PAPER

Driver landmark and traffic sign identification in early Alzheimer's disease

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Objective: To assess visual search and recognition of roadside targets and safety errors during a landmark and traffic sign identification task in drivers with Alzheimer's disease.

Methods: 33 drivers with probable Alzheimer's disease of mild severity and 137 neurologically normal older adults underwent a battery of visual and cognitive tests and were asked to report detection of specific landmarks and traffic signs along a segment of an experimental drive.

Results: The drivers with mild Alzheimer's disease identified significantly fewer landmarks and traffic signs and made more at-fault safety errors during the task than control subjects. Roadside target identification performance and safety errors were predicted by scores on standardised tests of visual and cognitive function.

Conclusions: Drivers with Alzheimer's disease are impaired in a task of visual search and recognition of roadside targets; the demands of these targets on visual perception, attention, executive functions, and memory probably increase the cognitive load, worsening driving safety.

Safe automobile driving requires a driver to perform multiple competing tasks and attend to a host of objects and ongoing events, while simultaneously monitoring traffic with central and peripheral vision to avoid roadway hazards.¹ Impairments of visual acuity and visual fields increase crashes and traffic violations.² However, drivers with certain neurological conditions may fail to perceive critical roadside targets and dangers even in the absence of a measurable field defect on standard perimetry or diminished visual acuity.¹

Alzheimer's disease affects processing of visual sensory cues and may produce attentional decline and agnosia.^{3–12} These deficits can impair drivers' processing of visual information such as roadway landmarks and traffic signs that provide key information about a driver's route, upcoming road hazards, and safety regulations. To address this real world problem, we used an instrumented vehicle (IV) to test the hypothesis that drivers with early Alzheimer's disease have impairments on a landmark and traffic sign identification task (LTIT). We also tested whether the impaired drivers would commit more safety errors under the influence of the cognitive load imposed by the LTIT, placing them at greater risk of a crash. Finally, we tested whether LTIT performance and safety errors could be predicted by visual and cognitive measures sensitive to decline in early Alzheimer's disease.

METHODS

Subjects

Subjects were 33 participants with mild Alzheimer's disease and 137 neurologically normal controls. Both groups had comparable years of education, but the Alzheimer subjects were older (table 1). The male predominance in the Alzheimer group may reflect the fact that women in this age group had not traditionally been the main driver in the family and more readily relinquished their driving privileges once they developed Alzheimer's disease. Subjects with neurological disorders other than Alzheimer's disease were excluded. No subject had acute, confounding medical or psychiatric conditions. Participants with Alzheimer's disease were recruited from a registry in the department of neurology. All Alzheimer patients had objective evidence of

memory impairment and related cognitive complaints that interfered with their social or occupational life consistent with the NINCDS-ADRDA criteria.¹³ Mini-mental state examination (MMSE) screening in patients with Alzheimer's disease (mean (SD) score, 26.1 (3.0)) reflected mild early cognitive decline. Impairments on memory and other cognitive domains on a standardised battery of neuropsychological tests (table 1) were consistent with early Alzheimer's disease.¹⁴ Computed tomographic and magnetic resonance imaging scans of the brain excluded destructive lesions caused by cerebrovascular and neoplastic disease.

Control participants were recruited from volunteers in the local community. All participants held a current valid state driver's license and were still driving, although some had reduced driving activity because of self imposed or family imposed restrictions.

The institutional review board approved the project and informed consent was obtained in accord with institutional and federal guidelines.

Cognitive and visual battery

All participants were tested on a battery of cognitive and visual tasks (tables 1 and 2). Judgment of Line Orientation (JLO) assessed visuospatial perception. Visuoconstructional ability was tested using the Rey-Osterreith Complex Figure Test copy version (CFT-copy) and the block design subtest (Blocks) from the WAIS-R (Wechsler Adult Intelligence Scale, revised). The CFT-recall version and the Benton Visual Retention Test (BVRT) tested non-verbal memory, while the Rey Auditory Verbal Learning Test (AVLT) provided an index

