Evaluating Driving Performance of Outpatients with Alzheimer Disease

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Background: Alzheimer disease (AD) is a progressive disease, with multiple physiologic, psychologic, and social implications. A critical issue in its management is when to recommend restrictions on autonomous functioning, such as driving an automobile. This study evaluates driving performance of patients with AD and its relation to patient scores on the Mini-Mental State Exam (MMSE).

Methods: This study compared 29 outpatients with probable AD with 21 age-matched control participants on an interactive driving simulator to determine how the two groups differed and how such differences related to mental status.

Results: Patients with AD (1) were less likely to comprehend and operate the simulator cognitively, (2) drove off the road more often, (3) spent more time driving considerably slower than the posted speed limit, (4) spent less time driving faster than the speed limit, (5) applied less brake pressure in stop zones, (6) spent more time negotiating left turns, and (7) drove more poorly overall. There were no observed differences between AD patients and the control group in terms of crossing the midline and driving speed variability. Among the AD patients, those who could not drive the simulator because of confusion and disorientation (n = 10) had lower MMSE scores and drove fewer miles annually. Those AD patients who had stopped driving also scored lower on their MMSE but did not perform more poorly on the driving simulator.

Factor analysis revealed five driving factors associated with AD, explaining 93 percent of the variance. These five factors correctly classified 27 (85 percent) of 32 AD patients compared with the control group. Of the 15 percent who were improperly classified, there were three false positives (control participants misclassified as AD patients) and two false negatives (AD patients misclassified as control participants). The computed total driving score correlated significantly with MMSE scores ($r = -.403, P = 0.011$).

Conclusion: Driving simulators can provide an objective means of assessing driving safety. (J Am Board Fam Pract 1998;11:264-71.)

It has been estimated that Alzheimer disease (AD) affects more than 10 percent of all persons aged 65 years and older and almost 50 percent of all adults older than 85 years.[1] Because the population is aging, the rate of AD in the United States is expected to rise considerably. Persons with AD have a variety of deficits in memory, visual attention, perception, judgment, and other cognitive functions,[2-5]

all of which are necessary components of safe driving, and deficits in these areas have been shown to result in impaired driving ability.[3,6-16] Since studies have implicated AD with an increased risk of accidents,[17-21] persons with AD who continue to drive could be putting themselves and others at risk.

Although surveys have not determined the number of persons with AD who drive, it is believed to be a common and important public health concern.[20] Almost 60 percent of drivers with AD continued to drive until they were involved in an accident.[15] Autopsies of elderly drivers involved in fatal accidents have found evidence of AD or early-stage AD in nearly 50 percent of the cases studied.[22] Despite the apparent dangers, many AD patients continue to drive for 3 to 4 years following diagnosis,[13] even after having had an accident.[16]

A critical issue for clinicians is to decide when it is appropriate to prevent further operation of a motor vehicle. Physicians face difficult ethical dilemmas when making this determination. In some states, physicians are required by law to report unsafe drivers.[23-29] Although few physicians actually report their patients to their departments of motor vehicles, many might feel that determining driving fitness is a physician's responsibility. Although family members might encourage the clinician to remove the patient's driver's license, patients often plead with their physicians to allow them to keep their licenses. Often spouses, even though concerned about safety, support continued licensing because they depend on the patient's driving. This situation strains the physician-patient relationship because the decision to terminate a patient's driving is subjective. Thus, a critical area for investigation is determining at what point driving ability becomes so impaired that the patient should no longer drive.

Because standardized neuropsychologic tests have not proved to be sufficiently sensitive and specific for the purpose of determining driving fitness,[30] some believe clinicians should refer their AD patients to local departments of motor vehicles for further on-road testing. Using improved performance-based on-road tests, recent studies have documented driving impairments in people with AD.[31] A major limitation with any road test, however, is that patients cannot be exposed to high-risk, nonroutine driving demands to determine the quickness and appropriateness of their judgment and subsequent execution of driving maneuvers. Although some drivers might be able to perform adequately under routine conditions and pass the on-road test, some driving impairments might express themselves only during non-routine, high-risk situations.

