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Computerized Maze Navigation and On-Road Performance by Drivers With Dementia

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Abstract

This study examined the ability of computerized maze test performance to predict the road test performance of cognitively impaired and normal older drivers. The authors examined 133 older drivers, including 65 with probable Alzheimer disease, 23 with possible Alzheimer disease, and 45 control subjects without cognitive impairment. Subjects completed 5 computerized maze tasks employing a touch screen and pointer as well as a battery of standard neuropsychological tests. Parameters measured for mazes included errors, planning time, drawing time, and total time. Within 2 weeks, subjects were examined by a professional driving instructor on a standardized road test modeled after the Washington University Road Test. Road test total score was significantly correlated with total time across the 5 mazes. This maze score was significant for both Alzheimer disease subjects and control subjects. One maze in particular, requiring less than 2 minutes to complete, was highly correlated with driving performance. For the standard neuropsychological tests, highest correlations were seen with Trail Making A (TrailsA) and the Hopkins Verbal Learning Tests Trial 1 (HVLT1). Multiple regression models for road test score using stepwise subtraction of maze and neuropsychological test variables revealed significant independent contributions for total maze time, HVLT1, and TrailsA for the entire group; total maze time and HVLT1 for Alzheimer disease subjects; and TrailsA for normal subjects. As a visual analog of driving, a brief computerized test of maze navigation time compares well to standard neuropsychological tests of psychomotor speed, scanning, attention, and working memory as a predictor of driving performance by persons with early Alzheimer disease and normal elders. Measurement of maze task performance appears to be useful in the assessment of older drivers at risk for hazardous driving.

Keywords

driving; dementia; mild cognitive impairment; maze; computerized assessment

Among those who continue to drive, dementia is a well-recognized, age-related risk factor for hazardous driving. A number of editorials and review articles have addressed the issue of driving and dementia.¹⁻¹⁹ There is evidence to suggest, however, that not all persons with dementia are incompetent drivers, particularly in the very early stages.²⁰⁻²⁴ Given this evidence, it is particularly important to determine the most important cognitive or functional factors that contribute to driving impairment among those with dementia.

There is limited evidence that performance on some tests of executive function is moderately related to real-world driving ability, including performance on Porteus mazes,²⁵ clock drawing,²⁶ and the Trail Making Test.^{27,28} A meta-analysis of the literature regarding neuropsychological testing and driving ability provided support for the particular importance of visuospatial skills for driving ability in persons with dementia.²⁹ As compared with performance in multiple specific cognitive domains (eg, attention, language, memory), only performance on neuropsychological tests of visuospatial skills was related to on-road tests of driving abilities.

Preliminary studies of small numbers of subjects with dementia suggest that maze test performance may be a useful predictor of impaired driving by cognitively impaired older drivers. Mazes may be considered a neuropsychological test proxy for the complex tasks of driving through roads with intersections, where judgment, planning, and visual attention are required. We previously reported on the significant correlation of hand-drawn Porteus maze scores with driving competence ratings by family caregivers of persons with dementia. A computerized maze battery of 10 mazes was also significantly correlated with reports of driving competence.²⁵ Furthermore, a later study of 23 subjects with questionable dementia and 23 age-matched controls³⁰ found a significant correlation of hand-drawn Porteus mazes with actual driving performance scores on a standardized road test.

On the basis of this preliminary experience, we incorporated a brief battery of computerized maze tests as part of a longitudinal study of drivers with mild dementia. Computerized methodology was selected instead of hand-drawn mazes because it would allow for more accurate assessment of planning and drawing times. Furthermore, automatically scored computerized tests offer promise for use in motor vehicle registries as a potential method to efficiently screen for hazardous older drivers with dementia.

In summary, the goal of this study was to determine if computerized maze test performance is predictive of on-road driving performance in a cross-section of cognitively intact and cognitively impaired older drivers.

Methods

Subjects

We enrolled 133 older drivers, including 65 with probable Alzheimer disease (AD), 23 with possible AD, and 45 controls without cognitive impairment, to participate in a longitudinal study of drivers with dementia. Baseline data from this study were used for the present report. All subjects had valid drivers' licenses. All patients were recruited from the outpatient practices of the Rhode Island Hospital Memory Assessment Program and the Memorial Hospital Alzheimer's Disease and Memory Disorders Center. Control subjects were recruited from the patients' family and friends. All subjects were between 40 and 90 years of age. All subjects signed a document of informed consent approved by the Memorial Hospital and Rhode Island Hospital human subjects committees before their participation.

