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Development and assessment of a neuropsychological battery to aid in predicting driving performance

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Abstract—*Purpose*. This study was conducted to select a neuropsychological battery that correlated with driving simulator skills, thus enabling practitioners to provide information to older patients and their families about driving risks. *Methods.* The study was conducted in two phases. In Phase 1, a survey inquiring as to the kinds of neuropsychological tests currently used to screen patients for driving was sent to 292 licensed neuropsychologists. Of these 292 surveys, 125 (43%) were returned. We used the responses to develop a battery of nine tests, including eight neuropsychological tests and one other cognitive measure: (1) the Seashore Rhythm Test, (2) Logical Memory (Immediate [I] and Delayed [II]) of the Wechsler Memory Scale—Revised (WMS-R), (3) WMS-R Visual Reproduction (Immediate [I] and Delayed [II]), (4) Trails A and B, (5) Digit Span, (6) Digit Symbol, (7) Block Design, (8) Visual Form Discrimination, and (9) a Zoo Map Test. The complete battery included 12 measures. In Phase 2, 22 licensed drivers were recruited ranging in age from 67 to 91 years (14 males and 8 females). The Mini-Mental Status Exam (MMSE) was administered to all subjects. Scores on this test served as a criterion cutoff for placement into a group of subjects with suspected dementia (Group 1, MMSE score below 25) or a group of control subjects (Group 2, with a MMSE score of 25 or above). None of the patients had any gross motor difficulties. Following screening, subjects were administered the neuropsychological battery, a driving simulator test, and a Driving Habits Interview. *Results*. Data revealed a significant difference between the performance of Groups 1 and 2 on the driving simulator test in two distinct areas, staying within one's lane boundaries and speed. The suspected dementia subjects had significantly more lane boundary crossings than the control subjects and drove at significantly slower speeds. Ten neuropsychological measures correlated with driving simulator performance. The number of lane boundary crossings correlated with the greatest number of neuropsychological tests, with more lane boundary crossings correlated with poorer performance on the neuropsychological tests. In particular, Trails A, Trails B, and Logical Memory (Immediate) correlated with the largest number of driving measures. *Conclusion*. Preliminary findings show that commonly used neuropsychological tests correlated with driving simulator skills as measured with a driving simulator. Because the driving simulator has been shown to be correlated with actual on-road driving, one may hypothesize that these neuropsychological tests may be predictive of on-road driving. This research is important in defining an appropriate battery to screen for driving skills in patients with known or suspected dementia.

Key words: *aging, dementia, driving, neuropsychological testing.*

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INTRODUCTION

Approximately 4 million Americans are estimated to have Dementia of the Alzheimer's Type (DAT). As the population continues to grow, Americans are living longer and the number with DAT is estimated to be 14 million by 2050 [1]. There is mounting evidence that patients with early Alzheimer's disease have impairments in multiple domains, including cortical visual perception and processing, visual attention, and selective attention, as well as in memory, insight, risk-taking, and judgment [2]. As the disease progresses, cognitive abilities worsen, and persons with DAT find performing daily activities, such as driving, increasingly difficult [3].

The assessment of an individual's ability to continue to drive after developing dementia is an increasingly frequent clinical problem. Because of the increased rate of dementia and crash risk in older individuals, accurately assessing driving skills in older individuals becomes essential. One clinically convenient way to assess these individuals is to use neuropsychological tests. Previous studies on the effectiveness of neuropsychological tests to assess driving-related skills have had varying results. Trobe et al. examined neuropsychological test scores as predictors of adverse driving events [4]. They reviewed crash and violation rates of 143 licensed drivers with DAT and 715 licensed drivers who were control subjects and found that neuropsychological test scores did not predict future crashes or violations. Their findings may be because there were too few crashes in this group to obtain statistical significance.

In contrast, Fitten, Perryman, and Wilkinson examined two mild dementia groups, a diabetic control group, an older control group, and a young control group on an on-road driving test and on tests that measure attention, perception, and memory [5]. Short-term memory, visual tracking, and the Mini-Mental Status Exam (MMSE) scores had the highest correlations with an overall driving score [6]. These researchers concluded that the type and degree of cognitive impairment are better predictors of driving skills than age or medical diagnosis. Bieliauskas et al. found clear differences between patients with DAT and control subjects on neuropsychological perceptual and reaction-time test measures, and on-road driving performance [7]. With the use of neuropsychological tests, these data provide some preliminary suggestions toward predicting certain aspects of driving safety among older individuals.

