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Neuropsychological Predictors of Driving Errors in Older Adults

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Abstract

Objectives—To identify neuropsychological factors associated with driving errors in older adults.

Design—Cross-sectional observational study.

Setting—Neuropsychological assessment laboratory and an instrumented vehicle on a 35-mile route on urban and rural roads.

Participants—One hundred eleven older adult drivers (ages 65–89 years; mean age 72.3 years) and 80 middle-aged drivers (age 40 to 64 years; mean age 57.2 years).

Measurements—Explanatory variables included age, neuropsychological measures (cognitive, visual, and motor), and a composite cognitive score (COGSTAT). The outcome variable was the safety error count, as classified by video review using a standardized taxonomy.

Results—Older drivers committed an average of 35.8 safety errors/drive (SD=12.8), compared to an average of 28.8 (SD=9.8) for middle-age drivers ($P<0.001$). Among older drivers, there was an increase of 2.6 errors per drive observed for each five-year age increase ($P=0.026$). After adjustment for age, education, and gender, COGSTAT was a significant predictor of safety errors in older drivers ($P=0.005$), with approximately a 10% increase in safety errors observed for a 10% decrease in cognitive function. Individual significant predictors of increased safety errors in older drivers included poorer scores on Complex Figure Test-Copy, Complex Figure Test-Recall, Block Design, Near Visual Acuity, and the Grooved Pegboard task.

Conclusion—Driving errors in older adults tend to increase, even in the absence of neurological diagnoses. Some of this increase can be explained by age-related decline in cognitive abilities, vision, and motor skills. Changes in visuospatial and visuomotor abilities appear to be particularly associated with unsafe driving in old age.

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Keywords

Neuropsychological tests; cognitive decline; safety errors; instrumented vehicle

INTRODUCTION

Many developed countries are about to enter a period characterized by a rapid rise in the number of older drivers. Older drivers have crash rates that are similar to those of high-risk younger drivers, and the potential personal and societal costs of crashes are high in this growing segment of the population. Older drivers are roughly three times as likely as younger adults to die in crashes of equal magnitude. They also are more likely than younger drivers to be injured and to require hospitalization. It has been estimated that drivers aged 65 and older will account for as much as 25% of driver fatalities by 2030, compared to just 14% presently.^{1,2}

Key to reducing the driving risks associated with aging is the identification of the specific age-related factors (cognitive, perceptual, physical, and behavioral) that account for the risk. The physical fragility that tends to characterize aging bodies is likely to account for much of the increased risk of injury and death due to crashes involving older adults, e.g., chest injuries and fractures are more in common in older vehicle occupants³. Likewise, aging of the brain is known to be associated with changes in cognitive abilities that may, in turn, affect driving safety. Cognitive status, rather than age, has been shown to be an independent predictor of on-the-road driving test (ORDT) performance.^{4,5} Some cognitive abilities are more important than others for driving performance. For example, memory difficulties may not impact on most aspects of driving, but visuospatial and attentional abilities may be critical for driving safety.⁶ The impact of aging on the ability to drive safely is complex. For example, some age-related changes, such as decreased speed of processing, may negatively impact driving safety, while other changes, such as increased caution, may actually improve driver safety.

In this study, we test whether specific age-related cognitive changes are associated with increased risk of driving safety errors. Standardized neuropsychological tests provide quantitative estimates of relatively specific cognitive abilities, and they have been found to predict driving performance in various patient populations such as Alzheimer's disease, Parkinson's disease, and stroke.⁷⁻⁹ We were interested in whether these same tests would prove useful in the prediction of driving safety in older persons without neurological disease. This could give better understanding of the contributions of specific age-related cognitive changes to unsafe driving. Specifically, identification of readily measurable cognitive factors that impact the aging driver may provide a basis for developing evaluations and interventions that may help mitigate these influences. For example, older drivers may be able to adopt compensatory strategies or use in-vehicle devices that are targeted at important age-related influences of driving safety.

