

Predictors of driving safety in early Alzheimer disease



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ABSTRACT

Objective: To measure the association of cognition, visual perception, and motor function with driving safety in Alzheimer disease (AD).

Methods: Forty drivers with probable early AD (mean Mini-Mental State Examination score 26.5) and 115 elderly drivers without neurologic disease underwent a battery of cognitive, visual, and motor tests, and drove a standardized 35-mile route in urban and rural settings in an instrumented vehicle. A composite cognitive score (COGSTAT) was calculated for each subject based on eight neuropsychological tests. Driving safety errors were noted and classified by a driving expert based on video review.

Results: Drivers with AD committed an average of 42.0 safety errors/drive (SD = 12.8), compared to an average of 33.2 (SD = 12.2) for drivers without AD ($p < 0.0001$); the most common errors were lane violations. Increased age was predictive of errors, with a mean of 2.3 more errors per drive observed for each 5-year age increment. After adjustment for age and gender, COGSTAT was a significant predictor of safety errors in subjects with AD, with a 4.1 increase in safety errors observed for a 1 SD decrease in cognitive function. Significant increases in safety errors were also found in subjects with AD with poorer scores on Benton Visual Retention Test, Complex Figure Test-Copy, Trail Making Subtest-A, and the Functional Reach Test.

Conclusion: Drivers with Alzheimer disease (AD) exhibit a range of performance on tests of cognition, vision, and motor skills. Since these tests provide additional predictive value of driving performance beyond diagnosis alone, clinicians may use these tests to help predict whether a patient with AD can safely operate a motor vehicle. *Neurology*® 2009;72:521-527

GLOSSARY

AD = Alzheimer disease; **AVLT** = Auditory Verbal Learning Test; **Blocks** = Block Design subtest; **BVRT** = Benton Visual Retention Test; **CFT** = Complex Figure Test; **CI** = confidence interval; **COWA** = Controlled Oral Word Association; **CS** = contrast sensitivity; **FVA** = far visual acuity; **JLO** = Judgment of Line Orientation; **MCI** = mild cognitive impairment; **MMSE** = Mini-Mental State Examination; **NVA** = near visual acuity; **SFM** = structure from motion; **TMT** = Trail-Making Test; **UFOV** = Useful Field of View.

People who develop Alzheimer disease (AD) will generally, at some point in the course of their progressive cognitive decline, become unable to safely drive an automobile. However, as the ability to diagnose AD in early and mild stages continues to improve, many individuals with a diagnosis of probable AD or mild cognitive impairment (MCI) may remain cognitively competent to continue driving for several more years. The obvious goal is to prevent crashes and other dramatic incidents while maximizing patients' rights and freedom of mobility. Complicating the decision-making process are the biases that patients and families may bring to the situation, e.g., patients may desire to continue driving beyond a point of safety, while family members may either prematurely restrict driving or unwisely encourage driving. Poor awareness of acquired deficits and impaired judgment associated with AD further complicates the decision-making process of patients and their compliance with driving recommendations.¹⁻³

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The prevalence of dementia is increasing as the population ages, and automobile-dependent societies such as the United States will face a growing public health problem with elderly and demented drivers.⁴ One approach to addressing this problem is to identify empirically based predictors of unsafe driving in persons with AD. A standardized road test can classify older drivers with a recent history of at-fault crashes,⁵ lending itself to be used as an index of driver safety. Performance on tests of cognition, visual perception, and motor function has been shown to be associated with driving safety in older drivers⁵⁻⁹ and drivers with dementia.¹⁰⁻¹² The use of neuropsychological tests to predict driver performance on a standardized road test may provide a noninvasive and relatively inexpensive index of cognitive impairments in AD that may decrease driver safety.

Neuropsychological test performance has previously been shown to be associated with driving safety in studies with a combination of AD and nondemented elderly individuals,¹³⁻¹⁵ but it has not been clear whether such tests provided additional predictive value beyond that of diagnosis alone. AD is known to impair visual, perception, and motor functions,¹⁶ which are critical for safe driving. The goal of the present study was to determine if performances on tests of cognition, visual perception, and motor function could predict the level of safety in licensed drivers with probable AD.

