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Driving behaviors in early stage dementia: A study using in-vehicle technology

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ABSTRACT

According to the Alzheimer's Association (2011), (1) in 8 people age 65 and older, and about one-half of people age 85 and older, have Alzheimer's disease in the United States (US). There is evidence that drivers with Alzheimer's disease and related dementias are at an increased risk for unsafe driving. Recent advances in sensor, computer, and telecommunication technologies provide a method for automatically collecting detailed, objective information about the driving performance of drivers, including those with early stage dementia. The objective of this project was to use in-vehicle technology to describe a set of driving behaviors that may be common in individuals with early stage dementia (i.e., a diagnosis of memory loss) and compare these behaviors to a group of drivers without cognitive impairment. Seventeen drivers with a diagnosis of early stage dementia, who had completed a comprehensive driving assessment and were cleared to drive, participated in the study. Participants had their vehicles instrumented with a suite of sensors and a data acquisition system, and drove 1–2 months as they would under normal circumstances. Data from the in-vehicle instrumentation were reduced and analyzed, using a set of algorithms/heuristics developed by the research team. Data from the early stage dementia group were compared to similar data from an existing dataset of 26 older drivers without dementia. The early stage dementia group was found to have significantly restricted driving space relative to the comparison group. At the same time, the early stage dementia group (which had been previously cleared by an occupational therapist as safe to drive) drove as safely as the comparison group. Few safety-related behavioral errors were found for either group. Wayfinding problems were rare among both groups, but the early stage dementia group was significantly more likely to get lost.

1. Introduction

According to the Alzheimer's Association (2011), (1) in 8 people aged 65 and older, and about one-half of people age 85 and older, have Alzheimer's disease (AD) in the United States (US). The number of people age 65 and older will more than double in the next 25 years, with a threefold increase for those age 80 and older (Herbel et al., 2006). In the next 4 decades, those age 80 and older are expected to increase from 15 percent of all older people in the United States to 24 percent of older Americans (Alzheimer's Association, 2011). This increase is projected to result in 15 million more oldest-old people living in the US and these individuals are the ones most at risk for developing Alzheimer's disease (Alzheimer's Association, 2011).

While it might be assumed that individuals with dementia would stop driving after onset of symptoms, it is estimated that around one-third of drivers with dementia continue to drive (Silverstein, 2008). Most drivers are early in the disease process when cognitive deficits are generally mild (Adler and Kuskowski, 2003) and changes to driving performance are minimal. Nonetheless, drivers with dementia are one of the groups considered at greatest risk for unsafe driving performance (Langford et al., 2007). Yet, decisions to enforce driving cessation are not straightforward and pose a difficult challenge to family members, licensing authorities, and health care professionals.

Compared to the general driving population, drivers with dementia are at an increased risk of unsafe motor vehicle operation (Man-Son-Hing et al., 2007). Problematic driving behaviors include becoming lost in familiar areas (Silverstein et al., 2002; Uc et al., 2004), incorrect turning (Uc et al., 2005), impaired signaling (Duchek et al., 2003), decreased comprehension of traffic signs (Carr et al., 1998), and lane deviation (Uc et al., 2005). Crashes, while infrequent, are also of concern for drivers with dementia, whose crash risk is two to five times that of unimpaired older drivers (Charlton et al., 2003). Furthermore, driving skills

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predictably worsen (Adler et al., 1999) and will ultimately require individuals with dementia to stop driving (Adler et al., 2005).