METHODS

Subjects

Subjects were 111 older adult drivers (age 65 to 89 years; mean age 72.3) and 80 middle-aged drivers (age 40 to 64 years; mean age 57.2). These drivers were recruited from the general community surrounding Iowa City, Iowa, by means of announcements in local newspapers or public service announcements, visits to local churches, senior centers and living facilities, and from visitors to the medical complex who were not seeking medical care, such as family members or friends of patients. All participants held a valid state

driver's license and were still driving, had no neurological diagnosis or complaints, and no personal or family report of abnormal cognitive decline. Specific exclusion criteria included personal or family report of abnormal cognitive decline, documented neurological disease, brain lesions due to cerebrovascular or neoplastic disease, alcoholism, stroke, depression or other psychiatric conditions, vestibular disease, and motion sickness. This study was approved by the Institutional Review Board at the University of Iowa, and informed consent was obtained in accord with institutional and federal guidelines for human subjects' safety and confidentiality.

Off-road neuropsychological battery

All participants were tested on a battery of cognitive, visual, and motor tasks (Table 1). The tests included in the battery, along with the functions assessed by each test, and conceptual ranges or descriptions of the test scores, are listed below.

Cognition—Complex Figure Test – Copy (CFT-Copy): Visuoconstructional ability (0 to 36 points).¹⁰

Complex Figure Test – Recall (CFT-Recall): Anterograde visual memory after a 30-minute delay (0 to 36 points).¹⁰

Block Design Subtest of the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III Blocks): nonverbal reasoning with time constraints (0 to 68 points).¹¹

Benton Visual Retention Test (BVRT): Visual working memory (0 to 26 errors).¹²

Trail Making Test, Part A (TMT-A): Visual search and visuomotor speed (time-to-completion measured in seconds).¹³

Trail Making Test, Part B (TMT-B): Attentional set shifting, working memory (time-to-completion measured in seconds).¹³

Rey Auditory Verbal Learning Test (AVLT): Anterograde verbal memory after a 30-minute delay (0 to 15 words correct).¹⁰

Judgment of Line Orientation (JLO): Visuospatial perception (0-30 points).¹⁴

Controlled Oral Word Association (COWA): Cued word finding with time constraints, using letters C, F, and L (number of appropriate words verbalized).¹⁵

Cogstat: A composite measure of cognitive function calculated by assigning and summing standard T-scores (mean=50, SD=10) to eight tests from the cognitive test battery (CFT-Copy, CFT-Recall, Block Design, BVRT, TMT-B, AVLT, JLO, and COWA).⁷⁻⁹

Vision—Useful Field of View (UFOV): Visual attention, summing four subtest measures of loss (0-2000 points).¹⁶⁻¹⁷

Pelli-Robson chart: Visual contrast sensitivity (0-2.25 points).¹⁸

Early Treatment Diabetic Retinopathy study chart (ETDRS): Far visual acuity (FVA), expressed as LogMAR (logarithm of minimum angle of resolution), with 0 representing 20/20 vision (high scores are worse).¹⁹

Snellen chart: Near visual acuity (NVA), also expressed on LogMAR scale.¹⁹

Structure from Motion (SFM): Perception of motion in stimuli (5-30 points).²⁰

Motor ability—Functional Reach: Balance (positive distance measured in inches).²¹⁻²²

Get-Up-and-Go: Short-range mobility (time-to-completion measured in seconds).²²⁻²³

Grooved Pegboard: Fine manual dexterity (time-to-completion measured in seconds).¹³

Administration of road test

The experimental drive was conducted in an instrumented vehicle (IV) known as ARGOS (Automobile for Research in Ergonomics and Safety), a mid-sized car with an automatic transmission and hidden instrumentation and sensors.²⁴ Electronic data (steering wheel position, accelerator and brake pedal position, lateral and longitudinal acceleration, and vehicle speed) were recorded at 10 Hz. Four miniature lipstick-size cameras captured driver behavior (two views) and anterior environment (two views).