As an alternative to on-road driving, driving simulator testing is a safe and efficient way to measure driving-related skills. It may provide unbiased evidence to aid in the difficult clinical decisions as to whether older individuals should continue to drive [8]. Bieliauskas et al. recommended the use of a driving simulator that will strongly challenge the driver to make active and informed driving decisions, such as measures of reaction to scenarios such as oncoming vehicles and a child running across the street [7]. The driving simulator has the potential to identify the neuropsychological tests that correlate with driving abilities. This is because a great deal of information about driving-related skills can be obtained in relatively short time periods, under controlled conditions. Because real-world accidents are infrequent events and the variability on this measure is so narrow, previous studies have been hindered by this restricted variance and the statistical power necessary to obtain correlations between real-world accidents and neuropsychological tests [4].

In the current study, we examined the relationships between a series of neuropsychological tests and driving simulator performance. We tested patients diagnosed with dementia related to Alzheimer's disease (using NINCDS criteria), and vascular dementia and compared their scores with normal control patients [9]. We hypothesized that patients with lower (poorer) MMSE scores would also have worse scores on many of the neuropsychological tests, which would in turn best correlate with poorer performance on the driving simulator test. Our goal was to determine which neuropsychological tests best predicted driving simulator performance in older subjects. Our neuropsychological test battery was based on the results of a questionnaire that was sent to 292 neuropsychologists asking them to rate which neuropsychological tests would best assess driving-related skills. We also included in our battery the Zoo Map Test, a cognitive measure that assesses executive functioning, and a self-reported Driving Habits Interview (provided by the National Highway Transportation Safety Administration) [10].

METHODS

Phase 1: Neuropsychological Test Battery Development

The neuropsychological test battery was developed from a survey questionnaire that was sent to 292 board-certified neuropsychologists. The first page of the questionnaire asked the neuropsychologists to indicate the characteristics that best described their patient population in terms of race, education, and occupation. From a list provided on the second page of the questionnaire, clinicians were asked to indicate tests they used most frequently in their evaluation of older drivers and to add any tests that were not listed. They were asked to rank the list of neuropsychological tests from one to five, where a score of one would be used to label the least discriminating test in terms of identifying problem drivers, and a five would be used to label the most discriminating test. **Table 1** contains the results from the survey.

Of the 292 neuropsychologists, 125 responded to the survey (43 percent response rate), and of those responses, 41 (33 percent) indicated that they did perform driving assessments on older individuals. Those 41 who performed assessments stated that of the populations they served, 77 percent were Caucasian, 14 percent were African American, 6 percent were Hispanic, and 3 percent were described as “Other.” They reported seeing patients from all levels of education, the majority of their patients having 12 years of school. These neuropsychologists reported seeing patients from all occupations, the majority being managers, administrators, clerical workers, and salespersons.

We chose the neuropsychological tests that were used in Phase 2 of the present study based on the survey results, and conferences with a neuropsychologist, a neurologist, and a psychologist, who are all authors of the

Table 1.
Tests used by surveyed neuropsychologists to assess driving skills.

Test	Mean Discriminability*	Neuropsychologists Using Test (%)
Trails B	3.65	90
Mattis Dementia Rating Scale	3.63	46
Block Design	3.50	66
Digit Symbol	3.41	73
Motor Free Visual Perception Test	3.33	12
Visual Form Discrimination Test	3.33	27
Money Standardized Road Map Test of Direction Sense	3.25	22
Rey Complex Figure (Copy)	3.14	56
Clock Drawing	3.13	39
Wechsler Memory Scale-R (Visual Reproduction)	2.95	49
Mini-Mental Status Exam	2.92	29
Trails A	2.89	73
Wechsler Memory Scale Visual Quotient	2.89	22
Judgment of Line Orientation	2.88	44
Facial Recognition	2.82	29
Picture Completion	2.70	54
Blessed Dementia Rating Scale	2.67	7
Benton Visual Retention Test (Correct)	2.63	20
Benton Visual Retention Test (Errors)	2.50	20
Ravens Progressive Matrices	2.50	29
Wechsler Memory Scale-R (Logical Memory I)	2.35	41
Wechsler Memory Scale-R (Logical Memory II)	2.35	41
Boston Naming Test	1.58	29

*Discriminability rated on a scale from 1 (least discriminating) to 5 (most discriminating) present study. The tests were selected after considering frequency of use by neuropsychologists and representativeness of visuocognitive motor skills related to driving. The final measures that we decided upon included—

1. The Seashore Rhythm Test that is a test of auditory attentional skills [11].
2. The Logical Memory I and II Subtests from the Wechsler Memory Scale—Revised (WMS-R) that measure immediate (I) and delayed (II) verbal memory [12].
3. The Visual Reproduction I and II Subtests (also from the WMS-R) that measure immediate (I) and delayed (II) visual memory.
4. Trails A and B Tests that measure mental tracking abilities and mental flexibility [13].
5. The Digit Symbol Subtest from the Wechsler Adult Intelligence Scale—Revised (WAIS-R) that measures speed of information processing [14].
6. The Digit Span Subtest from the WAIS-R that measures attention and mental manipulation.
7. The Block Design Subtest of the WAIS-R that assesses visual-spatial organization and visuomotor coordination.
8. The Visual Form Discrimination Test that measures attention to visual detail [15].

