DO SIMULATOR MEASURES IMPROVE IDENTIFICATION OF OLDER DRIVERS WITH MCI?

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ABSTRACT

This study considered the extent to which differences between drivers with mild cognitive impairment and controls on a sign recall task in a fixed-base driving simulator could better predict whether a driver will be diagnosed with MCI, compared to self-reports of a decrease in driving proficiency or of avoidance of driving, or age alone. The dependent measure in the simulator examined test conditions where working memory was subject to interference due to varying levels of demand for operational and tactical level driving tasks. Reliable between-groups differences in sign recall accuracy were demonstrated; sign recall similarly declined under higher task demand level. However, neither recall scores, nor self-reported frequency of avoiding driving, nor driver age predicted a clinical diagnosis of MCI; only self-reported decline in global driving ability was significant in this regard. Practical implications of these findings are discussed, while it is noted that this work must be viewed as exploratory due to its limited sample size.

Keywords: ageing, driving, cognitive impairment, assessment, screening, working memory, self-reported behavior, driving task demand

INTRODUCTION

With the aging of the driving population there is a greater prevalence of medical conditions and an associated loss of functional abilities needed to safely control a motor vehicle. There is considerable evidence that declines in cognition increase crash risk among older drivers, with a particular focus on neurological diseases such as dementia (and related medication use) that can lead to driving impairments (*1*), (*2*), (*3*), (*4*). Many people with dementia continue to drive, at least during early stages, and it has been shown that overall these drivers have a two-fold increase in crash risk compared to those without cognitive impairment (*5*).

Deficits associated with dementia that negatively affect driving performance, include memory loss; impairments in visuo-spatial skills, visual information processing efficiency, and judgment; and lack of insight into one's impairment that makes compensation for such limitations unlikely. In the early stage, detection of dementia is very difficult, as cognitive impairments are mild, and even family members may not realize that cognitive changes are occurring. It is in this stage that driving skills may still be preserved (*6)*.Researchers have underlined the "need for increased vigilance among clinicians, family members and individuals with MCI for initially benign changes in driving that may become increasingly problematic over time" (*7*) and also have reported that clinicians may fail in their judgment particularly in drivers with mild-cognitive decline (*8*). The importance of identifying drivers with early dementia or mild cognitive impairment (MCI) is underscored by their reduced capacity to self-regulate (*9*), (*10*).

Wadley et al. (*7*) examined the driving performance of 59 cognitively normal older adults and 46 persons with MCI (43 amnestic and 3 nonamnestic) using an on-road driving assessment. The groups were not matched on age (MCI group was significantly older) or gender (MCI group had fewer females), but there were no differences between groups in race, education, or visual acuity. Differences in mean driving performance ratings were small, with participants in both groups receiving high mean ratings. MCI patients were significantly more likely to receive a less-than-optimal rating on left turns, lane control and global ratings. The authors discussed specific difficulties in left turn negotiation and maintaining lane control among MCI patients in relation to greater demands in executive function associated with these maneuvers.

A study by Frittelli et al. (*11*) examined the impact of Alzheimer's disease (AD) and mild cognitive impairment (MCI) on driving ability using a low-cost, personal-computer-based interactive driving simulator (STISIM Driving Simulator). The study included twenty patients with mild AD (CDR = 1), 20 individuals with MCI (CDR = 0.5) and 19 neurologically normal aged controls. Drivers with AD were rated as significantly worse than MCI subjects and healthy elderly drivers on three driving behaviors: length of the run (sec), mean time to collision and number of off-road events (defined as occurring when the centre of the car's hood crossed the lateral border of the road). The only statistically significant difference between MCI patients and healthy controls was a shorter mean time to collision for the MCI subjects.

Devlin et al. (*12*) examined the performance of older drivers with and without mild cognitive impairment (MCI) when approaching intersections, testing fourteen male and female older drivers with MCI and fourteen age-matched, healthy drivers, using a portable driving simulator. Results indicated that drivers with MCI exhibited behaviors that were less situationally appropriate than controls when approaching controlled intersections and critical light-change intersections. Specifically, healthy drivers demonstrated a greater number of foot hesitations on approach to stop-controlled and critical light change intersections compared to the MCI group; this behavior was interpreted as a strategy to improve readiness in the event rapid braking was required. A large variation in cognitive ability amongst the drivers with MCI was found.

Whereas observed or reported deficits in performing basic activities of daily living (ADL) contribute to a diagnosis of dementia, when ADLs are preserved this can help differentiate MCI from mild dementia; at the same time, evidence that individuals experience difficulty in performing more complex *instrumental* activities of daily living (IADL), such as driving, is a more reliable marker to distinguish persons with MCI from healthy older individuals (*12*). This is consistent with evidence suggesting that observation and evaluation of IADL performance can assist in determining who might be an at-risk driver (13).