Abbreviations: ARGOS, Automobile for Research in Ergonomics and Safety; AVLT-recall, auditory verbal learning test-recall; Blocks, block design subtest; BVRT, Benton visual retention test; CFT-copy, complex figure test-copy; CFT-recall, complex figure test-recall; Cogstat, composite measure of cognitive impairment; COWA, controlled oral word association; CS, contrast sensitivity; FVA, far visual acuity; JLO, judgment of line orientation; LTIT, landmark and traffic sign identification task; MMSE, mini-mental state examination; NINCDS-ADRDA, National Institute of Neurological and Communicative Disorders and Stroke-Alzheimer's Disease and Related Disorders Association; NVA, near visual acuity; SFM, structure from motion; TMT-B, trail making test subtest B; UFOVTOT, total of subtests of the useful field of view task.

Table 1 Comparison of Alzheimer's disease and control groups

Variable	AD (n = 33)	Normal (n = 137)	p Values	
			Crude	Age adjusted
Demographics				
Sex (M, F)	28, 5	69, 68		
Age (y)	76.1 (6.3)	64.3 (11.4)	<0.0001	
Education (y)	15.2 (3.2)	15.6 (2.5)	0.3545	
Symptom duration (y)	2.1 (1.5)			
Cognitive tests				
Cogstat	298 (47)	405 (45)	<0.0001	<0.0001
AVLT-recall	3.2 (2.5)	10.5 (3.0)	<0.0001	<0.0001
BVRT (errors)	9.2 (3.2)	4.4 (2.5)	<0.0001	<0.0001
CFT-recall	9.1 (4.5)	15.8 (5.7)	<0.0001	<0.0001
JLO	23.5 (4.1)	26.2 (3.6)	0.0005	0.0156
Blocks	23.5 (10.0)	40.4 (10.8)	<0.0001	<0.0001
CFT-copy	28.7 (4.3)	32.0 (3.3)	<0.0001	0.0002
TMT-B	158 (74)	79 (39)	<0.0001	<0.0001
COWA	34.2 (10.8)	39.3 (10.8)	0.0160	0.1021
Visual tests				
NVA	0.057 (0.068)	0.018 (0.037)	<0.0001	0.0011
FVA	0.030 (0.113)	−0.098 (0.116)	<0.0001	0.0013
CS	1.64 (0.17)	1.85 (0.14)	<0.0001	<0.0001
SFM	12.7 (7.3)	10.3 (2.8)	0.1235	0.0067
UFOVTOT (ms)	1520 (1537)	615 (236)	<0.0001	<0.0001

Values are mean (SD) or n.

AD, Alzheimer's disease; AVLT-recall, auditory verbal learning test-recall; Blocks, block design subtest; BVRT, Benton visual retention test; CFT-copy, complex figure test-copy; CFT-recall, complex figure test-recall; Cogstat, composite measure of cognitive impairment; COWA, controlled oral word association; CS, contrast sensitivity; F, female; FVA, far visual acuity; JLO, judgment of line orientation; M, male; NVA, near visual acuity; SFM, structure from motion; TMT-B, trail making test subtest B; UFOVTOT, total of subtests of the useful field of view task; y, years.

of anterograde verbal memory. The Trail Making Test subtest B (TMT-B) and Controlled Oral Word Association (COWA) were used to test various aspects of executive function. These tasks are described in detail elsewhere.¹⁵ We calculated a composite measure of cognitive impairment (Cogstat) by assigning standard T scores (mean = 50, SD = 10) to each of the eight tests from the neuropsychological assessment battery.⁵

The Useful Field of View (UFOV) task (Visual Attention Analyser, Visual Resources Inc), measures speed (in ms) of visual processing, divided attention, and selective attention.¹⁶ We used the sum of four subtests of the UFOV task (UFOVTOT) in our analyses. UFOV loss has predicted crashes in the state records of drivers with visual and cognitive impairments.^{17, 18} Contrast sensitivity (CS) was assessed using the Pelli-Robson chart.¹⁹ The best corrected visual acuity was measured using the ETDRS chart²⁰ for far visual acuity (FVA) and the reduced Snellen chart for near visual acuity (NVA), both expressed as LogMAR (logarithm of the minimum angle of resolution), with 0 representing 20/20 vision. Perception of three dimensional structure-from-motion (SFM) and of motion direction were tested using computer generated animation sequences.⁷