Each participant was seated in the driver's seat, with an experimenter in the front passenger seat to give instructions and operate the dual controls, if needed. The drive began after the driver acclimated to the vehicle on a short test drive. Road testing was carried out only during the day on a 35-mile route within and surrounding Iowa City. Testing was not performed in weather that might cause poor visibility or road conditions. Training and quality control protocols were followed to ensure consistency in the route taken and in the delivery of the instructions to the drivers.

Evaluation of safety errors

A certified driving instructor, not present during the actual drive, reviewed the videotapes to ascertain the frequency and type of safety errors committed by the participants.²⁵ This driving expert applied a taxonomy of driver error based on the Iowa Department of Transportation's Drive Test Scoring Standards (September 7, 2005 version), which included 76 error types (e.g., "incomplete stop", "straddles lane line", etc.) organized into 15 categories ("stop signs", "lane observance", etc.). Of the 76 error types, 30 were classified by our research team as "more serious," and the rest were considered "less serious". For example, if a participant entered an intersection on a red light, this would be judged as "more serious," since this behavior may lead to a near or actual crash. We tabulated the total number of safety errors, the number of safety errors within each category, and the total number of "more serious" and "less serious".

Statistical analysis

We compared the groups with respect to demographics, cognitive/visual/motor measures, and safety error outcomes using the Wilcoxon Rank Sum test. Multiple linear regression was used to adjust for age, gender, and education when comparing groups with respect to neuropsychological measures and safety errors. We also used multiple linear regression to test for associations between neuropsychological measures and total safety errors within the older adult group, adjusting for age, gender, and education. For these analyses, we expressed the regression coefficients in terms of the average difference in safety errors per one-standard-deviation difference in each neuropsychological measure, to allow comparisons of magnitude of effect sizes across predictors. In addition to examining the effect of neuropsychological tests individually, we modeled their simultaneous effects using multiple linear regression.

RESULTS

Table 1 presents demographic and neuropsychological descriptions of the two groups. The two age groups were similar in gender distribution, education, and self-reported driving frequencies. Inferior scores in the majority of tests of cognition, vision, and motor abilities were observed in older drivers.

As shown in Table 2, the older drivers committed an average of 35.8 total safety errors/drive, compared to an average of 28.8 for middle-aged controls—a 24% increase. They also had a higher rate of “more serious” errors (a 75% increase), as well as “less serious” errors (a 27% increase). The older drivers had a significantly higher risk of committing safety errors in seven categories: speed control (e.g., too fast or too slow), lane change (no head check), lane observance (lane deviations, touching lane line or centerline), parallel parking (failure to signal), railroad crossing (failure to check for train), starting and pulling away from the curb (failure to signal), and turns (failure to signal, turns into wrong lane).

Within the older adult group, increased age was predictive of total safety errors, with a mean increase of 2.6 more errors per drive observed for each five-year age increment ($P=0.026$). By contrast, there was no significant relationship between age and total safety errors observed in the middle-aged drivers ($P=0.423$). However, a formal Wald test, based on means and standard errors of the two groups, for comparing these two slopes was not significant ($P=0.173$). We performed additional exploratory analyses to try to pinpoint the age associated with a notable increase in safety errors. Our results were inconclusive, as we observed that many hypothesized thresholds in the range of 55 to 65 years gave measures of model fit that were very similar.

Table 3 shows that the older drivers with better overall cognitive function (measured by COGSTAT) tended to make fewer safety errors ($P=0.005$). Specifically, there was an increase of 3.6 safety errors (~10%) observed for a one-standard-deviation decrease (~10%) in cognitive function, adjusting for age, gender, and education. Significant increases in safety errors were also found in older drivers with poorer scores on individual tests, including Complex Figure Test-Copy ($P=0.039$), Complex Figure Test-Recall ($P=0.046$), Block Design ($P=0.045$), Near Visual Acuity ($P=0.043$), and the Grooved Pegboard task ($P=0.023$).