The Zoo Map Subtest of the Behavioral Assessment of the Dysexecutive Syndrome Test that measures executive planning skills and mental tracking was added to the neuropsychological battery [10]. We administered the MMSE to all subjects and used the scores as a criterion cutoff for placement into a group of subjects with suspected dementia (Group 1, score below 25) or a group of control subjects (Group 2, with a score of 25 or above) [6]. Increasing age and lower educational levels are known to decrease the normative scores for the MMSE. Therefore, based on the published age-related modifications of the MMSE norms, we chose 25 as a discriminating criterion for MMSE scores between Groups 1 and 2 [16].

Phase 2: Driving Simulator Assessment

Participants

We included 22 participants (14 men and 8 women), recruited from the Department of Veterans Affairs (VA) Chicago Health Care System, West Side Division Memory Clinic and the Geriatric Clinic, and from the University of Illinois College of Medicine Memory Clinic. These participants were screened by a neurologist who is one of the authors (RS). Based upon the MMSE scores, the 22 subjects were placed into one of the two groups: Group 1 with suspected dementia (n = 8; 7 men and 1 woman), or Group 2, which served as the normal control group (n = 14; 7 men and 7 women). The age of the subjects from Groups 1 and 2 ranged from 67 to 85 years (mean [m] = 75.6 years; standard deviation [SD] = 7.0 years) and from 70 to 91 years (m = 77.0 years; SD = 6.2 years), respectively. The MMSE scores from Groups 1 and 2 ranged from 8 to 24 (m = 19.6; SD = 5.7) and from 26 to 30 (m = 27.9; SD = 1.2), respectively. Participants had driving experience ranging from 40 to 77 years (m = 57.2 years; SD = 9.1 years). All subjects were licensed drivers; 21 of the 22 subjects were currently driving. Participants were ambulatory with preserved motor coordination. All subjects had driving experience in the past 2 years. Individuals with severe cardiovascular disease, large strokes resulting in significant visual or motor impairment, seizure disorder, and visual impairments were excluded from the study.

Procedure

Neuropsychological Test Battery and Driving Habits Interview. The Neuropsychological Test Battery developed in Phase 1 was administered to all subjects. A Driving Habits Interview (provided by the National Highway Transportation Safety Administration), a 34-item self-report questionnaire that asks subjects about their driving behaviors, was also administered. The administration of the entire neuropsychological test battery, the Zoo Map Test, and the Driving Habits Interview took approximately 2 hours.

Driving Simulator Test. All participants underwent testing on an interactive driving simulator that was developed in collaboration with the Atari Corporation (Milipitas, California) and has been described in previous studies [17–19]. The simulator consisted of a seat, a steering wheel, gas and brake pedals, and an automatic transmission. The visual display system was composed of three 62.5-cm color monitors that were synchronized to display the appropriate view of a computer-generated environment. The visual display system provided 160° of horizontal viewing field and 35° of vertical viewing field to the subject seated 57.5 cm from the center screen. Testing was performed with the room lights off. We instructed subjects to operate the simulator, because they would normally drive their own car, and to obey all traffic signs and signals along the roadway. Following a

10- to 15-minute training session on a practice course (session length determined by patient competency), we collected data for subjects' responses during an 8-minute session of driving the course. The driving simulator provided the patients with challenges requiring them to make active driving decisions.

The simulator indexes that were analyzed included—

1. Mean speed (in miles per hour).
2. Brake pedal pressure (in arbitrary units, calculated as the SD in brake pedal pressure during the session).
3. Number of lane boundary crossings (defined as one of the four tires crossing over any of the lanes' boundaries).
4. Braking response time to a stop sign (defined as the elapsed time between the presentation of a stop sign and the initiation of a brake pedal response).
5. Braking response time to a traffic light (defined as the elapsed time between the presentation of a suspended red traffic light and the initiation of a brake pedal response).
6. Slope of the braking response curve (calculated as the change in speed divided by the change in time).
7. Horizontal and vertical eye movement (the SD of eye movement along the horizontal axis and along the vertical axis).
8. Number of times the subject ran stop signs and stoplights (calculated as the number of stop signs and stoplights run by the participant).
9. Number of near accidents (calculated as the number of times that a participant encounters a near accident).
10. Simulator accidents.