METHODS Subjects. Subjects were 40 participants (33 men and 7 women) with mild AD and 115 elderly drivers without dementia (60 men and 55 women). Participants with AD were recruited from a registry maintained by the Department of Neurology. The diagnosis of probable AD was based on National Institute of Neurological and Communicative Disorders and Stroke–Alzheimer’s Disease and Related Disorders Association criteria.¹⁷ Accordingly, all AD participants had symptoms of memory impairment and related cognitive complaints that interfered with their social or occupational life. Mini-Mental State Examination (MMSE) screening reflected mild early cognitive decline in these still licensed drivers (mean MMSE \pm SD = 26.5 \pm 2.9). Ten Subjects with AD were taking Aricept. Impairments of memory and other cognitive domains on a standardized battery of neuropsychological tests (table 1) were consistent with early AD.¹⁸ Control participants were recruited from volunteers in the local community, who had no neurologic diagnosis or complaints, and no personal or family report of abnormal cognitive decline.

All participants held a valid state driver’s license and were still driving, although some had reduced driving activity because of self-imposed or family-imposed restrictions. Exclusion criteria in both groups included non-AD neurologic disease, brain le-

sions 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 Rey-Osterreith Complex Figure Test-Copy version (CFT-Copy) requires participants to copy a complex geometric figure, which provides an index of visuoconstructional ability. In the CFT-Recall version, a measure of visual anterograde memory, the subject is asked to draw the figure from memory 30 minutes after copying the CFT. The Block Design subtest (Blocks) from the WAIS-R provides an additional measure of visuoconstructional ability that correlates with performance IQ. The Benton Visual Retention Test (BVRT) stresses visual working memory. The Trail-Making Test subtest A (TMT-A) assesses visual search and visual motor speed, while subtest B (TMT-B) places demands on executive functions, including working memory and attentional set shifting. Rey Auditory Verbal Learning Test (AVLT) measures anterograde verbal memory. Judgment of Line Orientation (JLO) assesses visuospatial perception, by requiring matching lines of different orientation to target. The Controlled Oral Word Association (COWA) Test requires subjects, within a 1-minute time limit, to generate as many words as possible that begin with a certain letter of the alphabet. All of the above tasks are described in detail elsewhere.^{19,20} We calculated a composite measure of cognitive impairment (COGSTAT) by assigning and summing standard *t* scores (mean = 50, SD = 10) to each of the eight tests from the neuropsychological assessment battery (COWA, CFT-Copy, CFT-Recall, AVLT, BVRT, Blocks, JLO, and TMT-B), as in our previous work.^{21,22}

The Useful Field of View (UFOV) task (Visual Attention Analyzer, Visual Resources Inc.) measures speed (in msec) of visual processing, divided attention, and selective attention.^{23,24} UFOV loss correlates with increased crash risk in simulated driving scenarios and real life crashes.^{23,24} We used the sum of four subtests of the UFOV task (UFOV-Total) in our analyses. Contrast sensitivity (CS) was assessed using the Pelli-Robson chart.²⁵ The best-corrected visual acuity was measured using the Early Treatment Diabetic Retinopathy Study chart²⁶ for far visual acuity (FVA) and reduced Snellen chart for near visual acuity (NVA), both expressed as logarithm of the minimum angle of resolution (logMAR), with 0 representing 20/20 vision. Perception of three-dimensional structure from motion (SFM) and motion direction were tested using computer-generated animation sequences.²²

We also administered tests of motor abilities. Functional Reach is the difference between arm length and maximal forward reach using a fixed base of support. It is portable, inexpensive, precise, reliable, quick to administer, and useful for detecting balance impairment and change of balance performance over time.^{27,28} The Get-Up-and-Go task requires subjects to stand up from a chair, walk a short distance, turn around, return, and sit down again. It is safe, shows excellent interrater reliability, and appears to predict an elderly individual’s ability to safely go outside alone.²⁸ The Grooved Pegboard task measures the time that it takes for subjects to insert noncylindrical metal pins into a small base stand using one hand per trial; we used the average time of the two trials per subject as a measure of motor dexterity and speed.