Alzheimer diagnoses by the study neurologist (BRO) were based on the NINCDS/ADRDA (National Institute of Neurological and Communicative Diseases and Stroke/Alzheimer's Disease and Related Disorders Association) criteria.³¹ All dementia subjects had a Clinical Dementia Rating³² (CDR) = 0.5 or 1, indicating very mild or mild dementia. All normal subjects had a CDR = 0 and a Mini-Mental State Examination³³ (MMSE) >26. The CDR and MMSE were completed by the neurologist before the maze and neuropsychological tests during 1 clinical office visit.

Diagnostic laboratory tests were performed in all dementia subjects, including serum cobalamin, chemistry panel, thyroid function tests, syphilis serology, complete blood count, and brain imaging (computed tomography [CT] or magnetic resonance imaging [MRI]) to exclude reversible causes of confusion other than AD. Computed tomography or MRI must have been done at a time following onset of dementia.

Exclusion criteria included reversible causes of dementia and physical, ophthalmologic, or neurological disorders other than dementia that might impair driving abilities. Subjects with hypothyroidism or vitamin B12 deficiency were permitted if they showed progressive decline in cognition and function despite at least 6 months of adequate replacement therapy. Major physical handicaps such as frozen joints, inadequately healed fractures, monocular blindness, and amputation were exclusionary. In all subjects, corrected visual acuity was better than 20/50 on eye chart testing, and visual fields were normal on confrontation testing. Psychiatric disorders were exclusionary, including mental retardation, schizophrenia, bipolar disorder, or history of alcohol/substance abuse within the past year. Depression was allowed if it was controlled with medications. Symptomatic antidementia drugs (eg, cholinesterase inhibitors) as well as antipsychotic and anxiolytic medications were permitted, but dosages were required to be stable for at least 6 weeks prior to entry into the study.

Among the 88 dementia subjects, there were 53 with very mild dementia (CDR = 0.5) and 35 with mild dementia (CDR = 1). Of these, 65 were diagnosed to have probable AD, and 23 were diagnosed to have possible AD. Other demographic data for the study sample are presented in Table 1. As expected, there were significant differences between dementia subjects and controls for MMSE, education (controls more highly educated), miles and trips driven per week (both more frequent for controls), and road test score (less impaired for controls).

Cognitive Measures

Mazes—Subjects completed 5 computerized maze tasks (MazeMaster Version 1.01, 81992, The Flatirons Group; see Figure 1). The mazes were selected based on results of the previously cited study using 10 mazes.²⁵ Specifically, the 5 mazes with the highest correlation with caregiver-reported driving competence were chosen. In this maze program, path length is determined by the total number of segments traversed. Maximum score is 100x the correct path length (range, 1400–3300). Final error score is the maximum score minus 25x the number of dead ends that are reached. Based on path length and number of quadrants traversed, maze 1 was the least difficult, and maze 2 was the most difficult, with mazes 3 to 5 of intermediate difficulty. The task is designed so that a subject cannot go through a dead end. When reaching a dead end, the subject must retrace the path back to another branch point. In addition to error scores, total time spent on the task and time drawing were recorded. Planning time was derived by subtracting drawing time from total time, such that it included both delay time to begin drawing and pauses during the task until the maze was solved. The primary predictor variables chosen for this test were the total scores and total times of all 5 mazes.

Subjects were seated at a comfortable distance of about 20 inches from eye to screen, in a softly lit room. After verbal explanation of the task, completion of up to 3 standard mazes of similar difficulty was allowed to familiarize the subject with the task. Maze lines were drawn by the subjects on an 18-inch diagonal Viewsonic touch-screen monitor, using a rubber-tipped stylus. Each maze was 9.5 square inches. The time required for completion of all of the mazes was approximately 5 minutes. A maximum time of 2 minutes was allowed for each maze.

Neuropsychological Measures

Global cognition: Subjects also completed a battery of standard neuropsychological tests after the maze task. The MMSE measured global cognitive function.