When predicting total errors in older adult drivers using non-composite measures, we found that age, Block Design, and the Grooved Pegboard task resulted in an appropriate balance of model fit (adjusted R^2 near the maximum achieved) and parsimony (e.g., only three predictor variables). According to this model (Table 4), an increase of one driving error was predicted by an increase of about three years in age, by a decrease of five points in Block Design, and by an increase of seven seconds on the Grooved Pegboard task. Table 5 illustrates how these three risk factors predict safety errors. For each of these risk factors, we chose low, medium, and high levels representative of the older in our study (i.e., approximate equal to the means $\pm$ one standard deviation of each factor). Across these ranges of risk factors, Table 5 shows that older drivers with high-risk profiles tend to commit noticeably more safety errors (about 30% more) than those with low-risk profiles, even when keeping age fixed. This model assumed that the factor effects were additive, which was supported by non-significant tests of interaction ($P=0.131$).

DISCUSSION

Overall, we found that older adult drivers committed 24% more total safety errors than middle-aged drivers, with seven out of 15 driving error categories significantly higher in the older group. We also found a significant age effect on driving errors in our group of older

adult drivers but not in our middle-aged drivers, suggesting an accelerated decline in safety as drivers advance into the older age range. Within older drivers, poor scores on our composite measure of cognition was associated with driving errors, as were three specific cognitive tests, one visual test, and one motor test.

Safe driving places demands on multiple cognitive abilities, in order for the driver to accurately perceive the constantly changing driving environment, make good decisions, and effectively control the vehicle. It is thus not surprising that the strongest predictor of age-related decline in driving performance was a composite measure that took into account a range of cognitive abilities. We have previously found good prediction of driving performance from this composite cognitive score in neurologic patient populations (Alzheimer's disease, Parkinson's disease, and stroke)^{7-9,26,27}. The combined findings of these studies, together with a functional analysis of the demands of driving, suggest that evaluation of aging drivers should take into account possible changes across a range of different cognitive abilities. A brief battery of tests is likely to be more effective than any single test.

The findings of this study also point to age-related decline in *specific* cognitive abilities as being particularly important in the increased risk of unsafe driving associated with aging. The tests that were most strongly associated with worse driving in old age specifically placed demands on visuospatial and visuomotor abilities. These tests require the subject to visually analyze a stimulus and then act upon it, for example, by drawing a copy of a complex geometric figure or creating a specific pattern with colored blocks. Some of these tests place demands on speed of visuomotor processing (e.g., placing small ridged pegs in corresponding holes as *quickly* as possible), but others stress only accuracy with no time demands (e.g., copying a drawing as *accurately* as possible). This suggests that declines in both the speed and the precision of visuomotor functions underlie the increased risk of unsafe driving in old age. The importance of age-related decline in visuomotor and visuospatial abilities to driving safety can be contrasted to the lack of significant impact that age-related memory decline has on driving. Although the older subjects had significantly poorer performance than the younger subjects on a test of anterograde memory (list learning), this was not associated with increased risk of driving safety errors. This is consistent with prior findings that even patients with severe memory problems can perform most aspects of driving quite well²⁸. Thus, it is not necessarily the forgetful older person who should elicit concern regarding driving safety, but rather individuals who show decline in skills or tasks that place demands on visuospatial and visuomotor abilities.

An important issue in studies of driving safety in medical populations is whether neuropsychological test provide any "added value" beyond diagnosis.⁶⁻⁸ This study shows that neuropsychological tests are associated with real world driver errors, even in the absence of neurological disease.