Ideally, AD patients could be monitored closely and then, when appropriate, have their license revoked when they become unfit to drive, but there has been no realistic way to quantify objectively their fitness to drive. A major barrier to assessing driving performance has been the absence of a driving simulator that presents realistic driving experiences. Such experiences should require the driver to negotiate routine traffic demands as well as have the driver encounter high-risk situations that assess the ability to control the vehicle and avoid accidents appropriately.

The Atari driving simulator[32] is a sophisticated, realistic research tool capable of addressing these issues. An earlier single-screen version of this simulator effectively detected the acute effects of hypoglycemia (45 mg/dL) among patients with type 1 diabetes,[33] which was reliable for more than 3 months,[34] and legal intoxication (≥ 0.08 percent blood alcohol level) among college students.[35] The current three-screen version of the simulator has been used to (1) differentiate middle-aged from elderly male drivers when sober and legally intoxicated,[36] (2) differentiate visually compromised drivers from control drivers,[37-42] and (3) correlate simulator performance with age-sensitive cognitive characteristics.[42] Not only has the Atari simulator detected high-risk groups, but results from the simulator correlate with both on-road test results (Guerrier J, Cox DJ, unpublished research, 1997] and parallel common driving errors among the elderly.[43]

In the current study we used the more sophisticated version of this interactive computer technology to evaluate driving performance of age-matched adults with and without probable AD. The following questions were examined:

1. Does performance on the Atari driving simulator differentiate AD patients from the control group matched by age and socioeconomic status?
2. Does simulator performance differentiate AD patients who have stopped driving from patients who are still driving?
3. Does simulator performance correlate with the Mini-Mental State Exam (MMSE)[44] scores, a well-established general field measure of dementia?

Methods

Twenty-nine adults who satisfied *Diagnostic and Statistical Manual of Mental Disorders, 3rd edition, Revised* (DSM-III-R)[45] criteria for probable AD were recruited from a sample of outpatients participating in AD drug protocols in the Department of Neurology at the University of Virginia Hospital. All patients who came to the hospital for a drug study screening appointment during an 8-month period were asked to participate in the current study before beginning the drug protocol. To be included in the study, the patients had to be older than 55 years, meet the DSM-III-R criteria for probable AD for a minimum of 6 months' du-

Table 1. Mean and Standard Deviations of Descriptive Characteristics of Alzheimer Disease Patients and Control Participants with Contrast _P_ Values.

Variable	Alzheimer Disease Patients (n = 29)	Control Participants (n = 21)	_P_ Value
Sex, % male	45	62	0.24
Age, y	72.0 ± 8.6	70.1 ± 10.0	0.571
Education, y	14.1 ± 3.5	15.8 ± 3.5	0.119
Years as licensed driver	53.9 ± 9.1	51.9 ± 0.5	0.549
Active driver's license, % (n)	93 (27)	100 (21)	0.26
Current driver, % (n)	59 (17)	100 (21)	0.002
Average miles driven per year	3957 ± 6662	6223 ± 4671	0.16
Self-reported accidents per 1 million miles driven, average n	9.8 ± 36	8.0 ± 28	0.9
Self-reported moving violations per 1 million miles driven, average n	15.1 ± 60	3.2 ± 10	0.40
Could not complete the driving test, simulator sickness, % (n)	7 (2)	24 (5)	0.09
Could not complete the driving test, cognitive impairment, % (n)	34 (10)	0 (0)	0.003
Mini-Mental State Exam score	21.2 ± 4.6	28.7 ± 9.6	< 0.0001

ration, and have a responsible spouse or caregiver able to participate. Patients who had other medical conditions that could affect driving performance or those taking medications that could impair driving performance were excluded based on their physician's determination.

Although patients were assured that participating in the study would not affect their licensing, some still chose not to participate because they feared that having hospital employees observe their driving might result in the loss of their license. Spouses or caregivers of the AD patients were also asked to participate in the study as control participants. These control participants were also 55 years of age and older and currently driv-

Table 2. Frequency of Driving Demands for 8-Mile Experimental Study Course.

