and Lane deviation in this case is considered to be a proxy of swerving, which is associated with potentially dangerous driving behavior. Although the type of parameters (i.e., lane deviation or speed maintenance) were similar across the two categories of variables, the controlled vs. automated distinction was made based on the portion of the scenarios during which each parameter was measured.

Coding. The Coding total correct score from the Attention Index will be used as one of the executive function predictors of driving performance, as ability to attend to several stimuli and switch between them is deemed to be an important skill in driving (e.g., Mantyla et al., 2009). During the Coding subtest of RBANS, the examinee is given a page with rows of boxes with a number from 1 to 9 above each box, and a blank space below the number. At the top of the page is a key with a unique, simple geometric shape beneath each number. The examinee is required to use the key in order to complete a page, filling in the numbers corresponding to printed marks, with a time limit of 90 seconds (Randolph, 1998). The raw total score of correctly completed items (range 0- 89) will be of interest to the proposed study.

The test-retest reliability for Coding, as reported by an independent study was r = 0.83 (Duff, Beglinger, Schoenberg, Patton, Mold, Scott, & Adams, 2005). Construct validity, as represented by concurrent validity with other measures of executive skills, was reported via correlations of the attention index with the Arithmetic subtest of the WAIS-R – another measure which requires working memory – recorded at r=0.52.

Appendix C: Supplemental Analyses

Individual Correlations between Cognitive and Driving Parameters Contrary to Expected Direction

Visuoperceptual predictors of driving parameters.

Better performance on BD was associated with higher speeds while entering an off-/on-ramp, *r* (72) = -.25, *p*< .01, one-tailed and when merging onto a freeway, *r* (73) = .33, *p*< .01, one-tailed (See Table 12). There was a tendency for individuals with better visuoconstructional skills on BD to also maintain higher speeds while executing an unprotected left turn, *r* (59) = .25, *p*= .03, one-tailed. With regard to lane deviation variables, higher BD scores were associated with lower lane deviation while driving straight ahead in a city environment, *r* (64) = -.31, one-tailed *p*< .01 (See Table 13) and lower performance on the HVOT was marginally associated with larger lane deviation during routine rural driving in daytime conditions, *r* (88) = -.18, *p*= .04. Several negative relationships between visuoperceptual variables and *lane deviation* parameters during controlled/tactical driving also emerged: Individuals with higher Line Orientation scores had lower lane deviations when executing an unprotected left turn, *r* (58) = -.38, one-tailed *p*< .01; Line Orientation performance was also associated with lane deviation during lane-changing maneuvers during daytime conditions, *r* (63) = .29, one-tailed *p*= .01, and was a marginally significant predictor of lane deviation during nighttime lane changes, *r* (75) = .20, one-tailed *p*= .04.

In addition, poorer visuoperceptual/ constructional abilities on HVOT and BD showed a tendency toward associations with larger lane deviations during freeway entry and freeway driving with moderate to heavy traffic, respectively (one-tailed *p*-s= .02 and .04, respectively, see Table 14).

EF components as predictors of driving parameters.

Although characterized as a section requiring *automated/routine*, rather than controlled driving skills, higher speed during *routine* nighttime driving was also associated with better visual attentional control, r (73) = -.31, one-tailed $p < .01$, as was higher speed during *routine* daytime driving, r (86) = -.25, one-tailed $p = .01$. In addition partial correlations with Shifting/Inhibition approached significance for routine nighttime speed maintenance, r (64) = -.24, one-tailed $p = .03$.

In addition, contrary to expectations, individual *routine* lane deviation parameters were associated with Shifting/Inhibition, reflective of larger deviations in those with poorer inhibition and shifting abilities with regard to driving straight ahead in daytime, r (84) =.28, one-tailed $p < .01$, and nighttime conditions, r (75) = .35, one-tailed $p < .01$. Visual Attentional Control was a marginal predictor of *routine* lane deviation during daytime driving and lane deviation while driving on a rural road at night, r (84) =.19, one-tailed $p = .04$ and, r (72) =.20, one-tailed $p = .05$, respectively (See Table 19).

Supplemental Analyses

In the literature, the role of self-imposed modifications to driving habits in older adults has been investigated as a potential indicator of driving difficulties on one hand, and as a potential solution to driving proficiency deficits on the other (Diagneault, Joly, & Frigon, 2002; Ross et al., 2009; Okonokwo, Crowe, Wadley, & Ball, 2008). Within our sample of healthy community-dwelling adults, individuals who self-reported that they modify their driving in any way did not differ in age, sex or education from those who denied any driving habit changes. The groups did not exhibit differences in visuoperceptual skills, processing speed, visual memory or EF components. Nevertheless, they demonstrated larger deviations from the center of the lane in an aggregation of routine driving situations, $t(52) = 2.081$, $p = .03$.

In addition, a subsample of participants provided information within the Driving history questionnaire, which was used to separate the sample into those who self-reported any instance of motor vehicle crashes, driving-related incidents, violations or errors within the last year and those who did not report any incidents in the year prior to study participation. The incident and incident-free groups did not differ with regard to age, sex, levels of education, cognitive abilities (including EF components) or aggregate driving parameters. See Tables C1and C2 for means and other statistics.

Table 22

Cross-tabulation of driving restriction and sex

		Does not Restrict	Restrict	χ^2	Φ
Female	Count	24	39	2.47	.12
	Adjusted Residual	(-1.6)	(1.6)		
Male	Count	24	21		
	Adjusted Residual	(1.6)	(-1.6)		

Table 23

Demographic, Neuropsychological, and Driving Parameter Means for Driving Restrictors and Non-Restrictors

	Driving Self-Restrictions?				
	Yes	No	t	df	Sig. (2-tailed)
Age	68.28 (7.47)	68.38 (6.63)	.07	106	.95
Education	16.67 (3.29)	15.92 (3.17)	-1.20	106	.24
WAIS-IV BD	37.27 (10.15)	38.5 (9.66)	.64	105	.526
BVRT	7.03 (1.43)	6.58 (1.32)	-1.68	105	.096
TMT A[1]	1.55 (.15)	1.52 (.16)	-1.01	104	.316
RBANS LO[2]	.58 (.22)	.56 (.22)	-.45	104	.651
HVOT[2]	.80 (.15)	.80 (.18)	-.14	104	.889
Visual Attentional Control	.004 (1.02)	.005 (1.0)	.01	99	.993
Shifting/In-hibition	-.04 (.91)	.04 (1.12)	.41	99	.682
WM Updating	1.0 (1.05)	-1.1 (.95)	-1.01	99	.313
Aggr. Speed Routine	49.14 (4.28)	49.48 (3.62)	.36	68	.723
Aggr. Speed Controlled/Tactical	41.28 (3.42)	42.28 (2.58)	.59	49	.559
Aggr. LD Routine	2.52 (.48)	2.8 (.60)	2.13^{*}	67	.037

Note. [1]Log10 transformed variable; [2]Reversed and log10 transformed variable. $^{*}p \leq .05$.