Driving decisions need to be made not on diagnosis but on an assessment of the dementia's progress and the disease's effects on functional abilities (Duchek et al., 2003; Eby et al., 2009a; Eby and Molnar, 2010). Unfortunately, there is little consensus on the means to make this assessment. A review of studies that measured driving competency of drivers with dementia found a wide array of different assessment approaches; even where common protocols were used, there were different conclusions about their usefulness and validity (Reger et al., 2004). Road tests seem essential to evaluating driving ability; however, on-road evaluations by themselves have not been able to fully answer questions of driving competency. Because driving is an over learned task, standard road tests with step-by-step instructions do not necessarily test the skills or expose errors commonly made by an experienced driver (Odenheimer, 1993). Another approach to assessing driving skills in individuals with dementia uses a driving simulator. Learning to use a simulator, however, can be difficult for drivers with dementia even when given time to adapt to the setting (Cox et al., 1998). An additional complication of using a simulator to assess driving skills is the fact that older adults, in general, are more likely than younger people to experience simulator sickness (Brooks et al., 2010). Furthermore, individuals with dementia retain abilities that are over learned and thus, actual driving skills may be better than those assessed under the artificial conditions of a simulator. Neuropsychological tests have frequently been used to predict fitness to drive, often in studies that incorporate on-road or simulator evaluation, although their association with driving impairment and crash risk is at best moderate. Such studies often report statistically significant associations, but their size and variability suggest that no single protocol can confidently indicate for a specific patient the impairment threshold for non-driving (Reger et al., 2004). As a result of current assessment inconsistencies and shortcomings, some drivers with dementia may remain on the road longer than is safe while other drivers may cease prematurely. Improved procedures for assessing driving risk are urgently needed (Reger et al., 2004).

Recent advances in sensor, computer, and telecommunication technologies provide a method for automatically collecting detailed, objective information about a person's driving performance (e.g., LeBlanc et al., 2006, 2007). This technology, placed unobtrusively in a driver's vehicle, can be used to study the driving behavior of individuals diagnosed with early stage dementia. The objective of this project was to use in-vehicle technology to describe a set of driving behaviors that may be common in individuals with early stage dementia (i.e., a diagnosis of memory loss) and compare these behaviors to a group of drivers without a diagnosis of cognitive impairment.

2. Methods

2.1. Participants

A convenience sample of older adults participated in the project. All participants met the following inclusion criteria: held a valid driver's license; had been told by a health professional that they had early stage dementia; passed a comprehensive driving evaluation provided free of charge and which included clinical and on-road testing; were willing to have their personal vehicle installed with unobtrusive, in-vehicle technology for at least 1 month; were willing to leave their vehicle at the University of Michigan Transportation Research Institute (UMTRI) overnight for the installation to take place; owned and regularly drove a vehicle in which the technology could be installed; and drove at least 40 miles per week. Ten of the participants also had a caregiver who was willing to complete a questionnaire at the end of the study for a separate research project (Eby et al., 2009b). Participants were recruited from the University of Michigan's (U-M) Drive-Ability program (located within the Occupational Therapy Division, Department of Physical Medicine and Rehabilitation); another local driving assessment center; the U-M Turner Geriatric Center's specialty clinics, Senior Resource Center, and Silver Club Programs (which sponsor several ongoing memory loss support groups); and the U-M Alzheimer's Disease Research Center registry that is comprised of people who have expressed interest in participating in U-M research and who may have been diagnosed with some type of cognitive impairment. Because "early stage dementia" is often not well defined nor used as a diagnosis by physicians and other health professionals, we used as our inclusion criterion concerns expressed by a health professional about the driver related to *memory loss* or *early stage dementia*. Institutional review board approval was obtained for all components of the study.

Seventeen people participated. Participants had a mean age of 76.2 years (SD = 10.4 years), with ages ranging from 63 to 93 years. Seventy-six percent of the early stage dementia group was male. The mean length of time that drivers participated was 43 days (SD = 10.9 days), with participation ranging from 29 to 65 days. To compare the driving data from the drivers to data from a group of drivers without a diagnosis of dementia, data from participants in a previous study conducted by UMTRI in which volunteer drivers drove UMTRI instrumented vehicles to test how an advanced collision warning system functioned and influenced behavior (LeBlanc et al., 2006) were used. In that study, participants were recruited from the general population (26 were age 60–70) and drove the vehicle for a 1-month period—1 week without the technology turned on and 3 weeks with the collision warning system active. Much of the objective driving data collected in that study were identical to the data collected from the early stage dementia drivers. Inasmuch as the collision warning system was not thought to influence driving behavior relative to trip characteristics (e.g., day versus night driving, number of designations, and miles driven) and executive functioning errors (inappropriate stops), data from all 4 weeks of driving were used for comparison for most behaviors of interest. In a few cases in which the project team thought the collision warning system might influence the behavior (e.g., following too closely), only data from the first week were utilized as a comparison. Two behaviors examined in this study, responding appropriately to traffic signals and pedal errors, could not be examined in the comparison group because the technology used for this group was not designed to measure those behaviors.