Instrumented vehicle. The experimental drive was conducted aboard an instrumented vehicle known as ARGOS (the Automobile

Table 1 Characteristics of Alzheimer disease (AD) and non-AD control groups, mean (SD)

	AD (n = 40)	Controls (n = 115)	p Values for difference	
			Crude	Age- and gender-adjusted
Demographics				
Age, y	75.1 (7.7)	69.4 (7.0)	<0.0001	
Education, y	15.6 (3.1)	15.8 (2.5)	0.5696	
No. of vision-related comorbidities	0.6 (0.7)	0.1 (0.3)	0.1101	
No. of medications	2.2 (2.8)	2.7 (2.3)	0.048	
Cognitive tests				
CFT-Copy*	28.3 (4.9)	31.8 (3.5)	<0.0001	0.0003
CFT-Recall*	8.7 (4.5)	15.3 (5.6)	<0.0001	<0.0001
Blocks*	25.2 (11.5)	39.1 (10.3)	<0.0001	<0.0001
BVRT (errors)*	9.3 (3.4)	4.8 (2.5)	<0.0001	<0.0001
TMT-A	53.8 (18.4)	35.8 (19.9)	<0.0001	<0.0001
TMT-B*	173.6 (87.3)	84.0 (41.7)	<0.0001	<0.0001
AVLT*	2.8 (2.5)	10.0 (3.1)	<0.0001	<0.0001
JLO*	23.5 (4.2)	25.8 (3.7)	0.0022	<0.0001
COWA*	33.0 (9.8)	38.7 (11.2)	0.0057	0.0348
COGSTAT	297.2 (54.4)	404.6 (43.7)	<0.0001	<0.0001
Visual tests				
Contrast sensitivity	1.65 (0.18)	1.83 (0.14)	<0.0001	<0.0001
Useful Field of View-Total	1232 (292)	676 (211)	<0.0001	<0.0001
Near visual acuity	0.05 (0.08)	0.02 (0.04)	0.0016	0.0042
Far visual acuity	0.03 (0.12)	-0.07 (0.12)	<0.0001	0.0003
Structure from motion	12.9 (5.7)	10.3 (2.7)	0.0240	0.0003
Motor tests				
Get-Up-and-Go	11.1 (2.1)	8.8 (2.5)	<0.0001	0.0001
Functional Reach	11.7 (2.9)	13.2 (2.7)	0.0034	0.1112
Grooved Pegboards	115.0 (33.4)	87.6 (17.4)	<0.0001	<0.0001

Groups were compared using Wilcoxon rank sum for crude *p* values and multiple linear regression for adjusted *p* values.

*The eight individual components of COGSTAT.

CFT = Complex Figure Test; Blocks = Block Design subtest; BVRT = Benton Visual Retention Test; TMT = Trail-Making Test; AVLT = Auditory Verbal Learning Test; JLO = Judgment of Line Orientation; COWA = Controlled Oral Word Association.

for Research in Ergonomics and Safety), a mid-sized car with an automatic transmission and hidden instrumentation and sensors.^{14,29-31} Experimental performance data (steering wheel position, accelerator and brake pedal position, lateral and longitudinal acceleration, and vehicle speed) were recorded at 10 Hz. Control of speed³² and lane position³³ are critical aspects of driving, and unplanned lane deviations occur with degradation of driving performance.³⁴ Driver's lane tracking and visual scanning activity of the environment were recorded by videotape at 10 frames per second using four miniature lipstick-size cameras mounted unobtrusively within the vehicle.

Administering the road test. The road test was generally administered within 2 months of the off-road battery, with a median of 28 days elapsed between the two visits. Each subject was seated in the driver's seat, with the experimenter in the front

passenger seat to give instructions and operate the dual controls, if needed. The experimental drive started after the driver acclimated to the vehicle on a short test drive, and lasted approximately 45 minutes. Road testing was carried out only during the day on specific roads within and surrounding Iowa City. Drivers were not tested in inclement weather that might cause poor visibility or road conditions. The drive incorporated several essential maneuvers such as turns, stopping at a stop sign, and maintaining vehicle control.

Safety errors. A certified driving instructor reviewed the videotapes to assess the number and type of safety errors committed by the drivers. This instructor used a taxonomy based on the Iowa Department of Transportation's Drive Test Scoring Standards (September 7, 2005 version), which included 76 error types (e.g., "unsafe passing," "tailgating") organized into 15 categories (e.g., "turns," "lane observance"). 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 subject failed to yield the right of way at a stop sign, this was judged as more serious, since this behavior may lead to a near crash or 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 safety errors.