Visuospatial: The Boston Qualitative Scoring System for the Rey-Osterrieth Complex Figure³⁴ (BQSS-ROCF) was used to measure visuospatial skills (Copy Condition Presence and Accuracy score).

Executive function: The BQSS-ROCF scoring system (Organization score) and Trail Making Test Part B (TrailsB; total time to complete) were used to measure executive function. Trail Making is a commonly used test from the Halstead Reitan Battery involving 2 parts: part A is a measure of psychomotor speed and visual search (see below). Part B is predominantly a measure of divided attention and executive function (ie, specifically, cognitive response set maintenance and shifting). An upper limit was set at 5 minutes.

Psychomotor speed and visual tracking: Trail Making Test Part A³⁵ was chosen to measure psychomotor speed and visual tracking. Part A time to completion was measured.

Motor: The Finger Tapping Test³⁶ subtest of the Halstead-Reitan Battery is a measure of fine motor speed. Average total taps per each hand were recorded.

Memory: Memory was assessed by the Hopkins Verbal Learning Test (HVLT).³⁷ This is a commonly used measure of verbal learning and recall, involving 3 list learning trials, a delayed free recall, and a recognition format. Total words retrieved on trial 1 (HVLT1); trials 1 to 3, following a 20-minute delay (HVLT-Delay); and Recognition Discrimination score (hits minus false positives) were measured. HVLT1 was entered into analyses as a measure of working memory.

Road Test

Within 2 weeks of the clinical assessment, participants were administered an on-road driving test by a professional and experienced driving instructor (15 years of licensed, full-time work as a driving instructor and trained in the evaluation of neurologically disabled drivers). The road test was based on a published and reliable driving test, the Washington University Road Test,³⁸ adapted for comparable streets in Rhode Island. Although the streets were different, all the same maneuvers and identical scoring procedures were used to produce a comparable test procedure for Rhode Island. Methods for the Rhode Island road test have been previously reported.³⁹ Interrater reliability for 20 participants on the adapted road test (rated by a second professional driving instructor in the back seat) yielded moderate to substantial agreement for the global rating ($\kappa = 0.65$). The intra-class correlation coefficient between the 2 raters (r) for the total on-road driving score was 0.82.

The test was administered during daylight hours under good conditions (no precipitation or wet roads) on local streets in Pawtucket and East Providence. The instructor was blind to the participants' diagnosis. A 10- to 15-minute pretest was completed in the parking lot prior to the actual road test to ensure that the test was safe to perform and to familiarize the participant with the car and the instructor. The actual road test lasted approximately 45 minutes. Participants received an on-road driving score based on safe completion of each of the required maneuvers, ranging from 0 (best score) to 108 (worst score). The instructor also made a trichotomous global rating of the participant's driving ability as safe, marginal, or unsafe. The "marginal" global rating was given to subjects who passed the road test but for whom the instructor had specific concerns about their driving practices or ability. The

driving instructor shared those specific concerns with the study participant upon completion of the road test and included them in his report to the principal investigator.

Analyses

Correlations for continuous variables were made using Pearson coefficients. Multiple linear regression models were derived for the continuous road test variable using stepwise subtraction procedures. Logistic regression models were applied to the dichotomous variable of global road test performance. The dichotomous variable was obtained by combining marginal with unsafe ratings to distinguish those drivers who were clearly judged to be safe from the other subjects. Furthermore, the numbers of actual road test failures were relatively low in each group of drivers (1/45 in controls and 17/88 in dementia subjects). Although dementia subjects were found to drive significantly fewer trips and miles compared with controls, we did not examine these as independent variables in analyses because these variables are most likely proxies for actual driving impairment, rather than contributing factors. All analyses were done with Stata statistical software package (Version 8.0).

Results

One dementia subject dropped out of the study before completing the road test. Eleven other dementia subjects were unable to complete all of the mazes and were dropped from further analyses. Zero, 9, 8, 4, and 7 subjects were unable to complete mazes 1 through 5, respectively. Of the 11 AD subjects who could not complete all the mazes, 2 failed the road test, 6 were rated as marginal, and 3 were rated as safe. All of the controls completed the road test and the mazes, leaving a total of 121 subjects completing all mazes and the road test. Because education was not matched between subject groups, this variable was examined for correlation with all maze measurements as well as road test scores, and no significant relationships were found.