Drivers with a suspected cognitive impairment may be referred to their licensing authority for medical review. Neuropsychological testing results, and reports by the driver (or knowledgeable others) of difficulties with ADLs and IADLs, are indispensable to this review. Where driving performance measures are sought to supplement these indicators of cognitive impairment, safety and cost considerations often dictate the use of a driving simulator.

Within recognized limitations, simulators permit objective measures of driver performance and driver errors in a controlled environment, for a wide range of operational and tactical driving tasks, in populations that vary according to their demographic characteristics as well their functional status. A major challenge in using a simulator to assess driver performance – which researchers also face when designing a simulator-based experiment – is to choose effective and well-defined performance measures in scenarios that are most likely to elicit behaviors with clear safety relevance and that provide information about the specific mechanisms of impairment that underlie them (*14*).

Although research investigating the effects of functional deficits associated with MCI often finds small decrements in safety-relevant driving behavior, the (simulated) driving tasks employed in such studies strongly influence their outcomes. Those presenting demands on drivers that tax an individual's capacity for serial information processing – working memory, for example – while also involving executive functions will arguably be more efficient in revealing differences that are operationally significant.

Working memory is a cognitive ability of key importance to driving; it allows a driver to remember—and apply when needed—navigational directions and rules for traffic operations, even as s/he is processing and responding to the real-time demands of steering, anticipating and avoiding conflicts, and performing other moment-to-moment vehicle control tasks (*9*), (*10*). Executive functions such as decision-making, impulse control, judgment, task switching and planning all strongly interact with working memory and with attention, which operates on the contents of working memory (*15*).

The present investigation builds upon the tentative conclusions from a pilot study (*16*), using an improved experimental methodology to examine how varying levels of operational and tactical driving task demands might differentially affect message recall for older drivers with MCI, versus a group of age-matched, healthy controls. This study examined the extent to which differences between drivers with mild cognitive impairment and controls on a sign recall task in a fixed-base driving simulator could better predict whether a driver will be diagnosed with MCI, compared to a self-reported decline in driving proficiency, frequency of avoiding driving, or age alone. Samples of drivers diagnosed with MCI and controls were administered a questionnaire and participated in simulated driving tasks, where task demand varied at operational and tactical levels; significant differences in recall performance were hypothesized due to interference of varying task demand on working memory.

METHODS

Participants

This study was part of a larger driving simulator experiment described in Yannis et al. (*17*), from which current participants were drawn. All participants in this research held a valid driving license and had to meet certain criteria. They had to have driven for more than 3 years; to have driven more than 2500km during the previous year; to have driven at least once a week during the previous year; to have driven at least 10km/week during the previous year; and to have a Clinical Dementia Rating (CDR) score <2. They were not permitted to have a significant psychiatric history of psychosis; to have any significant kinetic disorder preventing them from basic driving movements; to suffer dizziness or nausea while driving, either as a driver or as a passenger; to be pregnant; to be alcoholic or have any other drug addiction; to have any significant eye disorder preventing them from driving safely; or to have any disease of the central nervous system.

Samples of drivers diagnosed with MCI and controls without measurable cognitive impairment were recruited to participate in this study. The MCI group included 12 subjects with a mean age of 64.8 years (s.d. = 8.9, range 51-76), 8 males and 4 females. The control group consisted of 12 subjects, 6 men and 6 women, who were medically evaluated and found to have no pathological condition, with a mean age of 59.5 years (s.d.=7.2; range 51-78). Table 1 displays between-group comparisons for driver age, driving experience, driving exposure (number of days driven per week, number of trips per day and kilometers per week), number of years of education, total accidents, and accidents in the past two years. None of the differences were statistically significant.

TABLE 1 Comparison of patients with MCI and of the Control Group Without Neurological History on Various Demographics With the Use of the Wilcoxon Rank Sum Test

	MCI group	Control group	P-values[a]
Age, y, mean±SD(median; range)	64.8±8.9(66; 51-76)	59.5±7.2(58; 51-78)	0.178
Gender, n, M/F	12, 8/4	12, 6/6	0.514
Driving experience, y, mean±SD (median)	37.7±8.2 (37.5)	33.7±5.8(34.5)	0.178
Days/week, median (range)	4.5(1-7)	5 (2-7)	0.755
Kilometers driven/week[b], median (range)	3.0(1-5)	3(2-5)	0.478
Trips/day	2.0(1-4)	2(2-5)	0.347
Accidents (2 years)-reported, median (range)	0 (0-2)	0 (0-1)	0.713
Accidents (total)-reported, median (range)	2 (0-4)	1 (0-8)	0.671
Education, y, median (median; range)	12.9±3.6(12.5; 6-19)	13.3±3.0(13.0; 6-18)	0.843

a. Level of statistical significance for between-group difference a=0.05
b.1=1-20km; 2=21-50km; 3=50-100km; 4=100-150 and 5=>150

All MCI subjects were classified with amnestic MCI; 9 were single domain amnestic MCI and 3 multiple domain amnestic MCI. The diagnosis of mild cognitive impairment was based on the criteria of (*18*) which involve complaints about memory impairment by the patients or a family member, verified impairment on at least one cognitive domain but with preserved functional abilities of daily living and absence of dementia. Exclusion criteria involved a score on Clinical Dementia Rating Scale equal or greater than one, premorbid history of neurologic or psychiatric disorders and the presence of significant depression. The functional profiles of each sample are described by the results of standard neuropsychological tests presented in Table 2.