Driving Demand	Frequency
Left turns - driver needs to turn left at specific stop-sign intersections, negotiating oncoming and cross traffic	3
Red lights - driver needs to stop	2
Green lights - driver has throughway	4
Stop signs - driver needs to stop	6
Throughway stop-sign intersections - side-traffic stops	4
Speed limit changes - driver needs to change speeds	11
Sudden stops - car in front of driver slams on brakes, object in road comes into view as driver crosses hillcrest, car runs red light from left side	3
Detours at stop-sign intersections - driver needs to obey detour arrow	4
Encroaching fixed objects - vehicle parked in driver's lane	1

ing. As shown in Table 1, those in the control group were similar to AD patients in terms of sex distribution, age, education, years licensed, and average miles driven per year. The control group scored considerably better on the MMSE.

Instruments

Three instruments were used in this study: (1) a background and driving-history questionnaire, (2) the MMSE, and (3) the Atari driving simulator. The MMSE was used to measure dementia severity on a range of scores from 0 to 30. Generally, scores of 28 to 30 are considered normal, 21 to 27 suggest mild dementia, 11 to 20, moderate dementia, and 0 to 10, severe dementia.[44]

The Atari driving simulator has three 25-inch computer screens that wrap around the driver, providing a 165-degree visual field, and a programmed rearview mirror depicting rear traffic. While the center screen presents the front windshield display, the two adjacent side screens display side views of traffic and road conditions. The driving environment was realistic, incorporating a typical-sized steering wheel, gas and brake pedals, seat, and seat belt. Driving performance feedback was provided visually through the three screens that updated at a rate of 60 times per second, auditorily through quadraphonic speakers, and kinesthetically through the steering wheel and pedal pressure.

The experimental driving course was approximately 8 miles and was designed to simulate driving demands of a typical grade 2 US highway (Vir-

Table 3. Driving Performance Variables and Explanations.

Driving Variable	Driving Variable Explanation
Steering variables	
SD steering	Standard deviation of steering wheel rotation
Off road	Number of times car travels off road
Risk midline	Quadratic risk function that increases the longer and farther the car crosses the midline
Braking variables	
Full stops	Percentage of appropriate complete stops negotiated at stop signs and stoplights
Missed stops	Percentage of times at stop signs and red lights minimum speed was > 5 mph
Maximum brake	Maximum brake pressure applied in stop zones
Bump collisions	Percentage of times driver in accident traveling < 20 mph
Speed variables	
Low speed	Average percentage below speed limit when car is in 35 mph and 45 mph speed zones
High speed	Average percentage above speed limit when car is in 35 mph and 45 mph speed zones
SD speed	Standard deviation of speed in 35 and 45 mph zones
Stop sign hesitation	Average time spent stopped at stop sign
Left turning time	Seconds required to go from complete stop at the stop line to complete the left turn

SD - Standard deviation.

ginia Department of Transportation). Table 2 lists the demands of the course.

The simulator recorded data eight times a second and generated the 12 driving performance variables listed in Table 3. Because different participants completed different percentages of the course, and because the farther the participants drove, the more likely they were to encounter a critical event, full stops, missed stops, and collisions were calculated according to the percentage of the course completed for each driver. To incorporate two variables, such as time and speed or time and distance, quadratic functions were calculated for risk midline, low speed, and high speed.

Procedure

AD outpatients in the University of Virginia Department of Neurology drug protocols went through an initial 2-week baseline period before being given medications. During the baseline period, study participants signed an informed consent form and completed the background and driving history questionnaire. To validate patients' report of a recent accident and violation, spouses or caregivers completed the pertinent questionnaire concerning these issues. Next, the study participants were administered the MMSE. Study participants were then verbally oriented to the simulator before driving a standardized practice course.