Experimental drive

The experimental drive was conducted aboard a dual control instrumented vehicle known as ARGOS (the Automobile for Research in Ergonomics and Safety), a mid-sized 1995 Ford Taurus station wagon with automatic transmission and with hidden instrumentation and sensors.^{21, 22} Data on steering wheel position, normalised accelerator and brake pedal position, lateral and longitudinal acceleration, and vehicle speed were obtained at 10 Hz. Driver's lane tracking and visual scanning activity of the environment were videotaped at 30 frames per second.

The experimenter sat in the front passenger seat to score the on-road performance and operate the dual controls in

case of emergency. The experimental drive started after the driver acclimated to ARGOS and was carried out only during daylight and in good weather. It lasted approximately 45 minutes, and consisted of "on task" (for example, while performing LTIT) and "no task" segments.

Table 2 Comparison of Alzheimer's disease and control groups using one to one age matching

Variable	AD (n = 23)	Normal (n = 23)	p Value
<i>Demographics</i>			
Age (y)	74.1 (6.1)	74.1 (6.1)	1.0000
Education (y)	15.2 (3.0)	15.7 (2.2)	0.1515
Symptom duration (y)	2.0 (1.6)		
<i>Cognitive tests</i>			
Cogstat	294 (47)	397 (43)	<0.0001
AVLT-recall	3.0 (2.5)	10.3 (2.8)	<0.0001
BVRT (errors)	9.4 (3.2)	5.1 (2.2)	<0.0001
CFT-recall	9.3 (4.7)	15.7 (5.1)	0.0005
JLO	23.0 (4.4)	25.1 (4.5)	0.2242
Blocks	23.4 (8.9)	38.8 (10.6)	<0.0001
CFT-copy	29.1 (4.0)	31.7 (3.5)	0.0508
TMT-B	154 (81)	82 (27)	<0.0001
COWA	33.2 (11.6)	41.11 (9.4)	0.0002
<i>Visual tests</i>			
NVA	0.056 (0.070)	0.022 (0.036)	0.0179
FVA	0.034 (0.124)	-0.043 (0.129)	0.0324
CS	1.66 (0.18)	1.79 (0.16)	0.0057
SFM	14.0 (8.3)	10.4 (2.5)	0.0723
UFOVTOT (ms)	1257 (231)	778 (194)	<0.0001

Values are mean (SD).

AD, Alzheimer's disease; AVLT-recall, auditory verbal learning test-recall; Blocks, block design subtest; BVRT, Benton visual retention test; CFT-copy, complex figure test-copy; CFT-recall, complex figure test-recall; Cogstat, composite measure of cognitive impairment; COWA, controlled oral word association; CS, contrast sensitivity; FVA, far visual acuity; JLO, judgment of line orientation; NVA, near visual acuity; SFM, structure from motion; TMT-B, trail making test subtest B; UFOVTOT, total of subtests of the useful field of view task; y, years.

Landmark and traffic sign identification task

LTIT was administered as part of a sequence of on-the-road tasks in ARGOS. Drivers were asked to look for and report verbally on traffic signs and restaurants (a ubiquitous type of roadside landmark) along a one mile commercial segment of a four lane divided highway approximately one minute before these stimuli started to appear. These targets were classified as high saliency or low saliency stimuli, based on ratings and detection rates of drivers tested in pilot studies. For example, a speed limit sign is a high saliency stimulus detected by nearly all subjects, while a small and low mile marker is of lower saliency and is missed by some normal subjects. Likewise, a restaurant situated right on the road in its own building is a high saliency stimulus, whereas a delicatessen within a grocery store, or a restaurant where the sign or building can be seen from afar but is not on the route, is considered a lower saliency stimulus. There were in all 16 road signs (11 high saliency) and 13 restaurants (six high saliency) along the route. Dependent measures were the percentage of landmarks and traffic signs identified and the number of at-fault safety errors such as erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behaviour during the task.