Statistical analysis. We compared the groups with respect to demographics, neuropsychological measures, and safety error outcomes using the Wilcoxon rank sum test. Multiple linear regression was used to adjust for age and gender when comparing neuropsychological measures and safety errors. We also used multiple linear regression to test for associations between neuropsychological measures and total safety errors within the AD group, after adjusting for age and gender. For these analyses, we expressed the regression coefficients in terms of the average difference in safety errors per 1 SD difference in each neuropsychological measure, facilitating comparisons of magnitude of effect across predictors. In addition to examining the effect of neuropsychological tests individually, we modeled their simultaneous effects using multiple linear regression. We used standard regression diagnostic methods to assess the appropriateness of our models.

RESULTS Table 1 presents demographic and neuropsychological descriptions of the two groups. Compared to subjects without AD, the subjects with AD were older and on fewer medications. They also had more vision-related comorbidities, but this was not significant. The AD group performed worse than the control group on almost all neuropsychological tests.

As shown in table 2, drivers with AD committed an average of 42.0 total safety errors/drive, compared to an average of 33.2 for controls without AD. Adjusting for age and gender, the mean (95% confidence interval [CI]) of the between-group difference was 5.9 (1.2, 10.6) for total errors, 2.3 (1.5, 3.0) for more serious errors, 3.7 (0.0, 7.5) for less serious errors, and 5.1 (1.7, 8.5) for lane observance errors. Increased age was predictive of total safety errors, with a mean of 2.3 more errors per drive observed for each 5-year age increment; gender was not significant.

Table 2 Driver safety errors in Alzheimer disease (AD) and normal control groups

Safety errors	AD (n = 40)	Controls (n = 115)	p Values for difference	
			Crude	Age- and gender-adjusted
Starting and pulling away from curve	1.08 (0.97)	1.09 (0.81)	0.7097	0.4392
Traffic signals	2.35 (1.56)	2.18 (1.56)	0.5101	0.4739
Stop signs	3.80 (1.98)	3.61 (1.89)	0.7610	0.6587
Other signs	0 (0)	0 (0)	—	—
Turns	6.50 (3.09)	5.44 (2.79)	0.0838	0.1412
Lane observance	17.03 (11.00)	10.84 (7.77)	0.0003	0.0039
Lane change	5.75 (2.86)	5.00 (2.75)	0.1253	0.9386
Overtaking	0.10 (0.38)	0.15 (0.46)	0.5075	0.5539
Control of speed	4.03 (2.71)	3.56 (2.79)	0.2634	0.7504
Backing up	0 (0)	0 (0)	—	—
Parallel parking	0.38 (0.49)	0.37 (0.52)	0.8172	0.7172
Head-in parking	0 (0)	0 (0)	—	—
Curves	0.00 (0.00)	0.01 (0.09)	0.5653	0.7983
Railroad crossing	0.03 (0.16)	0.19 (0.58)	0.1115	0.0533
Miscellaneous	0.98 (1.03)	0.73 (1.05)	0.0859	0.4132
Total safety errors	42.00 (12.84)	33.18 (12.22)	<0.0001	0.0148
Total more serious errors	4.35 (2.97)	1.90 (1.59)	<0.0001	<0.0001
Total less serious errors	37.65 (11.66)	31.26 (11.49)	0.0009	0.0516

Groups were compared using Wilcoxon rank sum for crude *p* values and multiple linear regression for adjusted *p* values.

Other than lane observance errors (a.k.a., lane deviations), no other general category of errors was significantly more common in the AD group. Among more serious errors, straddling the center line (one of eight types of errors within the general category of lane observance errors) was the most common type, followed by failing to proceed through intersection even though the light had turned green (a specific type of traffic signal error). Both of these error types were significantly more common in drivers with AD than in drivers without AD. There was a borderline indication that railroad crossing errors may have been higher in the non-AD group (adjusted *p* = 0.053).

We randomly selected videotapes from 30 participants for a second video review by our driving expert, as well as by a second rater. Among these 30 drivers, we found that the intrarater correlation for total safety errors was 95%, while the interrater correlation was 73%.