TABLE 2 Comparison of Patients with Mild Cognitive Impairment (MCI) and of the Control Group on a Broad Array of Neuropsychological Tests With the Use of Wilcoxon Rank Sum Test

	MCI group	Control group	P-values
Mini Mental State Examination(MMSE)	28.2±2.53	29.5±.67	0.16
Immediate Recall_Hopkins Total[a]	18.55±2.82	24.25±4.33	0.009
Hopkins Delayed Recall[a]	3.73±2.94	7.42±3.12	0.012
Letter Number Sequencing(LNS)	8.55±3.36	10.33±1.87	0.288
Judgment of Line Orientation(JLO)	16.75±2.22	15.09±4.06	0.42
Symbol Digit Modalities Test [a](SDMT)	33.18±17.66	46.0±10.07	0.045
Trail Making Test Part A(TMTA)	72.64±67.14	40.5±8.47	0.131
Trail Making Test Part B(TMTB)	151.55±108.27	95.33±30.01	0.805
Immediate Recall_BVMT[b]Total	18.91±9.21	23.0±6.44	0.387
BVMT[b] Delayed Recall	7.55±4.11	9.17±1.70	0.619

a.statistically significant at a=0.05
b.Brief Visuospatial Memory Test

The analysis revealed significant differences between the control and the MCI group in measures assessing verbal episodic memory (Hopkins Verbal Learning Test-Revised) and information processing speed (SDMT). In contrast, measures of general cognitive functioning (MMSE), working memory (LNS), visuospatial memory (BVMT), psychomotor speed (TMTA), mental flexibility (TMTB) and visuospatial perception (JLO) did not differ in a significant way between the two groups.

All study participants were administered a questionnaire including items relating to global driving proficiency and driving avoidance, before simulator data collection.

Details of questionnaire administration

Participants were asked to complete an extensive questionnaire concerning demographic information; their driving experience, exposure and self-restrictions; a self-assessment of their driving skills; driving difficulties (*19*); specific driving behaviors associated with early dementia (*20*); distracted driving behaviors; their emotions while driving; and their history of incidents and accidents. Family members also completed questionnaires about their impressions of the study participants with impairment.

In the self-assessment part of the questionnaire, older drivers were asked (i) to assess whether their driving performance had declined over the previous five years, (ii) to indicate whether they avoided driving and (iii) to provide the reasons for avoiding driving (e.g. self-regulation, discouraged by family etc.). The inclusion of the items relating to self-assessment of global driving ability and driving ability in specific driving situations was based on findings of a previous study investigating perceptions of safe-driving ability in relation to actual and self-assessed performance of a group of older adults during an on-road trial (*19*).

Specifically, drivers reported on changes in global driving proficiency by comparing “your ability now to five years ago”, using a five-point scale: “much worse”, “a little bit worse”, “the same”, “a little bit better” and “much better.” Responses were consolidated into two categories to facilitate analyses of group differences with the present, small sample size: “worse” versus “unchanged or better.” Another item of the questionnaire asked drivers to report on the frequency with which they avoided making trips because of concerns about driving, by choosing one of four responses: “never”, “rarely”, “sometimes”, or “often”. Again, because of the small sample size, responses were consolidated into two categories: “never” versus “rarely or sometimes.” None of these participants responded “often.”

Details of simulator data collection

The driving simulation component of this study was conducted at the Department of Transportation Planning and Engineering of the School of Civil Engineering at the National Technical University of Athens (NTUA) in Athens, Greece, using a FOERST Driving Simulator FPF.

The driving simulator consists of driving position, fixed support base and 3 LCD wide screens 40" which provided a 170 degree field of view. Drivers viewed the LCD displays from a distance of 125 cm. Display resolution for the LCD screens was full HD (1920x1080pixels). The full dimensions are 230x180cm, with a base width of 78cm. It features adjustable driver seat, steering wheel 27cm diameter, pedals (throttle, brake, clutch), dashboard and two external and one central mirror that appear on the side and on the main screen. Performance data were extracted directly from the simulator and logged 30 times per second.