This study has a number of limitations. First, the cross-sectional nature of our design means that the neuropsychological tests we considered were predicting driving safety concurrently, rather than longitudinally. Also, although we found several predictors of driving safety, we are not able to propose specific thresholds of those predictors that can be used to as formal screening tests with acceptable levels of sensitivity and specificity. Furthermore, we do not have specific evidence to link the safety errors in our fixed-course drive to real world outcomes such as crashes and near crashes. Finally, there was too much variability in our data to accurately pinpoint a specific age when safety levels begin to decline quickly.

While this study and others show that driving safety is influenced by specific visuoperceptual and attentional abilities that tend to decline with age, safety is also

influenced by strategic factors that are often not measured. This included decisions such as what vehicle to drive, how often and where to drive, road conditions, the amount of distractions allowed in the vehicle (e.g., eating, smoking, listening to radio, cell phones), and the relative value that drivers put on safety versus performance. These strategic behaviors tend to evolve over longer time frames (e.g., days to weeks) that are not captured in an hour-long assessment or on routes chosen by the experimenter rather than the driver.

The fixed-route study design in this study standardized some of the strategic factors across drivers, allowing us to focus on actual driving skills. By contrast, naturalistic driving studies (which can involve instrumenting a driver's own car) would assess both driving skills and strategic factors. These naturalistic studies sacrifice experimental control to gain a window on real world behavior, in context, on roads and in situations where patients actually chose to drive. Such studies may find that even though driving abilities themselves may deteriorate over time, many older drivers may be able to offset this decline through strategic decisions. The metacognitive awareness of age-related decline may allow self-censorship of driving to reduce older drivers' exposure to riskier traffic situations (e.g, night, rush hour, bad weather, poor roads) and to restrict total mileage, which may mitigate older driver performance decrements and equalize overall safety levels and records (of crashes and citations) between older and younger drivers.

A variety of approaches are needed to study at risk older drivers, ranging from closely controlled neuropsychological tests which tend to lack real world context, to driving simulation, to field studies using IVs. Linkages between cognitive abilities measured by neuropsychological tasks and driving behavior assessed using IVs can help standardize the assessment of fitness-to-drive in at-risk populations of drivers. Quantification of real-world driving performance using a standardized approach in an IV is also potentially useful for determining the trajectories of disease or efficacy of medical and traffic safety interventions in real world settings. Human behavior depends on the context in which it is measured,²⁹ and IVs can provide objective real world outcome measurements for clinical trials, which often rely on quality of life assessments from questionnaires or diaries that are subject to poor observational skills and recall bias. Objective evidence of worsening performance over time can motivate more frequent or detailed assessments, both medical and driving.

By understanding patterns of driver error measured in an IV, it may be possible to design interventions to reduce these errors, particularly the more serious errors that are liable to lead to crashes and injuries. Relevant interventions that use this evidence may include driver performance monitoring devices, collision alerting and warning systems, road design, driver training, and graded licensure programs.

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REFERENCES

1. Lyman S, Ferguson SA, Braver ER, et al. Older driver involvements in police reported crashes and fatal crashes: Trends and projections. *Inj Prev.* 2002; 8:116–120. [PubMed: 12120829]
2. Evans L. Risks older drivers face themselves and threats they pose to other road users. *Int J Epi.* 2000; 29:315–322.