Table 3 shows that the drivers with AD with higher overall cognitive function (measured by COGSTAT) tended to make fewer total safety errors. Several individual tests also were significant predictors of safety errors among drivers with AD, including measures of working memory (BVRT), vi-

Table 3 Changes in total safety errors for a 1 SD increase in cognitive, visual, and motor predictors

Predictors	Coefficient estimate (SE)
Cognitive tests	
CFT-Copy	-3.54 (1.54)*
CFT-Recall	-4.44 (2.38)*
JLO	-0.58 (1.97)
Blocks	-2.29 (1.91)
BVRT (Errors)	4.12 (1.55)*
TMT-A	2.97 (1.46)*
TMT-B	2.40 (1.35)*
AVLT	2.43 (2.48)
COWA	-2.37 (2.31)
COGSTAT	-4.14 (1.66)*
Visual tests	
Contrast sensitivity	0.32 (1.86)
UFOV-Total	3.44 (1.72)*
Near visual acuity	-1.48 (1.38)
Far visual acuity	0.22 (2.06)
Structure from motion	-0.25 (1.49)
Motor tests	
Get-Up-and-Go	2.79 (2.55)
Functional Reach	-4.31 (1.99)*
Grooved Pegboard	0.80 (1.54)

Coefficients and *p* values for multiple linear regression, adjusting for age and gender. Values expressed as coefficient estimate (SE).

**p* < 0.05.

**p* < 0.10.

CFT = Complex Figure Test; JLO = Judgment of Line Orientation; Blocks = Block Design subtest; BVRT = Benton Visual Retention Test; TMT = Trail-Making Test; AVLT = Auditory Verbal Learning Test; COWA = Controlled Oral Word Association; UFOV = Useful Field of View.

visual search and visual motor speed (TMT-A), visuo-constructional abilities (CFT-Copy), and motor function (Functional Reach). Tests that were nearly significant in subjects with AD included CFT-Recall, TMT-B, and UFOV-Total.

Since lane observance errors were the most common type of safety error, accounting for the majority of the between-group differences, we repeated our analyses using lane observance errors as the outcome. We found that this outcome was significantly predicted by worse scores on CFT-Copy, UFOV-Total, and Functional Reach. COGSTAT, BVRT, and Get-Up-and-Go were nearly significant predictors.

When predicting total errors in subjects with AD, we found that age, BVRT, and TMT-A modeled together resulted in an appropriate balance of model fit (adjusted *R*² near the maximum achieved) and parsimony (e.g., only three predictor variables). Accord-

Table 4 Multivariable regression model predicting total safety errors in subjects with Alzheimer disease ($R^2 = 0.29$; adjusted $R^2 = 0.23$)

Variable	Coefficient estimate	Standard error	t Statistic	p Value
Intercept	-20.06	20.201	-0.99	0.3273
Age	0.5095	0.2381	2.14	0.0392
BVRT (Errors)	1.4083	0.5328	2.64	0.0121
TMT-A	0.1985	0.0985	2.02	0.0513

BVRT = Benton Visual Retention Test; TMT = Trail-Making Test.

ing to this model (table 4), an increase of 2 years in age corresponded to an increase of 1.0 driving error, an increase of 1 error on BVRT corresponded to an average increase of 1.4 driving errors, and an additional 5 seconds to complete the TMT-A task corresponded to an increase of 1.0 driving error. 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 subjects with AD in our study. Across these ranges of risk factors, table 5 shows that subjects with AD with high-risk profiles tend to commit noticeably more safety errors than those with low-risk profiles, even when keeping age fixed. This model assumed that the factor effects were additive, which was supported by nonsignificant tests of interaction.