The present investigation builds upon the tentative conclusions from a pilot study (*16*), using an improved experimental methodology to examine how varying levels of operational and tactical driving task demands might differentially affect message recall for older drivers with MCI versus a group of matched, healthy controls. Experimenters were blind to the results of the neuropsychological tests. All subjects gained a degree of familiarity with the simulator through participation in a prior experiment that lasted approximately 45 minutes. Subjects were afforded a rest period of at least 15 minutes between their experience in the prior experiment and their participation in the present study. This prior experience allowed participants to practice all their driving skills (distance judgment, pedal and steering control) and also served as a screen for susceptibility to simulator adaptation syndrome (SAS) for the study sample. None were so affected.

The experiment in the driving simulator was completed in a single laboratory session. The experiment included three conditions, TC1 and TC2 and TC3, completed using repeated measures for all subjects in three separate simulator drives of approximately two minutes’ duration each. The experiment measured the effect of different levels of intervening driving task demand (i.e., between message presentation and recall) on the recall of the sign information. The amount of time between the presentation and recall of the sign message was roughly equivalent across conditions. The sign message was presented for a fixed interval (~8 sec) that was constant across study participants. Three equivalent messages were constructed for presentation during the three test conditions, using a common format: each sign displayed three units of information, indicating the *type of situation ahead*, its *distance*, and a *driver action* that is required, using standard wording (*21*), (*22*). Before each of their three drives in the simulator, subjects were instructed to respond to traffic control information and always maintain safe gaps with other vehicles just as they would when actually driving. They were also instructed to maintain a constant speed at the posted speed limit unless this was not possible due to other traffic, road construction, etc. (*16*).

All driving scenarios involved driving along straight sections and gentle curves on a limited access, divided roadway. Scenarios avoided sharp curves or frequent stops (*23*) to reduce the likelihood of simulator adaptation syndrome. Across all test conditions, the driving scenario began with a period of low-demand driving, requiring minimal steering input and with the only other traffic being two vehicles ahead with the lead vehicle at a safe distance ahead of the driver. These low-demand driving conditions persisted throughout TC1. In test conditions TC2 and TC3, however, after the initial period of low-demand driving, the level of demand was varied by imposing different types of operational and tactical driving tasks on subjects. In TC2, subjects negotiated a road work section, where the lane width tapered to become narrower. In TC, the demand on working memory was increased by the addition of a concurrent driving task. The order of presentation of conditions was randomized. The test conditions are described below:

- TC1-Demand Level 1.In TC1, drivers experienced the lowest level of demand, required to respond only to operational-level driving tasks.
- TC2-Demand Level 2. In TC2, drivers made a double lane change that involved driving through a road work section containing large blocks (barriers) on each side of the road, causing the road to progressively narrow (1:20 taper ratio; lane width 3m). These requirements were designed to produce an intermediate level of demand, i.e., demand in this scenario was higher than in TC1.
- TC3-Demand Level 3. In TC3, drivers were presented with the same road work section and associated steering requirements as in TC2, but after these forced lane changes they were required to execute an additional lane change *if* a discriminative stimulus (activation of the brake lights on a lead vehicle) was presented. This decision rule was included in the pre-drive instructions. The addition of this working memory task was designed to result in the highest level of demand for this scenario.

In all test conditions, participants relied upon working memory to recall the sign message after completing each driving scenario. Immediately at the end of each drive, subjects were asked to recall the sign message. The experimenter assigned a score 0-3, indicating that none, 1, 2 or all 3 information units were recalled. With the exception of the distance unit, the accuracy of recall was assessed on the basis of the meaning of the message information, rather than the exact wording.

RESULTS

Self-reports of changes in driving proficiency and driving avoidance

As shown in Table 3, half of the drivers in the MCI group responded that their current driving ability was worse than 5 years earlier, while only very few (8.3%) drivers in the control group gave this response. Substantial majorities of drivers in both the MCI group (75%) and in the control group (83.3%) reported that they never avoided making trips because of concerns about driving (Table 3).

TABLE 3 Responses to Selected Questionnaire Items

	MCI		Controls	
	Worse	Unchanged or better	Worse	Unchanged or better
"How do you rate your driving ability now compared to 5 years ago?"	50%	50%	8.3%	91.7%
	Never	Rarely or sometimes	Never	Rarely or sometimes

"How frequently do you avoid making trips because of concerns about driving?"	75%	25%	83.3%	16.7%

Simulator performance measures

Two sets of data analyses were performed, concerning differences in 1) drivers' speed choice under each test condition, as a manipulation check that the hypothesized differences in task demand had operational consequences, and 2) sign recall scores, to evaluate the hypothesized deficit for MCI drivers versus controls, and a potential interaction of sign message recall with task demand level.

The first set of analyses, which examined drivers' speed reductions to negotiate the road work section, employed a two-way mixed ANOVA (using SPSS) to test for main effects of driver group, a between-subjects variable, and the level of demand for intervening driving tasks, a within-subjects variable, on drivers' speed; and also for a possible two-way interaction between these variables.