Twenty-six subjects from the existing UMTRI database of naturalistic driving described previously were selected as a comparison group. The mean age for participants in the comparison groups was 64.5 years (SD = 2.8), with ages ranging from 61 to 70 years. One-half of the comparison group was male. The mean number of days driving in the comparison group was 25 (SD = 0.4), with the number of days ranging from 24 to 26.

2.2. In-vehicle technology

Each driver's personal vehicle was equipped with an UMTRI-designed suite of sensors and a data acquisition system (DAS) to provide measurements and observations of the driver's travel patterns, driving performance, and behaviors during the period of testing. The system is depicted in Fig. 1. The heart of the system was the DAS main module which included a central processing unit (CPU), data storage media, power management electronics including a backup battery, and interfaces for the sensors, vehicle battery, ignition signal, Ethernet, and keyboard/monitor. The unit measured 3.5 in $\times$ 8 in $\times$ 22 in. The main module was mounted in the trunks of

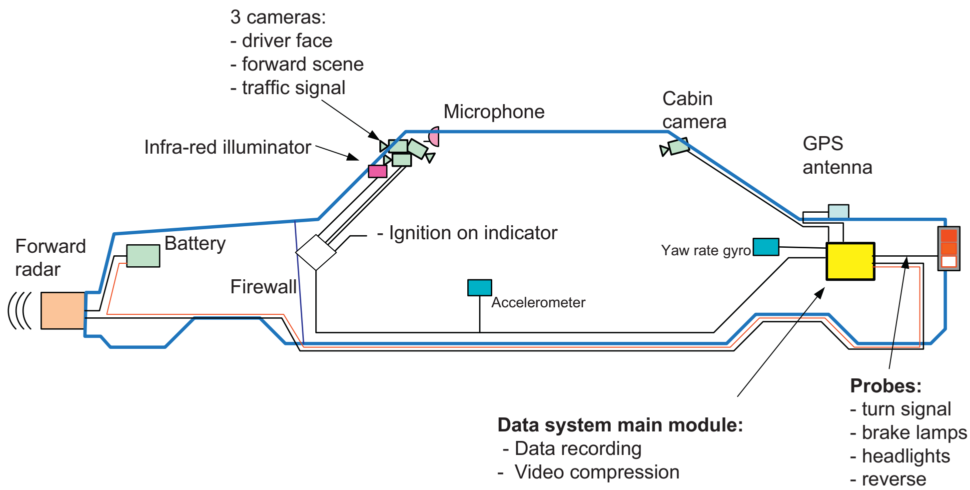

Fig. 1. Schematic of the onboard data system.

sedans (usually under the package shelf), in the cargo area of SUVs and vans, and behind the seat(s) of pickup trucks. Installation of the main module was done consistently with automotive industry techniques for ensuring the device would remain fixed in the event of a crash.

Four cameras were installed in the vehicle. Three were mounted behind the rear-view mirror and a fourth "cabin" camera was mounted in the rear of the cabin. Two forward views were collected: grey-scale images showing the forward scene with a horizontal field of view of approximately 60°, and a color image with a horizontal field of view of approximately 20° to allow us to see the state of traffic signals during intersection approaches. The forward views were vital to providing the context and driving circumstances of events. These cameras were placed in a small housing mounted behind the rearview mirror as shown in the left image of Fig. 2. A third camera captured the driver's head and shoulders as well as some portions of the exterior near the vehicle on the driver's side and sometimes to the rear of the vehicle (depending on the vehicle model). This camera allowed the driver to be positively identified, to capture indications of driver attentiveness, and to assess safety belt use. The right image in Fig. 2 shows the installation of the face-camera with the infrared illuminator and the microphone from the viewpoint of the driver. The fourth camera was mounted on the headliner or the rear or side glass to capture a view of the forward portion of the cabin. This provided information about secondary task activities, the presence of front-seat passengers, and the presence of any navigation devices. The four cameras were the only in-vehicle monitoring equipment visible to the driver and were all unobtrusive.

Video images were captured continuously at 5 Hz, except for the cabin camera data, which was collected at 1 Hz. The cabin and driver face video collection used infrared illumination of the driver's face and the dashboard and center console area for nighttime information. A microphone was installed in the cabin, just above the rear-view mirror. Audio data were continuously recorded with an 8 kHz sampling rate. Audio data provided further insight into the context of events which were reviewed by analysts.