DISCUSSION This study aimed to measure the association of cognition, visual perception, and motor function with driving safety in drivers with AD. We found that drivers with AD make more total safety errors, lane observance errors, and serious safety errors than elderly drivers without AD. For predicting safety errors within the AD group, off-road neuropsychological tests of cognition, vision, and motor abilities gave additional information above and beyond diagnosis alone. Hence, performance on these

Table 5 Expected total of driving safety errors as a function of age, TMT-A, and BVRT in subjects with Alzheimer disease

TMT-A	BVRT (Errors)	Expected total of driving safety errors		
		Age 70 y	Age 75 y	Age 80 y
40 sec	6	32.0	34.5	37.1
	9	36.2	38.8	41.3
	12	40.4	43.0	45.5
55 sec	6	35.0	37.5	40.1
	9	39.2	41.7	44.3
	12	43.4	46.0	48.5
70 sec	6	37.9	40.5	43.0
	9	42.2	44.7	47.3
	12	46.4	48.9	51.5

TMT = Trail-Making Test; BVRT = Benton Visual Retention Test.

tests can be helpful when predicting whether a patient with AD can safely drive a vehicle.

Our results showing that drivers with mild AD make more safety errors than older drivers without dementia on a standardized road test are compatible with other studies of driving in dementia.^{10,35} Previous studies of driving safety often have not adjusted analyses for diagnosis,³⁶ making it difficult to assess the added value of tests beyond the diagnosis of dementia. In AD, it is expected that cognitive abilities will continue to decline after the diagnosis, and there is a great range of cognitive abilities and impairments in individuals with a diagnosis of AD. Our finding that active drivers with AD and poorer cognitive abilities show greater performance impairments leading to safety errors is an important step in defining the hypothetical causal relationships between cognition, driving errors, and car crashes.

We found that a composite score reflecting test performances across multiple cognitive domains was the best predictor of driving safety in persons with AD. This is consistent with both the multifaceted cognitive demands of driving and the range of cognitive impairments resulting from AD. Given that driving puts demands on diverse cognitive functions, it is unlikely that a test of any single cognitive ability will be an accurate predictor of driving safety. It is clear that impairment of anterograde memory, generally considered to be the hallmark of AD, is not a good indicator of driving ability in this population, and we have previously found that even persons with severe amnesia can perform most aspects of automobile operation without substantial difficulty.³⁷ Lane deviations were the most common safety violations committed by the subjects with AD and, consistent with the findings of a recent meta-analysis,³⁶ we found that tests placing demands on both visuospatial abilities and motor responses were among the best predictors of driving safety. It appears likely that these tests are measuring impairments of the requisite visuospatial and visuomotor abilities for maintaining a moving vehicle within lane boundaries. Given that AD results in progressive and widespread dysfunction in posterior association cortices, which are known to provide necessary substrates for visuospatially mediated tasks, this is a plausible key contributor to the unsafe driving of persons with AD.

Of the 15 general categories of errors that we examined (table 2), only lane observance errors were significantly more common in drivers with AD. This suggests that drivers with mild AD have the ability to handle certain aspects of driving. Also, though not quite significant, the drivers with AD made fewer errors at railroad crossings. This may be an example where drivers without AD are likely to be confident

when approaching an area of potential hazard, while drivers with AD are likely to be cautious. Being overly confident often leads to safety errors when the potential hazard is a railroad crossing (where drivers without AD may make more errors), whereas in the case of traffic signals, being overly cautious can lead to the safety error of failing to proceed through a green light (committed more often by drivers with AD).

Our study has a number of limitations. Although our driving test was designed to be as unobtrusive as possible, it was still an experimental setting and drivers may have performed differently than they would have in their own vehicles in a more naturalistic setting. Also, driving safety is likely to be affected by a number of other environmental factors that we did not investigate, such as presence of family members in the vehicle, weather and road conditions, distance traveled, and time of day. Also, our sample of patients with AD only included seven women, so our study may have been underpowered to detect gender effects. Additionally, our subject identification numbering system was such that our expert rater may have been aware of a driver's diagnosis status (though not the specific off-road scores) when reviewing the tapes for errors. Finally, although we had videotaped information based on views from four cameras, our rater may have missed some errors that would have been easier to detect if he had been in the vehicle during the drive.

Our current results underscore the fact that linkages between driving performance and abilities measured by off-road tests of cognitive, visual, and motor abilities can help standardize the assessment of fitness to drive. By understanding patterns of driver errors that may cause crashes, it may be possible to design interventions to reduce these errors and injuries and preserve mobility.

AUTHOR CONTRIBUTIONS

Statistical analysis was conducted by J.D.D. and E.D.

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