Road test total score was significantly correlated with total time for the 5 mazes ($r = .54$, $P < .0005$). This maze score was significant for both AD subjects ($r = .40$, $P < .0005$) and control subjects ($r = .53$, $P < .0005$). One maze in particular, requiring less than 2 minutes to complete, was highly correlated with driving performance score ($r = .57$, $P < .0005$) for the entire sample (see Table 2).

Road test total score was significantly correlated with total planning time for the 5 mazes for controls ($r = .41$, $P = .006$) but not for AD subjects ($r = .19$, $P = .11$).

For the standard neuropsychological tests, highest correlations were seen with TrailsA ($r = .50$, $P < .0005$), TrailsB ($r = .48$, $P < .0005$), and HVLT1 ($r = -.47$, $P < .0005$) for the entire sample; HVLT1 ($r = -.37$, $P < .05$) and TrailsA ($r = .36$, $P < .005$) among AD subjects; and TrailsA ($r = .58$, $P < .0005$) and hand tapping ($r = -.37$, $P < .05$) among normal subjects (see Table 3).

Multiple regression models for road test score using stepwise subtraction of demographic variables (age, sex, education, visual acuity, driving experience) revealed significant independent contributions only for age, $F(1, 128) = 7.99$, $P = .005$, $R^2 = .06$. Multiple regression models for road test score using stepwise subtraction of maze and the standard neuropsychological test variables revealed significant independent contributions for total maze time, HVLT1, and TrailsA for the entire group; total maze time and HVLT1 for AD subjects; and TrailsA for normal subjects (see Table 4).

Finally, logistic regression models were examined to determine the relationships between the significant test variables listed above and driving competence defined categorically by

the instructor as safe versus marginal or unsafe. Receiver operating characteristics were determined and discriminant function analysis performed to assess classification rate (see Table 5). Maze total time accounted for 15% of the variance in these 2 categories, with a correct classification rate of 68.6%. Incremental improvements were achieved by adding age as well as HVLTI and TrailsA scores. This model accounted for 31% of the variance, with a correct classification rate of 81.0%.

The same models were examined for only subjects with CDR = 0.5 and controls. For this more mildly impaired sample, maze total time accounted for 23% of the variance, with a correct classification rate of 76.5%. Adding age, HVLTI, and TrailsA scores, the model accounted for 35% of the variance, with a correct classification rate of 85%.

Discussion

The results of our study show a close association between maze navigation on a computer monitor and road navigation in an automobile among cognitively impaired and normal older drivers. This observation may be of practical utility.

Our study lends further support to 2 previous reports on the significant relationship between maze test performance and driving ability in cognitively impaired and normal older drivers.^{25,30} The correlation between road test and maze performance in the present study was actually lower than the correlation previously reported between driving ability ratings by caregivers of persons with mild dementia and performance on the same computerized mazes ($r = .64$, $P < .0005$).²⁵ The “gold standard” for measuring driving ability among those with dementia remains unresolved,¹ and it is possible that caregiver ratings may indeed be more valid indicators of driving than standardized road tests because they observe the subject under more natural conditions and for longer periods of time and circumstance.

In the study by Whelihan et al,³⁰ a modified version of 8 Porteus mazes were hand drawn by drivers with questionable (CDR = 0.5) or no dementia and compared with road test scores. They found a significant correlation with total time to draw the mazes in patients but not in controls. Significant correlation with maze errors was not seen in either group. Classification accuracy for maze time compared with a categorical pass/fail rating was 80%. We also found a stronger correlation with drawing time compared with error scores; however, we found significant correlations between drawing times and driving scores for normal subjects as well.

Our classification rate of 69% for the global rating of safe versus marginal/unsafe was lower than that of the Whelihan et al³⁰ study. This difference was most likely due to dementia severity differences between study samples because we achieved a comparable classification rate of 76.5% if we excluded mildly demented subjects (CDR = 1). Differences in our global rating scheme may have also been contributory. Overall, these results compare favorably to the classification rates made by clinicians based on a complete medical assessment as well as a battery of neuropsychological tests, which have been reported to range from 62% to 78%.³⁹ The modest accuracy of predictions for road test performance in these studies may be related to limitations of the road test procedures themselves as well as the predictor tests as measures of driving competence.