An automotive long-range forward radar was used to measure the relative speed and distances to vehicles and other objects in front of the participant's vehicle. This radar was a 77 GHz unit capable of sensing to ranges well over 120 m. The radar was mounted to the center of the vehicle's front bumper and covered with a plastic shroud. The forward radar and forward cameras were both aligned to a common frame of reference established with respect to the longitudinal axis of the vehicle.

A two-axis accelerometer measured lateral and longitudinal acceleration. Whenever possible, this was mounted close to the vehicle center of gravity (CG), although on some vehicles (primarily minivans) it was mounted well aft of the CG, although still on the vehicle's centerline. A yaw rate sensor was also installed to determine the amount of turn around a vertical axis. The accelerometer and yaw rate sensor were aligned with respect to gravity. A global positioning system (GPS) antenna was magnet-mounted to the trunk lids of sedans and to the roofs of light trucks, vans, station wagons, and hatchbacks. The GPS was a 4 Hz differential system that used the WAAS satellite correction system for an approximate accuracy of 1–5 m. The GPS provided data regarding speed, time of day, latitude, longitude, and heading. The brake lamp, reverse lamp, and turn signals were monitored by connecting to the vehicle wiring harness.

In total, the installation of the in-vehicle technology required an average of 55 h per vehicle, using highly qualified automotive engineers. The resources required for installation greatly limited the number of participants in the study.

3. Data collection

Once data collection equipment was installed in the vehicles, participants were asked to drive as they normally would for a period of up to 2 months, depending on scheduling. Participants were contacted after 1 week in order to answer any questions from the participants and to schedule a time to check the in-vehicle technology was functioning properly. The technology was inspected and some data downloaded from the DAS to ensure that the sensors were functional and data were being collected properly. At the end of the data collection period, participants were contacted to schedule removal of the equipment.

4. Data reduction

4.1. Onboard data pre-processing

Over 10,800 miles of data were collected from the 17 drivers with early stage dementia and these data were compared to data from an existing archive of 26 comparison older drivers (23,000 miles). The main processing of the data included an integrated series of automatic calculations and analyst reviews of video, audio, and other sensor data. Analysts reviewed over 15,000 events/trips for this study (over 8000 for drivers with memory loss,

Fig. 2. An example mounting of the two forward cameras (left) and the face camera, infrared illumination module, and microphone (right).

nearly 7000 for the comparison group). The video reviews consisted of:

- Cabin review for each ignition cycle to identify the driver, and check for passengers and a navigation device.
- Seat belt review for each ignition cycle using driver face video, which showed the driver's shoulders.
- A sampling of all events in which the driver slowed to below 5 mph (8 kph) in order to assess behaviors at stop lights, stop signs, intersections, some unprotected left turns and other stops (including any mid-block stops).
- Red-light running review, which sampled instances of drivers passing through a signalized intersection at speeds remaining above 10 mph.
- Wayfinding trips of interest, a detailed review of video, audio, and numerical data to identify trips that may have contained driver wayfinding errors.

4.2. Computing measures for statistical analysis

Table 1 summarizes the driving metrics analyzed for this study. This table includes the type of critical driving skill, the metric(s) for assessing that skill, and a description of the metric. This description also notes whether the metric was based on randomly sampled data, because some metrics could not be computed on all data. Note that many metrics were normalized by an exposure variable, such as distance traveled, trips by that driver, or events of a specific type. The selection of the exposure variable for normalizing a measure was done to allow comparison of measures between drivers with varying participation periods. For example, seat belt use is expressed as the fraction of travel distance traversed while belted. Red-light running is expressed as the fraction of signalized encounters.

Travel patterns were determined primarily on GPS measurements that included location, time of day, speed, heading, and GPS quality indicators. An analyst calculated the proportion of distance traveled alone and with a navigation device based on review of brief driver-face video clips. Early stage dementia participants completed 1879 trips, while the comparison group completed 2682.