The practice course was similar to the experimental study course, but there were fewer road signals and less traffic. During the practice course,

room lighting was adjusted to the driver's preference to minimize glare on the monitors. Once drivers completed the practice course, they were allowed to continue driving until they felt fully comfortable operating the simulator. They next drove the experimental study course, which took approximately 20 minutes to complete. If the participants experienced simulator sickness (nausea and dizziness) or cognitively could not comprehend the operations of the simulator during the practice trial, the driving test was discontinued.

Results

Compared with the control group, AD patients were less likely to be current drivers (59 vs 100 percent, $z = 3.1$, $P < 0.002$), had lower MMSE scores (21.2 ± 5.0 vs 28.7 ± 1.0, $t = 5.1$, $P < 0.001$), and were less able to complete the driving test because of confusion or disorientation (34 vs 0 percent, $z = 0.0$, $P < 0.003$). No differences were observed between groups in terms of age, sex, education, years licensed, valid license status, miles driven per year, or number of self-reported moving violations (15 vs 3) or accidents in the past 5 years per 1 million miles driven (Table 1).

Among the AD patients, those who were unable to drive the simulator because of confusion or disorientation differed from those who were able to drive in terms of lower MMSE scores (19.6 ± 5.0 vs 22.5 ± 4.0, $t = 2.0$, $P < 0.05$) and drove fewer miles annually (2350 ± 3597 vs 4855 ± 8200, $t = 3.2$, $P < 0.005$). Similarly, AD patients who were not currently driving differed from currently dri-
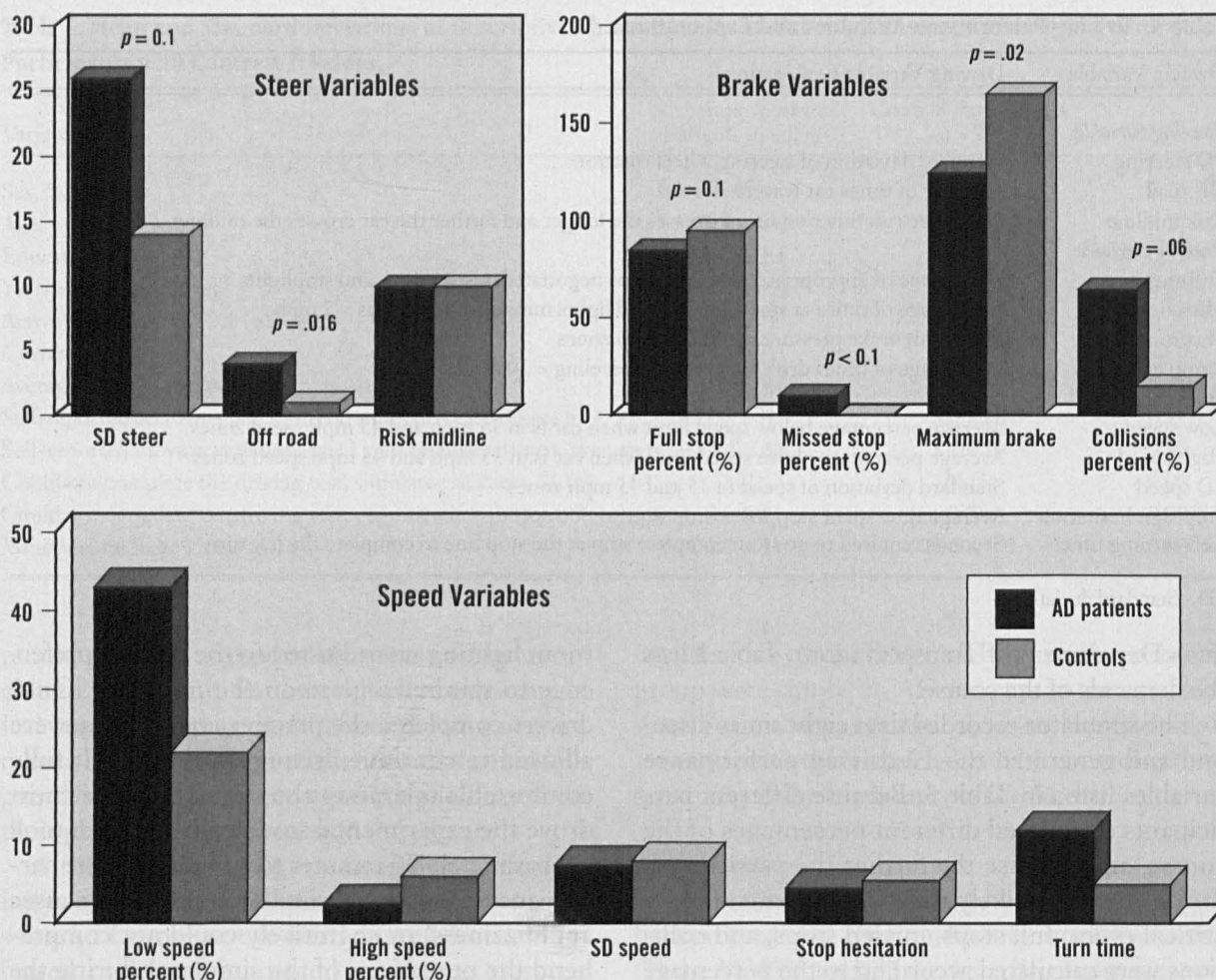
Figure 1. Comparison of Alzheimer disease patients and control participants on steering, braking, and speed variables. SD - standard deviation