3. Zhou, Q.; Rouhana, SW.; Melvin, JW. Age effects on thoracic injury tolerance. Society of Automotive Engineers; Warrendale, PA: 1996. SAE Technical Paper Series 962421
4. Cushman LA. Cognitive capacity and concurrent driving performance in older drivers. *IATSS Research*. 1996; 20:38–45.
5. Janke MK, Eberhard JW. Assessing medically impaired older drivers in a licensing agency setting. *Accid Anal Prev*. 1998; 30:347–361. [PubMed: 9663294]
6. Reger MA, Welsh RK, Watson GS, et al. The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. *Neuropsychology*. 2004; 18:85–93. [PubMed: 14744191]
7. Dawson JD, Anderson SW, Uc EY, et al. Predictors of driving safety in early Alzheimer disease. *Neurology*. 2009; 72:521–527. [PubMed: 19204261]
8. Uc EY, Rizzo M, Johnson AM, et al. Road safety in drivers with Parkinson disease. *Neurology*. 2009; 73:2112–2119. [PubMed: 20018639]
9. Uc EY, Rizzo M, Anderson SW, et al. Driver identification of landmarks and traffic signs after a stroke. *Transportation Research Record: J Transportation Research Board*. 2005; 1922:9–14.
10. Strauss, E.; Sherman, EMS.; Spreen, O. A compendium of neuropsychological tests: Administration, norms, and commentary. 3rd ed. Oxford University Press; New York: 2006.
11. Wechsler, D. WAIS-III administration and scoring manual. Psychological Corporation; San Antonio, TX: 1997.
12. Sivan, AB. Benton Visual Retention Test. 5th ed. The Psychological Corporation; San Antonio, TX: 1992.
13. Heaton, RK.; Grant, I.; Matthews, CG. Comprehensive norms for an expanded Halstead-Reitan battery: Demographic corrections, research findings, and clinical applications. Psychological Assessment Resources; Odessa, FL: 1991.
14. Benton, AL.; Hamsher, K.; Varney, NR.; Spreen, O. Contributions to neuropsychological assessment. Oxford University Press; New York: 1983.
15. Benton, AL.; Hamsher, K.; Sivan, AB. Multilingual Aphasia Examination. 3rd ed. AJA Associates; Iowa City: 1983.
16. Ball K, Owsley C, Sloane ME, et al. Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci*. 1993; 34:3110–3123. [PubMed: 8407219]
17. Owsley C, Ball K, Sloane ME, et al. Visual/cognitive correlates of vehicle accidents in older drivers. *Psychol Aging*. 1991; 6:403–415. [PubMed: 1930757]
18. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. *Clin Vision Sci*. 1988; 2:187–199.
19. Ferris FL III, Kassoff A, Bresnick GH, et al. New visual acuity charts for clinical research. *Am J Ophthalmol*. 1982; 94:91–96. [PubMed: 7091289]
20. Rizzo M, Nawrot M. Perception of movement and shape in Alzheimer's disease. *Brain*. 1998; 121:2259–2270. [PubMed: 9874479]
21. Duncan PW, Weiner DK, Chandler J, et al. Functional reach: A new clinical measure of balance. *J Gerontol*. 1990; 45:M192–M197. [PubMed: 2229941]
22. Alexander NB. Postural control in older adults. *J Am Geriatr Soc*. 1994; 42:93–108. [PubMed: 8277123]
23. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991; 39:142–148. [PubMed: 1991946]
24. Rizzo, M.; McGehee, D.; Petersen, AD., et al. Development of an unobtrusively instrumented field research vehicle for objective assessments of driving performance. In: Rothengatter, T.; Carbonnel, VE., editors. *Traffic and Transport Psychology: Theory and Application*. Pergamon; New York: 1997. p. 203–208.
25. Dawson, JD.; Rizzo, M.; Anderson, SW., et al. Ascertainment of on-road safety errors based on video review. *Proceedings of Driving Assessment 2009: The Fifth International Driving Symposium on Human Factors in Driving Assessment, Training and Vehicle Design*; 2009.
26. Uc EY, Rizzo M, Anderson SW, et al. Unsafe rear-end collision avoidance in Alzheimer's disease. *J Neurological Sci*. 2006; 251:35–43.

27. Uc EY, Rizzo M, Anderson SW, et al. Driving with distraction in Parkinson's disease. *Neurology*. 2006; 67:1774–1780. [PubMed: 17130409]
28. Anderson SW, Rizzo M, Skaar N, et al. Amnesia and driving. *J Clin Experimental Neuropsychol*. 2007; 29:1–12.
29. Rizzo, M.; Robinson, S.; Neale, V. The brain in the wild: Tracking human behavior in natural and naturalistic settings. In: Parasuraman, R.; Rizzo, M., editors. *Neuroergonomics: The Brain at Work*. Oxford; New York: 2007. p. 113-130.