Wayfinding trips of interest were defined as trips over 1/8 mile for which either: the route from the starting point to the end point deviated significantly from a direct route for a reason that could not be determined by review of the data; or the trip was part of a chain of trips that included navigation that was significantly indirect, such as an outing that included multiple destinations that used significantly inefficient routing. If the latter reason applied, only one trip was counted as a wayfinding trip of interest. Likewise, a single trip that had more than one instance of probable wayfinding errors was counted only once. An analyst reviewed all potential wayfinding trips of interest to either determine the purpose of the driver's travel behavior, or retain the trip as a wayfinding trip of interest. Because of the labor intensive nature of this wayfinding trips-of-interest analysis, data from only 17 randomly selected comparison drivers were processed for comparison with the 17 memory-loss drivers.

The filter that identified potential wayfinding trips of interest compared the actual trip distance (D) with the computed distance for a trip from the start to end points of the trip (CD), using a navigation software package (Microsoft MapPoint). The trip was flagged for review if it was at least 0.75 miles long, and if $D/(\mathrm{CD}) > 1.4$ or $D - \mathrm{CD} > 1.5$ miles. This filter was developed by reviewing a large sample of trips for nine of the drivers with memory loss (890 out of 988 trips). The filter captured 90% of the wayfinding trips of interest, while requiring a relatively limited review of trips (<150 trips). Only trips that satisfied the filter were included in the analysis. A total of 310 trips were reviewed for the early state dementia group and 287 for the comparison group. In many cases, the analyst identified the reason for the difference between the actual and the computed routes immediately—the driver may have taken an alternate route avoiding freeways, or taken a child to school without stopping the vehicle en route to another destination. For other trips, the analyst reviewed video of the trip, and possibly other trips, to identify a reasonable explanation for the inefficient routing. The analyst determined that these trips often involved ferrying passengers, going through drive-through restaurants, banks, or car washes, picking up newspapers from coin-operated machines, meandering through wooded parks or cemeteries, or taking alternate routes. High confidence was required to conclude that these were the actual purposes for the trips. For instance, meandering through wooded parks was not considered a wayfinding error for one participant because it was a regular activity on trips with the participant's spouse. Both occupants pointed at objects and the driver slowed to look at certain sites.

All remaining trips were classified as "wayfinding trips of interest" in which the analyst concluded that the driver had wayfinding problems, such as getting lost or seeming to forget a destination after starting the trip. Seventy-three trips of interest were identified (33 for drivers with early stage dementia and 40 for the comparison group). Seven trips, all made by drivers with early stage dementia, were identified in which the driver was likely to be lost. Four participants each had one trip and one participant had three trips with probable wayfinding errors.

The following distance measure was the proportion of "car-following time" that was spent with short headway times relative to a vehicle ahead. Car-following time was defined as intervals when the participant's vehicle was traveling at least 25 mph with a vehicle ahead at a headway time of no more than 3.5 s and with a relative speed within 5 mph. The metric was the percentage of

Table 1
Driving skills and metrics.

Driving skill	Metric	Description
Travel patterns	Trips per day	Ignition-on to ignition-off was 1 trip
	Miles driven per day	Based on GPS data
	Number of unique destinations per week	Unique destinations divided by the number of weeks in the testing period
	% of miles driven on freeways	Miles traveled on freeways divided by total miles traveled
	% of miles driven within 5 miles of home	Miles traveled while within 5 miles of the driver's residence divided by total miles traveled by that driver
	% of miles driven within 10 miles of home	Miles traveled while within 10 miles of the driver's residence divided by total miles traveled by that driver
	% of miles driven during daylight	Percentage of all miles traveled in daylight, as defined by civil twilight
	% of miles driven during rush hour	Percentage of all miles traveled during weekday rush hours (6.30–9 am, 4–6.30 pm)
	% of miles driven alone [Drivers with memory loss only]	Percentage of all miles traveled that were traveled with no passengers in the vehicle as determined by review of cabin video
Wayfinding	% of miles driven with a navigation device [Drivers with memory loss only]	Percentage of all miles traveled with a navigation device present as determined by review of cabin video
	Number of wayfinding trips of interest	Number of trips that were determined to be wayfinding trips of interest
	% of wayfinding trips of interest	Percentage of trips that were wayfinding trips of interest
	Number of trips likely lost	Number of trips that were judged as the driver getting lost
Safety belt use	% of distance belted	Percentage of miles traveled that occurred on trips where the driver was deemed to be belted, based on face video analysis
Headway	% of miles driven with short headway	Percentage of following time that the participant tailgated another driver (see text for description)
Speed	% of miles driven 10 mph slower than surrounding traffic	Time following a vehicle traveling 10 mph faster than the participant's vehicle, divided by the total time following a vehicle
Interaction with traffic control devices	% inappropriate midblock stops	Percentage of sampled midblock stops for no apparent reason
	% running stop signs	Percentage of sampled stop sign encounters where the vehicle did not slow down to 5 mph or less
	% red-light running	Percentage of signal encounters with minimum speeds of 10 mph or more in which the driver entered the intersection while the light had been red for at least 1.5 s
Left turns	% left turns causing traffic conflicts	Percentage of left turns that caused traffic conflicts as judged by an analyst
Signaling	% turn signal use for turns	The proportion of sampled turns during which the driver signaled appropriately
Gear errors	Number of wrong gear events per week	Wrong-gear events divided by the number of weeks in the testing period
Pedal errors	Number of pedal errors per week	Unintended forward accelerations observed at low speeds, divided by the test period weeks