ving AD patients only in terms of a lower MMSE score (19.4 ± 5.0 vs 22.5 ± 4.0, $t = 2.3$, $P < 0.05$).

Driving Performance

To assess driving performance, we could only analyze data from those who were able to drive the simulator (n = 17). Consequently, relevant driving data were not generated for anyone experiencing simulator sickness (n = 2) or who were cognitively unable to perform the driving task (n = 10). The 17 remaining AD patients performed more poorly on the simulator than those in the control group. AD patients went off the road more often ($t = 2.55$, $P = 0.016$), drove slower ($t = 4.08$, $P < 0.001$), spent less time driving above the speed limit ($t = 2.2$, $P = 0.040$, completed less of the course ($t = 3.7$, $P < 0.001$), applied less brake pressure in stop zones ($t = 2.33$, $P = .027$), and spent more time negotiating left-turns ($t = 2.75$, $P < 0.048$).

Although not statistically significant (P values ranging from 0.05 to 0.10), several trends emerged that further differentiated AD patients from the control group. AD patients had greater steering wheel variability ($t = 1.56$, $P = 0.10$), made fewer full stops ($t = 1.65$, $P = 0.10$), missed more stops ($t = 1.74$, $P = 0.1$), spent less time waiting at stop signs ($t = 1.77$, $P = 0.09$), and had more collisions ($t = 2.04$, $P = 0.06$) (Figure 1).

There were no observed differences between AD patients and those in the control group in terms of crossing the midline ($t = 0.13$, $P = 0.9$) or speed variability ($t = 0.57$, $P = 0.68$). Additionally, no differences were observed on the simulator between AD patients who were currently driving and those who were not currently driving (all, $P > 0.3$).

To distinguish the driving factors associated with AD, we used the following nine significant driving performance variables in a factor analysis:

Table 4. Driving Factors Associated With Alzheimer Disease and Degree of Variance for Each Factor.

Factor	Driving Variables	Degree of Variance, Percent
Poor steering control	SD steering, off road, collisions	38.1
Poor stopping control	Full stops, missed stops	24.0
Speed control	Low speed, high speed	16.0
Weak braking	Maximum braking	9.7
Improper braking	Inappropriate braking	5.1
Total		92.9

SD - standard deviation.

standard deviation of steering wheel rotation, off road, inappropriate braking, low speed, high speed, full stops, missed stops, maximum braking, and collisions. Because 5 participants never reached a left-turn stop sign, the stop sign hesitation and left turning time variables were omitted from this analysis to avoid any missing data. z Scores were computed for all variables to ensure that variables were of comparable size. Five factors extracted from the variables explain 92.9 percent of the variance. Table 4 lists these factors and shows the degree of variance for each factor.