In Table 4, descriptive statistics for each level of the two independent variables show that, on average, at Demand Level 1 the mean speed was higher than in Levels 2 and 3; in addition, the mean speed of the MCI group was lower than the mean speed of the control group across all levels of task demand.

TABLE 4 Descriptive Statistics for Speed Choice

	Group	Mean	Std. Dev.	N
Speed, Demand Level1	Control	65.25	8.07	12
	MCI	60.67	15.92	12
	Total	62.96	12.56	24
Speed, Demand Level2[a]	Control	44.58	13.21	12
	MCI	40.75	6.51	12
	Total	42.67	10.37	24
Speed, Demand Level3[a]	Control	44.92	13.37	12
	MCI	38.50	10.15	12
	Total	41.71	12.06	24

a. Average speed along the road work section

The ANOVA indicated that the effect of group membership on speed was nonsignificant ($F(1, 22)=2.28$, $p>0.05$), but that differences in speed associated with the level of driving task demand were reliable ($F(1.53, 35.57)=32.09$, $p<0.001$). In other words, disregarding group membership, subjects reduced speed across driving test conditions suggesting that the level of demand was indeed varied by imposing different types of operational and tactical driving tasks on subjects.

A Bonferroni corrected post hoc test showed that mean speed at Level 1 was significantly different than at both Levels 2 and 3 (both $p<0.001$); however, speeds at Level 3 were not significantly different than speeds at Level 2 ($p>0.05$).

The graph in Figure 1 illustrates the interaction between group membership and driving task demand. The "whiskers" (bars) denote one standard error around the mean of speeds for each group, at each demand level. This interaction was not statistically significant ($F(1.53, 33.57)=0.098$, $p>0.05$).

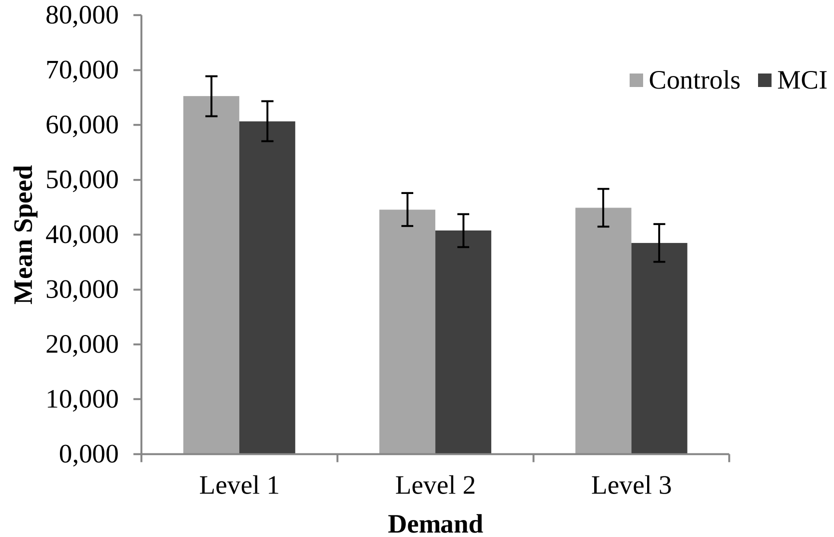

FIGURE 1 Mean speed for each group under varying levels of task demand.

Next, descriptive analyses of the sign message recall data are shown in Table 5 for MCI drivers and controls under each level of driving task demand. From this table it is apparent that the MCI group performed more poorly in message recall, demonstrating higher percentages of low recall scores (0 and 1) than the control group. At the same time, there is no clear pattern indicating an interaction between group membership and driving task demand.

TABLE 5 Recall Scores in Varying Levels of Intervening Task Demand

	Demand Level1 (TC1)	Demand Level2 (TC2)	Demand Level3 (TC3)
	Recall scores of MCI group		
percent of "0"	25.0%	0.0%	16.7%
percent of "1"	8.3%	8.3%	25.0%
percent of "2"	41.7%	33.3%	25.0%
percent of "3"	25.0%	58.3%	33.3%
Median	2.0	3.0	2.0
Range	0-3	1-3	0-3
	Recall scores of Controls		
percent of "0"	0.0%	0.0%	0.0%
percent of "1"	8.3%	8.3%	8.3%
percent of "2"	16.7%	16.7%	41.7%
percent of "3"	75.0%	75.0%	50.0%
Median	3.0	3.0	2.5
Range	1-3	1-3	1-3

A General Estimating Equation (GEE) model (ordered multinomial logistic regression) was specified to examine the relationship between participant group and performance in the sign recall task, adjusting for potential intercorrelations among sign recall task for each participant at the three test conditions. As shown in Table 6, the ordinal logistic GEE (applying a cumulative logit link function) indicated that controls were more likely to perform better than MCI drivers in the sign recall task; this trend was statistically significant Exp(b)=11.76, 95% CI 2.73, 50.62, p=0.001<0.05).