Our data show that, as a visual analog of driving, a brief computerized test of maze navigation time compares well to standard neuropsychological tests of executive function, psychomotor speed, scanning, and working memory as a predictor of driving performance by persons with mild AD and normal elders. As a single test taking as little as 2 minutes to perform, maze testing efficiently incorporates a number of these important cognitive functions at once. The maze test can be conceptualized to include the driving challenges of

planning a route, decision making at intersections, visually scanning a complex road environment, traveling at a confident or safe speed, and constant attention to motor task. In this regard, time to complete the task incorporates all of these visual attention and executive functions better than simply recording errors as a predictor of driving performance.

In general, total time completing the mazes was a better predictor than drawing time, probably because it incorporates planning as well as execution of the task. Interestingly, planning time was a significant factor related to driving for normal control subjects but not AD subjects, suggesting differential effects of executive dysfunction between the 2 groups. For example, AD drivers may be more impulsive in their approach to navigation.

It is noteworthy that trail making was also significantly correlated with driving performance, particularly in the control group, suggesting that psychomotor speed may be the most sensitive discrimination measure for driving performance among the best drivers. This traditional neuropsychological test incorporates many of the same cognitive abilities as maze drawing and has been shown in previous studies to correlate with risk for crashes,⁴⁰ as well as simulator²⁸ and road test performance.^{27,30} In our study, TrailsA performed better than TrailsB because of floor effects reached by some of the subjects. The findings for trail making in our study replicate previous observations; however, the significant correlation between the HVLT1 and driving in AD subjects is a new finding that should be further explored and replicated by future studies. It appears that working memory may be an important component of cognitive function that is related to driving impairment in this group.

The maze task in its present form is inadequate as a stand-alone test. As Table 5 demonstrates, addition of age plus other cognitive tests provides a more satisfactory model for prediction of driving ability on a road test. Further development of computerized tests such as this may lead to a practical screening procedure to easily identify potentially hazardous older drivers. The advantages of using computerized technology include speed of data collection and scoring as well as efficiency in test administration. Validation of computerized cognitive testing in this population, however, is in its infancy.⁴¹

Our study clearly demonstrates the feasibility of this approach; however, an important obstacle for use in older persons is unfamiliarity with the technology—what has been termed *computer-related anxiety*.⁴² Therefore, we chose to use a touch screen and stylus to replicate as closely as possible the natural experience of drawing on paper mazes. Nevertheless, 11 dementia subjects still found the mazes too difficult to complete in the allowed time. Of note, the more complex mazes were the most highly correlated with road test performance, but their utility was also limited by task difficulty. Better results might be obtained by allowing more than 2 minutes to complete the task. Further refinement of this technology will be necessary to develop a more sensitive and accurate measurement of the cognitive abilities needed for driving competence in the office or motor vehicle registry setting.

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Figure 1.
The 5 mazes.

Table 1

Characteristics of Subjects and Their Road Test Scores

	Controls (<i>n</i> = 45)	Alzheimer Disease Subjects (<i>n</i> = 88)	<i>P</i>
Age, y (SD)	73.6 (9.0)	75.8 (6.9)	.13
Sex (women/men)	25/20	35/53	.08
Education, y (SD)	15.3 (3.1)	13.8 (3.3)	.01
MMSE (SD)	29.1 (1.1)	24.0 (3.5)	<.0001
Handedness (right/ambidextrous/left)	42/3/0	79/6/3	.46
Ethnic (white/other)	44/1	83/5	.68
Shift (automatic/standard)	41/4	85/3	.18
Driving experience, y (SD)	52.4 (81.4)	55.7 (10.5)	.10
Miles driven/week (SD)	138.7 (119.5)	66.9 (76.9)	.0001
Trips/week (SD)	15.0 (13.2)	8.7 (7.4)	.0007
Road test score (SD)	6.2 (4.6)	13.3 (8.1)	<.0001
Global drive rating (safe/marginal/unsafe)	35/9/1	34/36/17	<.0001

NOTE: MMSE = Mini-Mental State Examination.