Table 1

Means (SD's) of demographic variables and of neuropsychological tests of middle-aged (40-64) and older adult (65-89) drivers.

Variable	Middle-Aged Drivers n=80	Older Adult Drivers n = 111	P-value
Demographics			
Education (yrs)	15.68 (2.28)	15.86 (2.66)	0.544
Gender	47.5% Males	52.3% Males	0.519
Days Driven per Week	6.23 (1.15)	6.06 (1.33)	0.513
Miles Driven per Week	131.09 (99.86)	147.65 (180.46)	0.697
Cognitive Tests			
CFT-Copy (0-36 pts)	31.25 (3.41)	31.24 (3.83)	0.691
CFT-Recall (0-36 pts)	16.66 (5.93)	15.21 (5.26)	0.094
Block Design (0-68 pts)	43.60 (10.15)	38.27 (9.92)	<0.001
BVRT-Errors (0-26 errors)	3.78 (2.25)	4.55 (2.50)	0.036
TMT-A (≥0 seconds)	30.86 (8.51)	36.86 (10.55)	<0.001
TMT-B (≥0 seconds)	69.35 (31.46)	86.31 (39.81)	<0.001
AVLT (0-15 words)	11.30 (2.87)	9.61 (3.27)	<0.001
JLO (0-30 pts)	27.06 (2.83)	25.78 (3.75)	0.026
COWA (≥0 words)	41.51 (11.97)	37.38 (10.02)	0.014
Cogstat Composite (unbounded)	427.52 (43.89)	400.25 (42.45)	<0.001
Visual Tests			
UFOV-Total Loss (0-2000 pts)	483.03 (209.21)	701.15 (194.23)	<0.001
Contrast Sensitivity (0-2.25 pts)	1.88 (0.12)	1.77 (0.18)	<0.001
FVA (unbounded)	-0.12 (0.10)	-0.04 (0.11)	<0.001
NVA (unbounded)	0.02 (0.04)	0.02 (0.05)	0.072
SFM (5-30 pts)	10.10 (2.91)	10.20 (2.67)	0.942
Motor Tests			
Functional Reach (≥0 inches)	14.09 (2.43)	12.48 (2.65)	<0.001
Get-Up-and-Go (≥0 seconds)	8.44 (1.37)	9.18 (2.53)	0.027
Grooved Pegboard (≥0 seconds)	72.46 (10.82)	91.60 (17.77)	<0.001

P-values are based on Wilcoxon Rank-Sum Tests. CFT=Complex Figure Task, BVRT=Benton Visual Retention Test, TMT=Trail Making Task (parts A and B), AVLT=Auditory Verbal Learning Test, JLO=Judgment of Line Orientation, COWA=Controlled Oral Word Association, UFOV=Useful Field of View, FVA=Far Visual Acuity, NVA=Near Visual Acuity, SFM=Structure From Motion.

Table 2

Mean (SE) of driving safety errors, within categories, of middle-aged (40-64 years) and older adult (65-89 years) drivers.