TABLE 6 Multinomial Regression Predicting Recall Scores

Parameter		Estimate (b)	Std. Error	95% CI Lower	95% CI Upper	Hypothesis Test Wald Chi-Square	df	Sig.
Threshold	Recallscores=0	-0.65	0.41	-1.45	0.15	2.55	1	0.110
	Recallscores=1	0.57	0.41	-0.23	1.37	1.93	1	0.165
	Recallscores=2	2.91	0.70	1.55	4.28	17.47	1	0.000
Controls		2.46	0.74	1.00	3.92	10.94	1	0.001
MCI		0.00						
TC1-Demand-Level 1		0.90	0.46	-0.01	1.81	3.77	1	0.052
TC2-Demand Level 2		1.58	0.43	0.73	2.43	13.33	1	0.000
TC3-Demand Level 3		0.00						

This analysis further revealed that, disregarding group membership, subjects performed better in the recall of sign information in TC1 versus TC3, although this difference was not significant Exp(b)=2.46, 95% CI 0.99, 6.12, p=0.052<0.05). Performance in the sign recall task was more likely to be higher in TC2 (lower level of driving task demand) than TC3 and this difference was statistically significant Exp(b)=4.85, 95% CI 2.08, 11.33, p<0.001). The interaction effects were considered during the model building process, but they were not included in the final model specification as they were not significant at any reasonable level. Age was considered during the model building process but the convergence criterion was not satisfied.

Prediction of MCI diagnosis

Building on the reliable differences between drivers with mild cognitive impairment and controls on a sign recall task, we further explored the extent to which such evidence could better predict whether a driver will be diagnosed with MCI, compared to self-reports of changes in driving proficiency, or of avoidance of driving, or on the basis of age alone. We used stepwise logistic regression (see Table 7) with a threshold of 0.05 for statistical significance. The dependent variable was group membership (a dichotomous variable) and the independent variables were age; self-reported changes in global driving proficiency (relative to five years earlier), where 1=*worse* and 2=*unchanged or better*; self-reported frequency of avoiding driving, where 1=*never* and 2=*rarely or sometimes*; and recall score in the high demand test condition, TC3, where1=a score of *0 or 1*, and 2=a score of *2 or 3*.

In the regression model, predictor variables that failed to meet the criteria for inclusion were dropped, at each step in turn, until it was revealed that self-reported changes in global driving ability was the only statistically significant predictor (see Tables 7 and 8). The associated odds ratio indicated that the odds of study participants who self-reported their driving ability as being “worse now than five years ago” also being diagnosed with MCI were 1/0.09 or *11 times more likely* than the odds of those participants who rated their driving ability as unchanged or better also being diagnosed with MCI (Table 8).

TABLE 7 Variables in Stepwise Logistic Regression

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for Exp(B)	
								Lower	Upper
Step 1	Age	0.05	0.07	0.45	1	.500	1.05	0.92	1.20
	Recall score	-1.91	1.44	1.77	1	.184	0.15	0.01	2.47
	Self-reported frequency of avoiding making trips	-0.54	1.40	0.15	1	.698	0.58	0.04	9.05
	Self-reported changes in global driving ability	-2.16	1.41	2.35	1	.125	0.12	0.01	1.82
	Constant	5.01	6.87	0.53	1	.466	149.92		
Step 2	Age	0.04	0.07	0.38	1	.536	1.04	0.91	1.19
	Recall score	-1.70	1.29	1.74	1	.188	0.18	0.01	2.29
	Self-reported changes in global driving ability	-1.99	1.29	2.38	1	.123	0.14	0.01	1.71
	Constant	3.93	5.98	0.43	1	.511	50.95		
Step3	Recall score	-1.85	1.28	2.09	1	.148	0.16	0.01	1.93
	Self-reported changes in global driving ability	-2.24	1.24	3.25	1	.071	0.11	0.01	1.22
	Constant	7.21	3.33	4.70	1	.030	1354.26		
Step 4	Self-reported changes in global driving ability	-2.40	1.19	4.04	1	.045	0.09	0.01	0.94
	Constant	4.19	2.22	3.56	1	.059	66.00		

TABLE 8 Logistic Regression Predicting Whether a Driver Will Be Diagnosed With MCI: Final Model

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.forExp(B)	
							Lower	Upper
Self-reported changes in global driving ability[a]	-2.40	1.19	4.04	1	.045	0.09	0.01	0.94
Constant	4.19	2.22	3.56	1	.059	66.00		

Final Model: R^2 = 0.16 (Hosmer&Lemeshow), 0.20 (Cox &Snell), 0.27 (Nagelkerke), Model x^2=5.455
a. statistically significant at 0.05 level

CONCLUSIONS AND DISCUSSION

This research achieved multiple aims. First, it replicated earlier findings (*16*) from the same laboratory showing that drivers with mild cognitive impairment (MCI) performed significantly more poorly on a sign recall task across varying levels of driving task demand than a cognitively-intact comparison group. However, in the earlier study the MCI group was, on average, over a decade older than the controls, while in the present study the healthy control group and the MCI drivers were comparably aged.