car-following time during which headway time was less than 0.7 s. This time headway threshold is generally recognized as tailgating.

The speed metric identified drivers who traveled much slower than surrounding traffic. The measure was the fraction of time that the forward radar detected that same-direction vehicles were traveling more than 10 mph faster than the participant's vehicle. The metric was normalized by the total time during which other same-direction traffic was present.

To determine the frequency of red-light running, analysts reviewed a sample of events in which the participant drove through a signalized intersection with a minimum speed of 10 mph or more to identify instances when the driver ran red lights. Only data from the memory loss group were analyzed as data for the comparison group did not include a wide angle view of the forward scene that included the traffic signal.

Gear errors were defined as events that were close in time to the driver being in reverse, which involved any indications of the driver using the wrong gear, including backing into traffic and bumping into an object. Analysts reviewed all events in which the driver changed backing acceleration (jerked) by at least 10 m/s^2 per second in order to capture events that included impacts as well as firm braking. For drivers with early stage dementia, 152 events were reviewed. For the comparison driver set, 145 events were reviewed.

Two types of pedal errors (operationally defined as unintended accelerations) were analyzed. The first type included cases with a substantial forward acceleration that began at a low speed (less than 5 mph). The second type involved events where the final vehicle speed 10 s after the acceleration began was less than 5 mph, based on the assumption that an unintended acceleration would be followed within this time period by a recovery by the driver, and the car would be slowed. Both types of events were reviewed to determine if the events involved a near crash or a lack of driver intention to increase speed.

4.3. Data analysis

Data were analyzed using the SAS Statistical Software package. Analysts compiled descriptive statistics for both groups. Data for each group were plotted to assess normality and determine the most appropriate statistical tests for comparing the groups. Because several of the variables were not normally distributed and the sample sizes were small, the project team used a nonparametric test, the Wilcoxon Signed Rank Test, rather than a *t*-test to compare group means (see Cody and Smith, 1997). Nonparametric methods are generally resistant to the influence of extreme values. The project team used a one-tailed test for each of the group mean comparisons, given that the objective was to examine conditions under which the drivers with early stage dementia exhibited poorer performance than the comparison group.

5. Results

The number of participants (*N*), mean score, confidence interval, and probability level of the Wilcoxon Signed Rank Sum test (*p*-value) for each variable investigated in the study can be found in Table 2. Note that some variables could not be investigated in the comparison group sample. In addition, for two variables, 17 comparison subjects were randomly selected from the 26 for analysis, as these variables required labor-intensive analysis of video. *p*-Values shown in bold indicate a statistically significant difference ($p < .05$) between the early stage dementia and comparison groups.

Table 2
The number of participants (*N*), mean score, confidence interval (±), and probability level of the Wilcoxon Signed Rank Sum test (*p*-value).