Safety Error Category	Middle-Aged Drivers n=80	Older Adult Drivers n = 111	P-value
Backing Up	0.00 (0.00)	0.01 (0.09)	0.402
Curves	0.00 (0.00)	0.01 (0.09)	0.402
Control of Speed	2.39 (2.59)	3.69 (3.03)	0.001
Lane Change	3.88 (2.37)	5.14 (2.84)	0.003
Lane Observance	9.86 (6.56)	12.44 (8.38)	0.027
Miscellaneous	0.66 (0.81)	0.87 (1.18)	0.569
Overtaking	0.10 (0.38)	0.11 (0.39)	0.738
Parallel Parking	0.13 (0.33)	0.28 (0.47)	0.015
Railroad Crossing	0.00 (0.00)	0.20 (0.58)	0.003
Starting & Pulling Away from Curb	0.55 (0.71)	0.90 (0.87)	0.006
Stop Signs	4.34 (2.10)	4.19 (2.02)	0.841
Turns	3.90 (2.23)	5.51 (2.69)	<0.001
Traffic Signals	1.98 (1.46)	2.41 (1.65)	0.059
“More Serious” Errors	1.23 (1.20)	2.05 (1.69)	<0.001
“Less Serious” Errors	26.55 (9.32)	33.71 (12.13)	<0.001
Total Safety Errors	27.79 (9.75)	35.77 (12.84)	<0.001

P-values are based on Wilcoxon Rank Sum Tests.

Table 3

Estimated changes (standard errors) in total driving safety errors for 1-SD increases in cognitive, visual, and motor predictors, for older adult drivers.

Variable	Coefficient (SE)	P-value
Age	0.54 (0.23)	0.026
Education	−0.56 (0.46)	0.298
Gender	0.58 (2.44)	0.941
Days Driven per Week	−1.61 (1.24)	0.197
Miles Driven per Week	0.17 (1.27)	0.891
Cognitive Tests		
CFT-Copy	−2.54 (1.21)	0.039
CFT-Recall	−2.46 (1.22)	0.046
Block Design	−2.61 (1.28)	0.045
BVRT-Errors	0.72 (1.21)	0.553
TMT-A	1.39 (1.28)	0.282
TMT-B	1.54 (1.29)	0.236
AVLT	−1.66 (1.26)	0.188
JLO	−2.60 (1.40)	0.066
COWA	−1.54 (1.23)	0.213
Cogstat Composite Score	−3.55 (1.24)	0.005
Visual Tests		
UFOV-Total Loss	0.73 (1.33)	0.586
Contrast Sensitivity	−0.22 (1.28)	0.861
FVA	−1.93 (1.24)	0.123
NVA	2.58 (1.26)	0.043
SFM	−1.06 (1.25)	0.395
Motor Tests		
Get-Up-and-Go	0.46 (1.27)	0.718
Functional Reach	−0.13 (1.32)	0.924
Grooved Pegboard	3.11 (1.34)	0.023

Coefficients and P-values were computed via multiple linear regression, adjusting for age, education, and gender. CFT=Complex Figure Task, BVRT=Benton Visual Retention Test, TMT=Trail Making Task (parts A and B), AVLT=Auditory Verbal Learning Test, JLO=Judgment of Line Orientation, COWA=Controlled Oral Word Association, UFOV=Useful Field of View, FVA=Far Visual Acuity, NVA=Near Visual Acuity, SFM=Structure From Motion. See Table 1 for possible ranges of test scores.

Table 4

Multivariate regression model predicting total safety error in older adult drivers. ($R^2 = 0.1242$, Adjusted $R^2 = 0.0992$).

Variable	Estimate	Std. Error	t-value	P-value
Intercept	7.245	17.985	0.40	0.688
Age	0.321	0.241	1.33	0.186
Grooved Pegboard	0.147	0.073	2.01	0.047
Block Design	-0.212	0.124	-1.71	0.091

Table 5

Predicted number of driving safety errors using the model presented in Table 4, based on predictor variable values corresponding approximately to the mean and one standard deviation above and below the mean.

		Predicted Number of Total Errors		
Block Design	Grooved Pegboard	Age = 70	Age = 75	Age = 80
48	72	30.1	31.7	33.3
	90	32.7	34.4	36.0
	108	35.4	37.0	38.6
38	72	32.2	33.8	35.4
	90	34.9	36.5	38.1
	108	37.5	39.1	40.7
28	72	34.3	35.9	37.5
	90	37.0	38.6	40.2
	108	39.6	41.2	42.8