Previous studies have demonstrated a significant correlation between driving simulator measures and real-world driving in three major areas: lane boundary crossings, speed, and simulator accidents [20–21]. Fewer lane boundary crossings on the simulator were correlated with better scores on several subindexes of the road test, including a composite score for merging, maintaining proper lane position while making a left turn, adjusting speed properly while merging, visually checking blind spot while merging, determining sufficient distance to merge, and using a signal properly. Lower speeds on the simulator were correlated with worse scores for lane observance and worse scores for proper use of a signal before merging. More simulator accidents were related to worse scores for lane observance in the real-world condition. These studies provide data to demonstrate the validity of the driving simulator as it relates to real-world driving.

RESULTS

Neuropsychological Tests

The test results of Groups 1 and 2 on the neuropsychological tests are shown in **Table 2**. We performed parametric t-tests and nonparametric T-tests to analyze for differences between the groups. The following tests were significant at $p \le 0.001$: Logical Memory I, Logical Memory II, Trails B, Digit Symbol, and Digit Span. Trails A was significant at $p \le 0.01$. The following tests showed significant differences between the groups at $p \le 0.05$: Visual Memory (Immediate), Visual Form Discrimination, and Block Design. Visual Memory II, the Zoo Map Test, and the Seashore Rhythm Test did not show significant differences between the groups.

Driving Simulator and Neuropsychological Tests

The correlations between neuropsychological test scores and the driving simulator performance measures are shown in **Table 3**. We performed correlations on the tests using either a Pearson correlation with parametric data or a Spearman correlation with nonparametric data. The following relationship was significant at $p \le 0.001$: Trails A and number of lane boundary crossings. The following relationships were significant at $p \le 0.01$: Logical Memory I and number of lane boundary crossings, Logical Memory I and brake pedal pressure, Seashore Rhythm Test and number of lane boundary crossings, Trails A and brake pedal pressure, Trails B and number of lane boundary crossings, Trails B and speed, and Trails B and brake pedal pressure. The following correlations were significant at $p \le 0.05$: Logical Memory II and speed, Logical Memory II and brake pedal pressure, Visual Memory I and number of lane boundary crossings, Block Design and number of lane boundary crossings, Block Design and speed, Digit Span and brake pedal pressure, Digit Span and horizontal eye movement, Digit Symbol and number of lane boundary crossings, Trails A and speed, and Visual Form Discrimination and horizontal eye movement.

Table 2.
Significant differences between Groups 1 (suspected dementia) and 2 (control) on neuropsychological measures. If mean is indicated, a t is presented; if median is indicated, a T is presented.

Test	Size		Missing		Mean		Median		SD		T(df) or t (df)	p Value
	Group		Group		Group		Group		Group			
	1	2	1	2	1	2	1	2	1	2		
Logical Memory I	8	14	1	0	9.42	19.21	—	—	5.22	3.37	–5.26(19)	≤0.001*
Logical Memory II	8	14	1	0	4.14	13.00	—	—	4.53	3.82	4.72(19)	≤0.001*
Trails B	8	14	1	0	348.14	121.50	—	—	127.25	44.26	6.10(19)	≤0.001*
Digit Symbol	8	14	1	0	15.86	40.29	—	—	11.92	8.71	–5.36(19)	≤0.001*
Digit Span	8	14	2	0	12.67	18.36	—	—	2.73	2.93	–4.06(18)	≤0.001*
Trails A	8	14	1	0	—	—	135.00	44.50	—	—	118(19)	0.003†
Visual Memory I	8	14	1	0	17.00	28.57	—	—	8.31	9.34	–2.77(19)	0.012‡
Visual Form Discrimination	8	14	2	0	—	—	28.00	31.00	—	—	33.00(18)	0.015‡
Block Design	8	14	1	1	—	—	8.00	23.00	—	—	43.5(18)	0.019‡
Visual Memory II	8	14	1	0	7.14	17.14	—	—	10.12	12.72	1.81(19)	0.087
Zoo Map	8	14	3	0	—	—	2.00	2.00	—	—	44.5(17)	0.642
Seashore Rhythm	8	14	2	0	—	—	23.00	26.00	—	—	40.0(18)	0.063

*$p \leq 0.001$
†$p \leq 0.01$
‡$p \leq 0.05$
df = degrees of freedom
SD = standard deviation

Driving Simulator Performance

The differences between the performance of Groups 1 and 2 on the driving simulator are shown in **Table 4**. We made comparisons using a parametric t-test or a nonparametric Mann Whitney Rank Sum test. Significant differences ($p \leq 0.05$) were shown between the suspected dementia and control groups with the suspected dementia subjects having slower speeds and more lane boundary crossings.