Statistical analysis

We compared the Alzheimer's disease and control groups with respect to demographic, visual, cognitive, and LTIT outcome measures using the Wilcoxon rank sum test. We used regression models to adjust the LTIT outcome comparisons for age, sex, visual acuity, and previous familiarity with the route. Because of the significant age difference between the groups, we also compared the LTIT outcomes, cognitive tests, and vision tests using one to one age matching.

We used Fisher's exact test to compare the proportion of drivers in each group who made at-fault safety errors. We compared demographic factors and cognitive and vision test scores of drivers with Alzheimer's disease who drove without committing any safety errors with those who made safety errors.

We calculated Spearman correlation coefficients for the LTIT outcome measures with the cognitive and visual tests. We used stepwise linear regression to identify predictors of total landmark and traffic sign identification percentages, and ordinal logistic regression for at-fault safety errors. First,

Table 4 Outcome measures of the landmark and traffic sign identification task in Alzheimer's disease and normal controls with one to one age matching, compared using the Wilcoxon rank sum test

	AD (n = 23)	Normal (n = 23)	p Value
<i>Landmark identification (%)</i>			
All	29.1 (14.7)	44.5 (14.8)	0.0056
High saliency only	46.4 (22.4)	68.1 (21.3)	0.0002
<i>Traffic sign identification (%)</i>			
All	44.9 (25.0)	68.5 (20.1)	0.0013
High saliency only	54.7 (27.6)	80.9 (21.5)	0.0002
<i>Total LTIT identification (%)</i>			
All	37.7 (13.8)	57.7 (16.4)	0.0001
High saliency only	51.9 (19.4)	76.7 (20.0)	0.0001
<i>At-fault safety errors</i>			
During LTIT	1.8 (1.7)	0.5 (1.0)	0.0009
Baseline	5.9 (5.3)	2.0 (1.9)	0.0058

Values are mean (SD).

AD, Alzheimer's disease; LTIT, landmark and traffic sign identification task.

the individual components of Cogstat were used to model for cognitive predictors, followed by modelling for visual variables that was adjusted for general cognitive performance by using Cogstat in the model. This allowed us to see the overall effect of the main two classes of variables (cognitive and visual).

RESULTS

Drivers with Alzheimer's disease identified a significantly smaller percentage of restaurants and traffic signs, and committed more at-fault safety errors during LTIT, than the neurologically normal controls (table 3). The difference between the groups persisted after adjusting for familiarity with the neighbourhood, age, far and near visual acuity, and sex. The Alzheimer group also committed more at-fault safety errors at baseline segments of the drive (that is, when no secondary task like LTIT was administered) (tables 3 and 4). Drivers with Alzheimer's disease continued to show a greater number of safety errors than the controls, even after adjusting the errors during LTIT for baseline errors

Table 3 Outcome measures of the LTIT in Alzheimer's disease (n = 33) and normal controls (n = 137), compared using Wilcoxon rank sum test

	AD	Normal	Crude p value	Adjusted p values						
				Age	NVA	FVA	CS	Famil	Sex	ALL*
<i>Landmark identification (%)</i>										
All	28.9 (15.5)	45.4 (15.7)	<0.0001	0.0001	<0.0001	<0.0001	0.0030	<0.0001	<0.0001	0.0320
High saliency only	44.9 (22.6)	67.9 (20.0)	<0.0001	<0.0001	<0.0001	<0.0001	0.0011	<0.0001	<0.0001	0.0071
<i>Traffic sign identification (%)</i>										
All	44.4 (22.9)	72.0 (17.1)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
High saliency only	53.8 (26.2)	83.9 (17.2)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
<i>Total LTIT identification (%)</i>										
All	37.4 (13.1)	60.0 (13.2)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
High saliency only	50.8 (18.6)	78.5 (14.7)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
<i>At-fault safety errors</i>										
During LTIT	1.8 (1.6)	0.4 (0.8)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Baseline	5.6 (5.1)	1.7 (2.1)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Values are mean (SD).

*Adjustment for all covariates together.

AD, Alzheimer's disease; CS, contrast sensitivity; Famil, familiarity; FVA, far visual acuity; LTIT, landmark and traffic sign identification task; NVA, near visual acuity.