A logistic regression based on the five factors (poor steering control, poor stopping control, speed control, weak braking, and improper braking) accurately classified 27 of 32 (85 percent) of the participants as AD patients. Of the 15 percent who were inaccurately classified, 3 were false positives (control participants misclassified as AD patients) and 2 were false (AD patients misclassified as control participants).

Next, we computed a total driving score based on the same five factors, with a lower total score indicating better driving performance. The total driving scores correlated significantly with the MMSE scores ($r = -.403$, $P = 0.011$). We could also use this total driving score for additional comparisons of driving performance between currently driving AD patients and currently nondriving AD patients and control participants. Using the total driving score, we consequently conducted a 1 X 3 multiple analysis of variance with planned contrasts. AD patients (current drivers and nondrivers) performed significantly worse than control participants ($t = 4.4$, $P < 0.001$). Similarly, currently driving AD patients performed worse than control participants ($t = 3.4$, $P = 0.002$). Among the AD patients, currently driving patients did not perform differently from patients currently not driving ($t = 0.86$, $P = 0.394$).

Discussion

Driving simulator performance was able to differentiate AD patients from control participants and correlated with MMSE scores; those who could not drive the simulator had significantly lower MMSE scores. Specifically, these results suggest that, in general, patients with AD do not drive across the midline more often; instead, they drive off the side of the road significantly more often, possibly as a compensatory response. An additional possible compensatory response was to drive slowly, both on the open road (low speed) and while turning left (left turning time), which was further verified by the observation that AD patients spent less time speeding (high speed) than control participants. Although these strategies might allow AD drivers more time to process information and react, it puts them at greater risk of being hit, especially when turning left and crossing through three lanes of traffic. That 62 percent of AD patients were involved in possible crashes, compared with 15 percent of control participants, suggests such compensatory strategies are ineffectual.

The wide difference in collision rate (62 versus 15 percent) between AD patients and the control group does not reach significance ($P = 0.06$) in part because of the great variation among AD drivers. Standard deviations for AD and control participants were 100 and 15, respectively, which suggests that all AD drivers are not high risk. That some AD patients might be safe drivers is further suggested by the regression analysis, which misclassified 2 AD drivers as control participants (false negatives). These 2 patients might have been safe drivers, as suggested by MMSE scores of 28 and 22, and total driving scores of -1.5 and -1.4. The implication is that the mere diagnosis of early-stage AD does not necessarily equate with poor driving risk.

It was also noteworthy that AD patients who had stopped driving did not drive the simulator more poorly. This finding suggests that either the simulator does not discriminate between good and poor drivers with AD or that the AD driver's decision to continue driving was not based on actual ability to drive.

Thus driving simulators could have clinical utility in determining a person's driving fitness. It appears to be a sensitive instrument, correctly classifying 85 percent of AD patients. It also singled out 10 AD patients who could not even complete the course as a result of confusion and cognitive impairments. Because the driving simulator results correlate well with MMSE scores, this quick examination can be used as an early screening tool.

AD is a complex disease process that affects people physically, psychologically, and socially in diverse ways. Even so, we were able to find five driving performance factors that explained 93 percent of the outcome variance. Perhaps this progressive disease process affects people more homogeneously than previously thought, at least in terms of driving performance. Although AD can ultimately impair driving performance in similar ways, a continuum of safe driving exists, and AD drivers will eventually reach an unsafe threshold. Blanket restrictions based on diagnosis alone, however, such as those suggested by Barrett et al,[7] might be too severe.

That these findings are from a relatively small, select sample of willing patients and caregivers might limit generalization. Nevertheless, the findings justify further studying patients with AD on interactive driving simulators. Until standardized simulation testing is widely available, the physician is left to determine fitness to drive based on clinical findings. Our study findings suggest that restricting driving should not be based either on the patient's diagnosis or willingness to drive. Instead, the MMSE and reliable reports of how attentive and reactive the patient is while driving are the basic elements on which to make this decision. The latter determination can be achieved by referring the patient to the department of motor vehicles for further testing.

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