Driving Habits Interview

The differences between Groups 1 and 2 on the Driving Habits Interview are shown in **Table 5**. We analyzed data using a parametric t-test or a nonparametric Mann Whitney Rank Sum Test. The following differences were significant at $p \leq 0.05$: distant towns, total passengers rode with subject over the past year, and total places driven to in an average week. The control Group 2 drove to more distant towns, with more passengers over the past year, and to more places in an average week than the suspected dementia Group 2.

We performed correlational analyses between the results of the MMSE and the Driving Habits Interview. The results are shown in **Table 6**. The following correlations were significant at $p \leq 0.05$ with the MMSE scores:

Table 3.
Correlations between neuropsychological tests and driving simulator performance.

Test	LBC	Speed	BPP	Horizontal Eye Movement
Logical Memory I	–0.594 0.006†	0.0547 0.0126‡	0.664 0.0014†	—
Logical Memory II	—	0.490 0.028‡	0.551 0.012‡	—
Visual Memory I	–0.503 0.0239‡	—	—	—
Block Design	–0.480 0.0377‡	0.469 0.043‡	—	—
Digit Span	—	—	0.484 0.036‡	0.525 0.0366‡
Digit Symbol	–0.474 0.0346‡	—	—	—
Seashore Rhythm	–0.671 0.002†	—	—	—
Trails A	0.729 0.0001*	–0.532 0.016‡	–0.610 0.004†	—
Trails B	0.608 0.004†	–0.571 0.009†	–0.563 0.01†	—
VFD	—	—	—	0.597 0.0147‡

Note: Only values of significant correlations are shown. All others had no significant relationships.
*$p \leq 0.001$
†$p \leq 0.01$
‡$p \leq 0.05$
LBC = lane boundary crossing
BPP = brake pedal pressure
VFD = Visual Form Discrimination

seat-belt use, total places driven in a week, total passengers rode with subjects over the past year, traveling to distant towns, traveling outside of Illinois, traveling outside of the Midwest, and number of traffic tickets. Participants with a higher (better) MMSE score wore their seat belts more often, drove to more places, and drove with more passengers than subjects with a lower (poorer) MMSE score. Participants with a higher MMSE score also drove more often to more distant towns, outside of Illinois, and outside of the Midwest than subjects with a lower MMSE score drove, and had fewer traffic tickets. No significant correlations were found between MMSE scores and number of accidents or number of times pulled over by the police.

DISCUSSION

Neuropsychological Tests

As expected, the suspected dementia subjects and normal control subjects performed at a significantly different level on 9 out of 12 tests in our battery (**Table 2**). The most significant difference occurred on tests that examined logical memory, immediate and delayed memory (Logical Memory I and II, Digit Span), complex scanning, visuomotor coordination, and speed of information processing (Trails A and B, Digit Symbol). The second significant area involved tests that examined skills in visual memory and immediate recall (Visual Memory I), visual recognition and complex form recognition (Visual

Table 4.
Driving simulator performance measures for Groups 1 (suspected dementia) and 2 (control). If mean is indicated, a t is presented; if median is indicated, a T is presented.

Test	n		Missing		Mean		Median		SD		T(df) or t (df)	*p* Value
	Group		Group		Group		Group		Group			
	1	2	1	2	1	2	1	2	1	2		
Speed	8	14	0	1	15.49	23.54	—	—	7.81	7.39	–2.37(19)	0.028*
Number of Lane Boundary Crossings	8	14	0	1	—	—	8.00	5.00	—	—	116.50(19)	0.043*
Brake Pedal Pressure	8	14	0	1	18.39	26.47	—	—	10.05	8.57	–1.97(19)	0.064
Braking Response Time to Red Lights	7	13	2	2	1.97	3.01	—	—	1.69	2.05	–0.99(14)	0.340
Slope of Braking Response Curve	8	13	1	1	–4.26	–5.47	—	—	3.07	2.73	0.89(17)	0.384
Horizontal Eye Movement	8	14	3	2	27.08	34.61	—	—	11.64	17.19	–0.89(15)	0.388
Braking Response Time to Stop Signs	8	13	1	1	—	—	1.47	0.43	—	—	80(17)	0.422
Number of Times Subject Ran Red Light & Stop Signs	8	14	0	1	—	—	0.00	0.00	—	—	94.5(19)	0.662
Vertical Eye Movement	8	14	3	2	—	—	27.65	22.54	—	—	47(15)	0.874
Simulator Accidents	8	14	0	1	—	—	0.00	0.00	—	—	90(19)	0.913
Number of Near Accidents	8	14	0	1	—	—	1.00	1.00	—	—	87(19)	0.971

*$p \leq 0.05$
df = degrees of freedom
SD = standard deviation

Form Discrimination), and visual-spatial organization (Block Design).