($p < 0.0001$). However, on a straight segment of the drive with no task load, there was no difference between the groups in basic vehicular control measured by the standard deviation of steering wheel position (degrees), number of large changes (> 6 degrees) in steering wheel position/min, and the standard deviation of mean speed (data available upon request).

The proportion of subjects who made at least one at-fault safety error was higher in the Alzheimer group (table 5) ($p < 0.0001$). The difference persisted even when the cut off value of at least two errors was used (table 5) ($p < 0.0001$). There were no significant differences in age, MMSE score, or cognitive and vision tests between the "safe" and the "unsafe" subgroups of Alzheimer's disease subjects (Wilcoxon rank sum test). The only exception was that the "unsafe" group performed worse on Cogstat ($p = 0.0375$), AVLT-recall ($p = 0.0351$), and CS ($p = 0.0461$) when the cut off value of at least two errors was used. There was no difference in LTIT outcomes between the subgroups in either comparison.

To further assess the effect of age difference between the two experimental groups, we also analysed the LTIT outcome measures and cognitive/visual tests using a one to one age matched control group which included 23 perfectly matching pairs. This additional analysis produced very similar results to those obtained from the analyses in the whole experimental group. Specifically, LTIT main outcome measures (table 4) and critical visual and cognition test scores did not differ between these tightly matched experimental groups except for COWA and SFM (table 2). These findings supported our use of all the data from the whole experimental group (33 Alzheimer subjects and 137 controls), which provided increased statistical power for modelling of independent predictors of LTIT outcomes.

The Alzheimer group performed worse than the control group on several neuropsychological and visual tests showing mild dementia and visual perception and processing deficits (table 1). Measures of verbal (AVLT-recall) and non-verbal memory (CFT-recall, BVRT), executive function (TMT-B, COWA), visual perception (FVA, NVA, CS), visual attention (UFOVTOT), visuoconstructional abilities (CFT-copy, Blocks, JLO), and overall cognitive function (Cogstat) correlated significantly (Spearman coefficients) with the outcome measures of the LTIT (table 6). Using regression analyses as described above, we identified TMT-B ($p < 0.0001$), AVLT-recall ($p < 0.0001$), CS ($p = 0.0007$), and JLO ($p = 0.0379$) as important predictors of total landmark and traffic sign identification percentage for all targets (high and low saliency together). These same four tests emerged also as predictors of identification rate of the high saliency target subset. AVLT-recall ($p = 0.0018$) and SFM ($p = 0.0299$) were predictors of at-fault safety errors.

Table 6 Significant Spearman correlation coefficients for outcome measures of the LTIT

	Variable	R_s	p Value
Total LTIT identification (%) (all targets)	UFOVTOT	-0.52	<0.0001
	AVLT-recall	0.50	<0.0001
	Cogstat	0.48	<0.0001
	TMT-B	-0.45	<0.0001
	CS	0.44	<0.0001
	Blocks	0.40	<0.0001
	FVA	-0.40	<0.0001
	BVRT	-0.38	<0.0001
	JLO	0.25	0.0009
	CFT-copy	0.23	0.0023
	COWA	0.21	0.0053
	CFT-recall	0.21	0.0070
At-fault safety errors	NVA	-0.20	0.0086
	AVLT-recall	-0.28	0.0002
	BVRT	0.27	0.0021
	Blocks	-0.24	0.0022
	CS	-0.23	0.0022
	Cogstat	-0.23	0.0035
	UFOVTOT	0.22	0.0037
	CFT-recall	-0.18	0.0194
	CFT-copy	-0.17	0.0263
	FVA	0.16	0.0344
	TMT-B	0.16	0.0408

AVLT-recall, auditory verbal learning test-recall; Blocks, block design subtest; BVRT, Benton visual retention test; CFT-copy, complex figure test-copy; CFT-recall, complex figure test-recall; Cogstat, composite measure of cognitive impairment; COWA, controlled oral word association; CS, contrast sensitivity; FVA, far visual acuity; JLO, judgment of line orientation; LTIT, landmark and traffic sign identification task; NVA, near visual acuity; SFM, structure from motion; TMT-B, trail making test subtest B; UFOVTOT, total of subtests of the useful field of view task.