Metric	Early stage dementia Mean (N = 17)	Comparison Mean (N = 26; $^*N$ = 17)	*p*-Value
Trips per day	3.7 ± 1.0	4.3 ± 0.7	0.08
Miles per day	14.9 ± 5.2	35.7 ± 6.1	**<0.01**
Number of unique destinations per week	6.1 ± 1.8	12.8 ± 2.2	**<0.01**
Freeway miles (%)	15.0 ± 9.2	32.9 ± 6.8	**<0.01**
Miles driven within 5 miles of home (%)	70.2 ± 10.4	43.0 ± 6.5	**<0.01**
Miles driven within 10 miles of home (%)	84.2 ± 9.5	60.3 ± 8.3	**<0.01**
Miles driven during daylight hours (%)	93.2 ± 5.1	86.2 ± 6.1	**<0.05**
Miles driven during rush hour (%)	15.2 ± 4.6	16.6 ± 4.7	0.30
Miles driven alone (%)	53.3 ± 17.1	Unavailable	N/A
Miles driven with a navigation device (%)	0.0 ± 0.0	Unavailable	N/A
Number of wayfinding trips of interest	1.9 ± 1.2	2.4 ± 0.9*	0.16
Wayfinding trips of interest (%)	2.1 ± 1.6	2.8 ± 1.5*	0.13
Number of likely lost trips	0.4 ± 0.4	0.0 ± 0.0*	**<0.01**
Miles belted (%)	88.3 ± 11.6	98.8 ± 2.3	**<0.01**
Miles driven with short headway (%)	2.9 ± 1.6	6.1 ± 3.4	**<0.05**
Miles driven 10 mph or more slower than surrounding traffic (%)	3.9 ± 1.2	1.8 ± 0.5	**<0.01**
Inappropriate midblock stops (%)	0.0 ± 0.0	0.1 ± 0.0	0.51
Running stop signs (%)	0.0 ± 0.0	0.0 ± 0.0	N/A
Turn signal use for turns (%)	77.2 ± 10.4	79.4 ± 8.0	0.26
Left turns causing traffic conflicts (%)	0.0 ± 0.0	0.0 ± 0.0	N/A
Red-light running (%)	0.4 ± 0.0	Unavailable	N/A
Number of gear error events per week	0.0 ± 0.0	0.0 ± 0.0	0.28
Number of pedal error events	0.0 ± 0.0	Unavailable	N/A

Bolded *p*-values are significant at the .05 probability level.
* Indicate where the sample size was on 17 participants (rather than 26) for the comparison group.

As shown in Table 2, several variables did not differ significantly between the groups. The project team found that the number of trips taken per day averaged 4.31 for the comparison group and 3.65 for the early stage dementia group. Although these means were not statistically different, the Wilcoxon score approached significance ($p = .08$). Groups were similar in trips that potentially demonstrated wayfinding errors, but only drivers with early stage dementia logged trips in which analysts determined the driver was lost. Both groups used turn signals slightly less than 80% of the time and both groups had little travel that involved inappropriate stopping. The study found that no driver in either group ran a stop sign or made a left turn that caused a traffic conflict and there were few cases in either group of drivers using the wrong gear.

Data for time traveling alone, using an electronic navigation device, and red light running were only collected for the early stage dementia group. These participants traveled alone slightly more than one-half of the time and never used an electronic navigation device. Participants rarely ran red lights (less than 0.5% of trips). None of the participants exhibited pedal errors.

Groups differed significantly on several driving behaviors. The early stage dementia group drove significantly fewer miles per day, traveled less often on the freeway, drove to about half as many unique destinations per week, and stayed significantly closer to home. Drivers with early stage dementia drove less at night, with less than 7% of travel occurring during nighttime hours (13% for comparison group). Thus, the early stage dementia group exhibited a much more limited driving space than the comparison group.

The groups differed in some safety-related driving behaviors. The early stage dementia group was about twice as likely to travel at least 10 mph slower than surrounding traffic while the comparison group was twice as likely to follow too closely, although both behaviors were rare. Drivers with early stage dementia were less likely to use a safety belt (88% versus 99%).

6. Discussion

This report describes a study using custom in-vehicle technology to objectively measure driving behaviors of people with early stage dementia and to compare these behaviors with existing data on similar measures from a sample of older drivers. The study revealed several differences in driving behaviors between participants with early stage dementia and the comparison sample of older drivers. Foremost, few safety-related errors were found for either group. However, the early stage dementia group followed too closely less often than the comparison group, a behavior which can be considered safe driving. On the other hand, participants with early stage dementia drove slower than surrounding traffic more often and used safety belts less often.