The results indicated that the neuropsychological tests were significantly correlated with a number of driving simulator indexes. These results reflect the work of other researchers who have found a correlation between neuropsychological tests and driving skills [5,22–24]. Logsdon et al. found that mental status screening and functional assessments were significantly different between drivers and nondrivers, as were scores on a visual-spatial task [22]. Fitten et al. examined patients with Alzheimer's disease and Vascular Dementia and found that short-term memory, visual tracking, and MMSE scores had the highest correlation with an overall driving score [5]. Mazer and colleagues showed that subjects who passed an on-road driving evaluation had better average scores on a majority of perceptual tests compared with subjects who failed the evaluation [23]. Last, the results of our study are consistent with other research that has shown an association between Trail Making test performance and driving ability [24–26]. Lane boundary crossing was the one measure on the driving simulator that correlated with the highest number of neuropsychological tests (**Table 3**). Individuals who are unable to maintain their lane position may be at risk for accidents such as being hit by oncoming or passing traffic.

Driving simulator speed and brake pedal pressure each correlated with five neuropsychological tests. Individuals scoring well on these tests drove faster and applied more brake pedal pressure. The increased brake pedal

Table 5.

Results of driving habits interview for Groups 1 (suspected dementia) and 2 (control). If mean is indicated, a t is presented; if median is indicated, a T is presented.

Question	n		Missing		Mean		Median		SD		T(df) or t (df)	*p* Value
	Group		Group		Group		Group		Group			
	1	2	1	2	1	2	1	2	1	2		
During past year, have you driven to more distant towns (0 = no; 1 = yes)	8	14	0	0	—	—	0.00	1.00	—	—	61(20)	0.036*
Total No. of passengers rode with subject over past year (0 = no; 1 = yes)	8	14	1	0	1.14	3.00	—	—	1.22	1.30	–3.15(19)	0.005*
Total No. of places traveled to in typical week	8	14	1	0	4.04	5.93	—	—	1.16	1.33	–3.20(19)	0.005*
During past year, have you driven outside of Illinois (0 = no; 1 = yes)	8	14	0	0	—	—	0.00	1.00	—	—	65(20)	0.068
Total dependency score: When traveling, who usually drives†	8	14	1	0	1.54	2.05	—	—	0.74	0.62	–1.68(19)	0.110
Total number of trips taken in a typical week	8	14	1	0	8.54	12.68	—	—	4.94	5.90	–1.60(19)	0.127
During past year, have you driven to places outside Midwest (0 = no; 1 = yes)	8	14	0	0	—	—	0.00	1.00	—	—	70(20)	0.140
If you had to go somewhere & didn't want to drive yourself, what would you do‡	8	14	1	0	—	—	2.00	1.00	—	—	96.5(19)	0.154
No. of times in last year have you received a traffic ticket	8	14	0	0	—	—	0.00	0.00	—	—	113(20)	0.156
During past 3 months, have you driven when it is raining§	8	14	1	0	4.71	4.29	—	—	0.49	0.73	1.40(19)	0.177
Do you wear a seat belt when you drive (1 = always; 2 = sometimes; 3 = never)	8	14	1	0	—	—	1.00	1.00	—	—	95(19)	0.186
During past 3 months, have you driven at night§	8	14	1	0	—	—	5.00	4.00	—	—	92(19)	0.278
During past 3 months, have you driven in rush-hour traffic§	8	14	1	0	—	—	4.00	5.00	—	—	63(19)	0.311
Total No. of miles driven in a typical week	8	14	1	0	72.21	118.78	—	—	84.05	104.12	–1.02(19)	0.319
During past year, have you driven to neighboring towns (0 = no; 1 = yes)	8	14	0	0	—	—	1.00	1.00	—	—	78(20)	0.349
During past 3 months, have you driven on interstates or expressways§	8	14	1	0	—	—	5.00	5.00	—	—	65(19)	0.387
No. of accidents involved in over past year where you were the driver & police were called to scene	8	14	0	0	—	—	0.00	0.00	—	—	105(20)	0.389

Table 5. (Continued)
Results of driving habits interview for Groups 1 (suspected dementia) and 2 (control). If mean is indicated, a t is presented; if median is indicated, a T is presented.