This research also examined the utility of this measure of cognitive status obtained in a (fixed-base) driving simulator in a broader context: license renewal policies and practices, where the need for early identification (screening) and assessment of drivers at risk due to cognitive impairment is likely to become more pronounced in an aging population. Should jurisdictions that are sensitive to the risks associated with normal aging, plus the diseases and medical conditions more prevalent among older drivers, regard testing on a driving simulator as a useful or necessary procedure to determine fitness to drive? Can early identification of drivers who are at risk due to MCI be accomplished with much more cost-effective methods? The results demonstrated in this study, while tentative given its small sample size, bear on these questions.

While individuals with MCI as well as those in the earliest stages of a progressive, dementing illness may be able to continue to drive safely for some time, a proper diagnosis is important not only for planning treatment but also when considering appropriate driving (licensing) restrictions and requirements for periodic review to determine license status. Exploring which data best predict a diagnosis of MCI, it was found in this study that neither message recall scores in a simulated driving scenario with elevated working memory demands, nor self-reported frequency of driving avoidance, nor driver age predicted a clinical diagnosis of MCI; only self-reported changes in global driving ability were significant in this regard. This suggests that screening programs keyed to age-related cognitive impairment should incorporate subjective perceptions of changes in driving proficiency—i.e., using one's earlier self as the baseline—to complement clinical test results for early identification of drivers that merit medical review.

Where more in-depth assessment is needed, simulators that obtain objective measures of driver performance will remain an essential tool to better understand the interaction between individual differences and varying situational demands on safe and effective vehicle control. Even with a small sample, a reliable main effect of group membership indicates that (older) drivers with mild cognitive impairment will be at a disadvantage when new information is presented, for example, on a variable message sign, that must be retained in working memory and applied after some additional period of driving. In addition, differences shown in this study, though not reliable with the small sample size, suggest that this effect will be exaggerated as driving task demands increase. As a platform for research as well as assessment, fixed-base driving simulators may become even more important as assistive technologies and automated control systems are introduced, to delineate the conditions under which healthy as well as (cognitively) impaired drivers may retain control of their vehicles.

Certain caveats apply to this report. It should be noted (*24*) that informant or self-reported measures may become less useful the older the target population and the greater the extent of cognitive impairment. It is also quite possible that an investigation with a substantially larger sample could reveal additional, significant predictors of a MCI diagnosis among a broad array of simulator measures, exposure data, and self- and/or informant reports on diverse driving behaviors. In addition, larger samples with appropriate measurement techniques could better account for (analytically) the influence on driving behaviors and performance of confounding variables such as age, and individual characteristics, e.g., driving experience and driving exposure, that are associated with driving competence.

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REFERENCES

1. Hakamies-Blomqvist, L., Wahlström, B. Why do older drivers give up driving? *Accident Analysis & Prevention*, Vol. 30, No. 3, 1998, pp. 305-312.
2. Sims, R.V., McGwin, G.Jr, Allman R.M., Ball, K., Owsley, C. Exploratory study of incident vehicle crashes among older drivers. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences*, Vol. 55, Is. 1, 2000, pp. 22-27.

3. Breker, S., Henrikson, P., Falkmer, T., Bekiaris, E., Panou, M., Eeckhout, G., Siren, A., Hakamies-Blomqvist, L., Middleton, H., Leue, E. *Aged people Integration, mobility, safety and quality of Life Enhancement through driving (AGILE) Project, Deliverable 1.1: Problems of elderly in relation to the driving task and relevant critical scenarios*, 2003.

4. Hakamies-Blomqvist, L. Safety of Older Persons in Traffic. Proceedings of *Transportation in an Ageing Society. A Decade of Experience*, Transportation Research Board, Washington D.C., 2004, pp. 22-35.

5. Carr, D. B., & Ott, B. R. The older adult driver with cognitive impairment. "Its a very frustrating life". *Journal of the American Medical Association, 303*(16), 2010, pp.1632-1641.

6. Lundberg C, Johansson K, Ball K, Bjerre B, Blomqvist C, Braekhus A, Brouwer WH, Bylsma FW, Carr DB, Englund L, Friedland RP, Hakamies-Blomqvist L, Klemetz G, O'Neill D, Odenheimer GL, Rizzo M, Schelin M, Seideman M, Tallman K, Viitanen M, Waller PF, Winblad B. Dementia and driving: an attempt at consensus. Alzheimer Dis Assoc Disord; 11(1), 1997, pp. 28-37.