Given that several studies that have shown that individuals with early stage dementia drive less well than controls, as measured on-the-road, in simulators, and from family/caregiver report (Man-Son-Hing et al., 2007), it might seem surprising that this study did not discover more safety problems in the early stage dementia group. One likely explanation for this finding is related to how participants were recruited. Prior to enrolling in the current study, all participants with early stage dementia completed and passed a comprehensive driving evaluation that included an assessment of on-road driving performance. Dementia is a progressive disease and even though participants had been judged to be safe to drive initially, some would be expected to experience cognitive declines that could result in declines in driving ability. In the present study, all experimental participant data were collected within 3 months of the initial assessment. The time between successful completion of the assessment and the start of data collection averaged less than 1 month and the longest time a participant was in the study was 2 months. It is possible that if the project had a longer data collection period (e.g., 6 months), the study would have found greater driving safety problems in the latter months of data collection.

The data showed a significantly smaller driving activity space for the early stage dementia group than for the comparison sample. Participants in the early stage dementia group drove shorter distances, to fewer destinations, and avoided freeways. Most restricted driving to daytime. The finding regarding driving space is consistent with findings in the literature based on self reported data (Barberger-Gateau and Fabrigoule, 1997; May et al., 1985; Marottoli et al., 1997; Stalvey et al., 1999). The present study is the first to show, using objective measures of driving, that drivers with early stage dementia restrict their driving space.

This study also investigated wayfinding errors. The project team hypothesized that drivers in the early stage dementia group would exhibit wayfinding errors because "wandering behavior" is common in people with dementia (see e.g., Silverstein et al., 2002). The study found a low incidence of wayfinding errors in both groups. However, trips during which the participant got lost (based on the project protocol) were only found for the early stage dementia group, providing support for the project team's hypothesis.

The research team relied on heuristics to identify trips with wayfinding errors. Analysts viewed trip video and listened to recordings of conversations within the vehicle to determine whether the driver had a reason for following an inefficient route. One driver with early stage dementia took two trips about 1 h apart. On both trips, he traveled different short routes in his neighborhood and returned home without stopping. The video did not reveal a purpose for the trips and the driver did not appear to be under stress or concerned. The project team concluded that the driver was not lost, but rather lost track of his destinations once he began each trip. It is also possible that these trips were simply non goal-directed trips that were taken simply as a diversion. Thus, the wayfinding results reported here should be considered exploratory in nature. The study heuristics may have missed instances of wayfinding errors, and some of the subjective conclusions may have been incorrect.

One conclusion from this project is that a much larger sample of drivers who drive for a longer period of time is needed to make definitive conclusions about the driving behaviors of people with early stage dementia. Based on the issues we addressed in this project we provide several recommendations for a large scale, longitudinal study of driving among individuals with early stage dementia: (1) study participation should commence with a comprehensive driving assessment to ensure that participants have been cleared to drive by a health professional; (2) drivers should participate for at least 6 months and preferably for 1 year so that changes in behavior can be analyzed; (3) a quantitative measure of early stage dementia should be used in the study that can classify participants on their level of cognitive impairment; (4) because of the difficulties encountered with participant recruitment, a large scale study should utilize multiple participant recruitment sites and possibly multiple data collection sites; and (5) participants' own vehicles should be instrumented. With regard to this latter recommendation, it is clear that the in-vehicle data collection technology will need to be simplified so that installation time can be significantly reduced. Based on the results of the present study, the technology should include, at a minimum, GPS, forward video, and face video.

The study had several limitations that should be considered when interpreting the results. First, the experimental participants represent a convenience sample of drivers who were willing to have their driving monitored and their own vehicles instrumented. As such, the behaviors of these drivers may not be representative of the population of drivers with early stage dementia. The comparison group was also a convenience sample of people age 60–70. Second, the drivers in the comparison group were not screened for early stage dementia. Since these participants responded independently to recruitment advertisements, showed up on time, and completed questionnaires they were presumed to be cognitively intact. Third, even though the project team ended up using "memory loss or early stage dementia concerns expressed by a health professional" as the diagnostic inclusion criteria, there was likely great variability in the level of cognitive impairment among the participants. A comprehensive measurement of cognitive function is critical in future work relating specific unsafe driving behaviors to early stage dementia.

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