DISCUSSION

The findings in this study support our hypothesis that drivers with Alzheimer's disease perform worse than neurologically normal drivers on an LTIT (tables 3 and 4). These group differences could not be explained by the older age or predominantly male sex of the Alzheimer subjects. Performance on standardised tests of visual perception, processing, attention, verbal and visual memory, executive functions, and visuoconstructional abilities correlated with the LTIT outcome measures (table 5) consistent with its demands on vision and cognition. These demands probably increased the cognitive load during driving, which may explain the larger number of at-fault safety errors we measured in these drivers, who have limited cognitive resources. This view is supported by the persistence of the significant between-group difference in at-fault safety errors during the LTIT, even after adjusting for baseline errors, and the lack of a group difference in basic vehicular control during a straight away baseline segment.

Table 5 Classification of subjects based on their driving safety

	AD				Normal		
At-fault safety errors	n	%	Age (y)	MMSE	n	%	p Value
Classification 1							
1 or more	25	(75.8%)	76.3 (6.5)	25.9 (3.1)	41	(29.9%)	<0.0001
None	8	(24.2%)	75.6 (6.1)	26.8 (2.9)	96	(70.1%)	
Classification 2							
2 or more	17	(51.5%)	77.9 (3.6)	26.5 (2.4)	16	(11.7%)	<0.0001
None or 1	16	(48.5%)	74.3 (9.2)	25.7 (3.5)	121	(88.3%)	

The proportion of subjects who made at-fault safety errors with either cut off value ($0 \leq 1$ or $0 \leq 2$) was higher in the Alzheimer's disease group (Fisher's exact test). There was no statistically significant difference in the ages or MMSE scores between the "safe" and "unsafe" Alzheimer subgroups (Wilcoxon rank sum test). AD, Alzheimer's disease; MMSE, mini-mental state examination; y, years.

Inability to recognise traffic signs²³ and landmarks may be an early complication in patients with Alzheimer's disease.^{24,25} Although multiple studies have evaluated on-the-road driving in Alzheimer subjects,^{8,26-32} to our knowledge, the current study is the first to test landmark and traffic sign identification during actual driving. Although basic visual sensory functions such as CS, FVA, and NVA correlated with LTIT performance, visual perception alone is unlikely to explain the difficulties in LTIT because the group differences remained significant after statistical correction for these measures, and visual acuity (FVA, NVA) was not a predictor by regression modelling. The finding that JLO and SFM predict landmark and traffic sign identification and driving safety, respectively, underscores the role of higher order visuo-perceptual abilities, including motion processing, in visual search and object recognition during automobile driving. Our findings are consistent with reports that visual attention,^{6,7} reading, object localisation and recognition,^{11,33,34} and visuospatial abilities⁷ are impaired even in early Alzheimer's disease.^{5-8,10-12}

Regression modelling showed that the TMT-B is an independent predictor of landmark and traffic sign identification rate. TMT-B depends on cognitive flexibility to switch attention between two competing tasks (tracking numbers and letters) and is considered a task of executive function.¹⁵ In a similar vein, the LTIT requires executive control over attention to switch between the tasks of searching for landmarks and controlling the vehicle on the road. AVLT-recall performance reflects the integrity of anterograde verbal memory and can be considered an index of general Alzheimer's disease severity.³⁵⁻³⁸ Correlation of both verbal and non-verbal abilities with LTIT outcomes suggests that LTIT depends on distributed neural systems involving both hemispheres.

A subset of drivers with Alzheimer's disease did not make any safety errors, suggesting that some individuals with mild dementia remain fit drivers and may be allowed to continue to drive.³⁹ The current findings indicate that the approach to assessments of driver fitness in at-risk drivers with cognitive impairment can benefit from introducing controlled challenges of vision, perception, memory, and attention during driving scenarios implemented in an instrumented vehicle. Future work in this area must address the relation between relatively high frequency, low severity safety errors such as we measured in ARGOS and low frequency, high severity incidents such as injurious crashes.

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