Table 2

Maze Correlations With Road Test Total Score

Error Score	Controls (n = 45)	Alzheimer Disease Subjects (n = 76)	All Subjects (n = 121)
Maze 1	.07	.05	-.05
Maze 2	-.04	-.47 ^c	-.45 ^c
Maze 3	-.24	-.23 ^a	-.32 ^c
Maze 4	-.12	-.21	-.27 ^b
Maze 5	-.24	.01	-.13
Maze total score	-.24	-.28 ^a	-.40 ^c
<i>Drawing time</i>			
Maze 1	.34 ^a	.12	.25 ^a
Maze 2	.32 ^a	.50 ^c	.57 ^c
Maze 3	.48 ^b	.28 ^a	.41 ^c
Maze 4	.27	.28 ^a	.37 ^c
Maze 5	.49 ^c	.20	.35 ^c
Maze total drawing time	.49 ^c	.38 ^b	.50 ^c
<i>Overall time</i>			
Maze 1	.35 ^a	.16	.31 ^b
Maze 2	.44 ^b	.49 ^c	.57 ^c
Maze 3	.49 ^c	.29 ^a	.43 ^c
Maze 4	.32 ^a	.30 ^a	.40 ^c
Maze 5	.58 ^c	.22	.40 ^c
Maze total overall time	.53 ^c	.40 ^c	.54 ^c

^a $P < .05$.^b $P < .005$.^c $P < .0005$.

Table 3

Neuropsychological Test Correlations With Road Test Score

	Controls	Alzheimer Disease Subjects	All Subjects
HVLT Trial 1	-.27	-.37 ^b	-.47 ^c
HVLT Delay	-.13	-.17	-.42 ^c
BQSS-ROCF presence	-.13	-.22	-.35 ^c
BQSS-ROCF organization	-.27	-.16	-.35 ^b
Tap dominant hand	-.37 ^a	-.27 ^a	-.29 ^b
Tap nondominant hand	-.25	-.13	-.15
TrailsA time	.58 ^c	.36 ^b	.50 ^c
TrailsA scaled score	-.29	-.18	-.36 ^c
TrailsB time	.36 ^a	.26	.48 ^c
TrailsB scaled score	-.19	-.18	-.41 ^c
MMSE	-.38 ^a	-.28 ^b	-.47 ^c

NOTE: HVLT = Hopkins Verbal Learning Tests; BQSS-ROCF = Boston Qualitative Scoring System for the Rey-Osterrieth Complex Figure; MMSE = Mini-Mental State Examination.

^a $P < .05$.

^b $P < .005$.

^c $P < .0005$.

Table 4

Stepwise Subtraction Multiple Regression Models: Prediction of Road Test Total Score for Subjects

Controls		
$F(1, 40) = 20.00$	$P = .0001$	$R^2 = .33$
TrailsA	$t = 4.47$	$P < .001$
Alzheimer disease subjects		
$F(2, 66) = 9.66$	$P = .0002$	$R^2 = .23$
Maze total	$t = 3.35$	$P = .001$
HVLT1	$t = -2.41$	$P = .019$
All subjects		
$F(3, 105) = 23.62$	$P = .00001$	$R^2 = .40$
Maze total	$t = 3.55$	$P = .001$
HVLT1	$t = -2.78$	$P = .006$
TrailsA	$t = 2.44$	$P = .016$

NOTE: HVLT1 = Hopkins Verbal Learning Tests Trial 1.

Table 5

Logistic Regression Models and Discriminant Function Analysis: Prediction of “Safe” Versus “Marginal/Unsafe” for All Subjects

Maze total time
$R^2 = .15$
Correct classification = 68.6%
ROC = 0.79
Maze total time + Age
$R^2 = .20$
Correct classification = 73.5%
ROC = 0.80
Maze total time + HVLT1 + TrailsA
$R^2 = .27$
Correct classification = 78.2%
ROC = 0.83
Maze total time + HVLT1 + TrailsA + Age
$R^2 = .31$
Correct classification = 81.0%
ROC = 0.85

NOTE: ROC = receiver operating curve; HVLT1 = Hopkins Verbal Learning Tests Trial 1.