Question	n		Missing		Mean		Median		SD		T(df) or t (df)	*p* Value
	Group		Group		Group		Group		Group			
	1	2	1	2	1	2	1	2	1	2		
How would you rate quality of your driving¶	8	14	1	0	3.57	3.86	—	—	0.79	0.66	–0.88(19)	0.392
During past 3 months, have you made left-hand turns across oncoming traffic§	8	14	1	0	—	—	5.00	5.00	—	—	66(19)	0.430
During past 3 months, have you driven alone§	8	14	1	0	—	—	5.00	5.00	—	—	66.5(19)	0.449
Which way do you prefer to get around**	8	14	1	0	—	—	3.00	3.00	—	—	67.5(19)	0.496
In an average week, how many days a week do you normally drive	8	14	1	0	—	—	7.00	7.00	—	—	68.5(19)	0.546
During past 3 months, have you parallel parked§	8	14	1	0	—	—	5.00	5.00	—	—	69(19)	0.573
Has anyone suggested over past year that you limit driving or stop driving (0 = no; 1 = yes)	8	14	1	0	—	—	0.00	0.00	—	—	84(19)	0.623
Do you currently drive (0 = no; 1 = yes)	8	14	0	0	—	—	1.00	1.00	—	—	85(20)	0.651
Number of times in past year been pulled over by police	8	14	0	0	—	—	0.00	0.00	—	—	97(20)	0.757
Number of accidents been involved in over past year when you were driving	8	14	0	0	—	—	0.00	0.00	—	—	97(20)	0.757
During past year, have you driven to neighboring towns (0 = no; 1 = yes)	8	14	0	0	—	—	1.00	1.00	—	—	96(20)	0.808
How fast do you usually drive compared to general flow of traffic††	8	14	1	0	—	—	3.00	3.00	—	—	75(19)	0.910
During past 3 months, have you driven on high-traffic roads§	8	14	1	0	—	—	5.00	5.00	—	—	76(19)	0.970
During past year, have you driven to places beyond your neighborhood (0 = no; 1 = yes)	8	14	0	0	—	—	1.00	1.00	—	—	92(20)	0.972
Do you wear glasses or contact lenses when you drive (0 = no; 1 = yes)	8	14	0	0	—	—	1.00	1.00	—	—	93(20)	0.972
Do you have a valid driver's license	8	14	0	0	—	—	1.00	1.00	—	—	92(20)	0.972

*$p \leq 0.05$
†Scale from 1 to 3, higher No. = increased independence.
‡Scale from 1 to 5, 1 = ask friend, 2 = taxi or bus, 3 = drive self, 4 = cancel plans, and 5 = other.
§Scale from 1 to 5, 1 = not able 2 = extremely difficult, 3 = moderate difficulty, 4 = a little difficulty, and 5 = no difficulty at all.
¶Scale from 1 to 5, 1 = poor, 2 = fair, 3 = average, 4 = good, and 5 = excellent.
**Scale from 1 to 3, 1 = public transportation, 2 = someone else, and 3 = self.
††Scale from 1 to 5, 1 = much slower, 2 = somewhat slower, 3 = about the same, 4 = somewhat faster, and 5 = much faster.
SD = standard deviation.

pressure may suggest that these individuals use their brakes more over the driving course when they encounter stop signs, stoplights, accidents, and other road hazards. The significant relationships between the driving simulator indexes and the neuropsychological tests may indicate that individuals with better cognitive abilities have more confidence about their driving abilities. Patients with dementia may have greater psychomotor slowing, poorer reaction time, and a decline in self-regulation.

Horizontal eye movement, as measured while driving the simulator, correlated with two neuropsychological tests (Digit Span and Visual Form Discrimination). The better an individual performed on these neuropsychological tests, the greater their horizontal eye movement. The results suggest that individuals with skills in attention, form discrimination, and visual spatial attention, scan more along the horizontal axis and may pay greater attention to their surrounding visual environment.

Differences Between Groups on Driving Simulator

Results revealed that there were significant differences in driving simulator performance between the two groups on two parameters: number of lane boundary crossings and speed (**Table 4**). Group 1 subjects crossed the centerline significantly more often than the Group 2 control subjects did. This may be due to decreased visual attention because lane boundary crossing was also correlated with poorer performance on neuropsychological tests measuring attention and visual form discrimination. Group 1 subjects also drove significantly slower than the Group 2 control subjects. They may be less comfortable driving and more cautious than control subjects or may have overall slower processing abilities as evidenced by the correlation of speed with the neuropsychological tests (Block Design and Trails A and B).