7. Wadley, V. G., Okonkwo, O., Crowe, M., Vance, D. E., Elgin, J. M., Ball K.K, and C. Owsley. Mild Cognitive Impairment and Everyday Function: An Investigation of Driving Performance. *J Geriatr Psychiatry Neurol*. 22(2): 87–94.June 2009 ; doi:10.1177/0891988708328215.

8. Uc, E., and Rizzo, M.. Driving in Alzheimer's Disease, Parkinson's Disease, and Stroke. *Handbook of Driving Simulation for Engineering, Medicine and Psychology*. CRC Press, 2011.

9. Staplin, L., Lococo, K. H., Gish, K. W., Decina, L.E. Model Driver Screening and Evaluation Program. Final Technical Report. Volume 2: Maryland Pilot Older Driver Study. Washington, D.C., National Highway and Traffic Safety Administration, 2003. http://www.nhtsa.dot.gov/people/injury/olddrive/modeldriver/

10. Staplin, L. Choosing Among Measures of Driver Cognitive Status that Predict Crash Risk. Maryland Older Driver Symposium. May 2012.

11. Frittelli, C., Borghetti, D., Iudice, G., Bonanni, E., Maestri, M., Tognoni, G., Pasquali L. and Iudice, A. Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test, *International journal of geriatric psychiatry*, 24(3), 2009, pp. 232-238.

12. Devlin, A., McGillivray, J., Charlton, J., Lowndes, G., and Etienne, V.. Investigating driving behaviour of older drivers with mild cognitive impairment using a portable driving simulator, *Accident Analysis & Prevention*, (49), 2012, pp. 300– 307.

13. Dickerson AE, Reistetter T, Davis ES, Monahan M., Evaluating driving as a valued instrumental activity of daily living, *Am J Occup Ther.*, 65(1), 2011, pp. 64-75.

14. Vardaki, S., Yannis, G. & S. Papageorgiou, A Review of Driving Performance Assessment in Simulators, Proceedings of the *Road Safety and Simulation RSS013 International Conference*, Rome, 2013.

15. Rizzo M. Medical Disorders. *Handbook of Driving Simulation for Engineering, Medicine and Psychology*. CRC Press, 2011.

16. Vardaki, S., Yannis, G. Pavlou, G.,Beratis, I., Papageorgiou, S. Sign recall in a fixed-base simulator as a measure of fitness-to-drive, Proceedings of the *93nd Annual Meeting of the Transportation Research Board* (TRB), January 12-16, 2014, Washington, D.C., USA.

17. Yannis G., Golias J., Antoniou C., Papadimitriou E., Vardaki S., Papantoniou P., Pavlou D., Papageorgiou S., Andronas N., Papatriantafyllou I., Liozidou A., Beratis I., Kontaxopoulou D., Fragiadaki S., Economou A., Design of a large driving simulator experiment on performance of drivers with cerebral diseases, Proceedings of the *Road Safety and Simulation RSS013 International Conference*, Rome, 2013.

18. Petersen, R.C., Morris, J.C. Mild Cognitive Impairment as a Clinical Entity and Treatment Target. *Archives of Neurology, 62(7)*, 2005, pp. 1160-1163.

19. Vardaki, S., Karlaftis, M. G. An investigation of older driver road safety perceptions and driving performance on freeways, *Advances in Transportation Studies, Special Issue 2011*, 2011, pp.7-18.

20. Eby, W. D., Silverstein, M. N., Molnar J. L., LeBlanc, D., Adler, G., Gottlieb, A., Stroupe, J., Gilbert, M., Way, J.. Fitness to Drive in Early Stage Dementia: An Instrumented Vehicle Study, The University of Michigan Transportation Research Institute, 2009.
21. Campbell, J. L., Lichty, M. G., Brown, J. L., Richard, C. M., Graving, J. S., Graham, J., Mitchell O' Laughlin, Darren Torbic and Douglas Harwood. *NCHRP Report 600 (Second Edition): Human Factors Guidelines for Road Systems*. Transportation Research Board of the National Academies, Washington D.C, 2012.
22. Hellenic Ministry of Transport and Infrastructure, *Freeway Signing Guidelines*. Hellenic Ministry of Transport and Infrastructure, Athens, 2010.
23. Trick, L. M. and Caird, J. K.. *Methodological Issues When Conducting Research on Older Drivers*. Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press, 2011.
24. Zimmerman S. I., Magaziner J., Methodological issues in measuring the functional status of cognitively impaired nursing home residents: the use of proxies and performance-based measures. Alzheimer's Disease and Associated Disorders, 8 (1), 1994, pp. 281-90.