In this study, several neuropsychological tests have been shown to be significantly related to the driving simulator. The driving simulator has been shown to be related to real-world driving abilities [20]. Therefore, one may hypothesize that these neuropsychological tests would be good predictors of on-road driving.

Driving Habits Interview

We assessed the driving habits of all participants using a 34-item self-report questionnaire. Results revealed

Table 6.
Correlations between MMSE and driving habits interview.

		r	***p* Value**
	Driving Habits		
MMSE	Seat belt use 1 = always, 2 = sometimes, 3 = never	–0.435	0.0481*
	Total places driven	0.433	0.0497*
	Total passengers rode with subjects	0.482	0.0268*
	Driving Distance		
MMSE	Distant towns 0 = no; 1 = yes	0.0495	0.0192*
	Outside Illinois 0 = no; 1 = yes	0.465	0.0288*
	Outside Midwest	0.455	0.0329*
	Crash and Citation Rate		
MMSE	Accidents	–0.109	0.624
	Police-reported crashes	–0.224	0.311
	Times pulled over by police	–0.233	0.292
	Traffic tickets	–0.453	0.0343*

*$p \leq 0.05$

significant differences between the two groups in three distinct areas (**Table 5**). First, Group 2 control subjects reported that they ventured to distant towns significantly more often than subjects did from Group 1. Second, Group 2 subjects drove with significantly more passengers in their car over the past year than Group 1 subjects. Third, Group 2 subjects drove to significantly more places in a typical week than the subjects from Group 1. These findings may indicate that the subjects with suspected dementia are practicing some self-restricting driving behaviors.

A correlational analysis between the MMSE score and the Driving Habits Interview revealed several significant relationships (**Table 6**). First, individuals with a higher (better) MMSE score wore their seat belt more often and drove to more places with more passengers in a typical week. This may indicate that individuals with a higher cognitive status are more conscientious about safety and are more active drivers than individuals with a lower cognitive status. It may also be that individuals with lower MMSE scores drive less and travel with fewer passengers in the car because friends and family are aware of their cognitive losses. Second, a significant relationship between driving distances and MMSE score was found. It was shown that individuals with a higher MMSE score drove to more distant towns, outside of the state, and outside of the Midwest significantly more often than individuals with a lower MMSE score. Finally, data revealed that a significant relationship did not exist between MMSE scores and crash rate. It may be that those with lower scores self-restrict to reduce this risk. This self-restriction has been found previously in groups of older drivers to reduce their on-road risk [20].

The results of the study are consistent with other surveys on patients with Alzheimer's disease and driving safety. It has been reported that reduced driving exposure of patients with dementia kept their crash rate equal to that of comparison subjects [4]. It has also been reported that the existing evidence suggests that patients with Alzheimer's disease who drive present a slightly increased risk for crashes compared with drivers of all ages, but a lower risk than young unimpaired drivers, especially males [27].

CONCLUSIONS

The study revealed four important findings. First, as expected, a significant difference was found between the performance of Groups 1 and 2 on 9 of the 12 psychology tests that we selected for our battery. Second, 10 neuropsychological tests correlated with driving simulator performance. Lane boundary crossings were found to be the most sensitive simulator measure, related to the highest number of neuropsychological tests. Speed, brake pedal pressure, and horizontal eye movement were also significantly correlated with neuropsychological test performance. Trails A and B and Logical Memory (Immediate) were the neuropsychological tests that correlated with the largest number of driving simulator measures. Third, there was a significant performance difference between Groups 1 and 2 on the driving simulator test in two distinct areas. Control subjects remained in their traffic lane more often and had an increased rate of speed. Fourth, a significant difference was found between Groups 1 and 2 on the Driving Habits Interview in three different areas: traveling to distant towns, total passengers rode with subjects over the past year, and total places driven to in a typical week. The subjects with suspected dementia traveled less often to distant towns, drove to fewer places in a typical week, and drove with fewer passengers over the course of a year.

Our findings show that commonly used neuropsychological tests are related to driving skills as measured by the driving simulator, demonstrating that these tests are effective for evaluating suspected dementia and simulated driving. Because our driving simulator has been shown to correlate with on-road driving in previous studies [20,21], we hypothesize that these neuropsychological tests may be predictive of real-world driving.

This research is important in helping to define a useful neuropsychological battery to screen for driving safety in patients with suspected dementia. Future research should be focused upon examining levels of severity of dementia and driving capabilities. Additionally, researchers may want to directly examine the relationship between this group of neuropsychological tests and on-road driving tests.

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