Do simulator measures improve identification of older drivers with MCI?

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Introduction

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. 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. Drivers with a suspected cognitive impairment may be referred to their licensing authority for medical review. Where driving performance measures are sought to supplement indicators of cognitive impairment, such as neuropsychological testing and changes in one's ability to perform ADLs and IADLs, safety and cost considerations may dictate the use of a driving simulator. The present investigation used a sign recall task to explore the association between working memory and MCI in a driving simulator, and examined whether performance in sign recall better predicts MCI diagnosis compared to a self-reported decline in driving proficiency, frequency of avoiding driving, or age alone.

Study Objectives

- To determine how varying levels of operational and tactical simulated driving task demands might differentially affect message recall for older drivers with MCI, versus a group of age-matched, healthy controls.
- To examine the extent to which performance 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.

General Information

The study was part of a larger driving simulator investigation. Key elements:

- Designed for the purposes of the DISTRACT project
- Used a FOERST Driving Simulator FPF with 3 LCD screens (40" wide), where total field of view = 170 degrees. Drivers viewed the LCD displays from a distance of 125 cm. Display resolution for the LCD screens was full HD (1920x1080pixels). The full simulator dimensions are 230x180cm, with a (fixed) base width of 78cm.
- Participants in the larger investigation provided the pool of subjects for this study. These individuals included current drivers with a cerebral pathological condition (neurological disease) and drivers with no known pathological condition. They:
  - had to have driven for more than 3 years; more than 2500km during the last year; at least once a week and at least 10km/week during the last year;
  - had a Clinical Dementia Rating scale (CDR) score <1;
  - had no significant psychiatric history of psychosis or significant kinetic disorder;
  - could not suffer dizziness or nausea; be pregnant; be alcoholic or have any other drug addiction; have any significant eye disorder or any disease of the central nervous system.

Study Participants

- Two driver groups: A MCI group and a control group.
- The MCI group: 12 subjects; mean age = 64.8 years (s.d. = 8.9, range 51-76); 8 males and 4 females.
- The control group: 12 subjects; 6 men and 6 women; with no pathological condition; mean age = 59.5 years (s.d.=7.2; range 51-78).

Demographics and Functional Status of Study Sample

- The two groups were not statistically different (a=0.05) in terms of age, driving experience and exposure, number of years of education, and (total and recent) accidents.
- 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 Petersen et al. (2005), 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 the Clinical Dementia Rating Scale equal or greater than one, premorbid history of neurologic or psychiatric disorders and the presence of significant depression.
- 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), visual search (TMTA), mental flexibility (TMTB) and visuospatial perception (JLO) did not differ significantly between the two groups

TABLE 1 Comparison of Patients with MCI and of the Control Group on Various Demographics (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 (between-group difference) a=0.05
b.1=1-20km; 2=21-50km; 3=50-100km; 4=100-150 and 5=>150

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

	MCI group	Control group	P-values[a]
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

Questionnaire Administration

- All study participants were administered an extensive questionnaire before simulator data collection.
- Drivers reported on
  - changes in global driving proficiency by comparing "your ability now to five years ago", using a five-point scale. Responses were consolidated into two categories: "worse" versus "unchanged or better."
  - the frequency with which they avoided making trips because of concerns about driving, using a four-point scale. Responses were consolidated into two categories: "never" versus "rarely or sometimes."

Simulator Data Collection

All subjects were familiar with the simulator as a consequence of their participation in a prior experiment (45 minutes); they were afforded a rest period of at least 15 min. before participating in the present study.

Experiment

- A repeated measures design included three conditions of increasing task demand: TC1,TC2, and TC3; these were simulator drives of approximately 100 sec duration each.
- The experiment measured the effect of different levels of intervening driving task demand on the recall of the sign information.
- A sign message was presented for a fixed interval (8 sec) that was constant across study participants before the beginning of each drive.
- Three alternate messages were constructed for use in each test condition, each with three items of information: a type of situation ahead, a distance, and a driver action that is required.
- Drivers were asked to read aloud and rehearse the message and then the drive began.
- Immediately after the end of each drive, the experimenter assigned a score 0-3, indicating that none, 1, 2 or all 3 information items were recalled.
- The research design required drivers to remember and apply rules for car following and lane changes.
  - TC1-Demand Level 1. Drivers experienced the lowest level of demand, required to respond only to operational-level driving tasks.
  - TC2-Demand Level 2. Drivers made a double lane change that involved driving through a road work section containing large blocks on each side of the road, causing the road to progressively narrow
  - TC3-Demand Level 3. Drivers met the same steering requirements as in TC2, and in addition, they were required to execute a lane change if a discriminative stimulus was presented. This decision rule was included in the pre-drive instructions.
- The order of presentation of conditions TC1, TC2, and TC3 was randomized.

Instructions to subjects

- Respond to traffic control information and always maintain safe gaps with other vehicles just as they would when actually driving.
- Maintain a constant speed at the posted speed limit unless they are forced to slow down due to road conditions. "In this situation, drive at what you feel is the maximum safe speed for conditions."
- Execute a lane change in response to a discriminative stimulus (activation of the brake lights on a lead vehicle).
- "Please look at and remember this highway sign message. I will ask you to recall this message at the end of the drive."

Results

Self-reports of changes in driving proficiency and driving avoidance

- 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.

Simulator performance measures

Differences in speed

Data analyses examined differences in drivers' speed choice under each test condition, to check that the hypothesized differences in task demand had operational consequences.

- A two-way mixed ANOVA (using SPSS) was used 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.
- On average, at Demand Level 1 the mean speed was higher than in Levels 2 and 3; the mean speed of the MCI group was lower than the mean speed of the control group across all levels of demand.
- The effect of group membership on speed was non-significant; differences in speed associated with the level of driving task demand were reliable ($F(1.53, 35.57)=32.09$, $p<0.001$). Disregarding group membership, the reduced speeds across driving test conditions suggested that the level of demand was indeed varied by imposing different types of operational and tactical driving tasks on subjects.

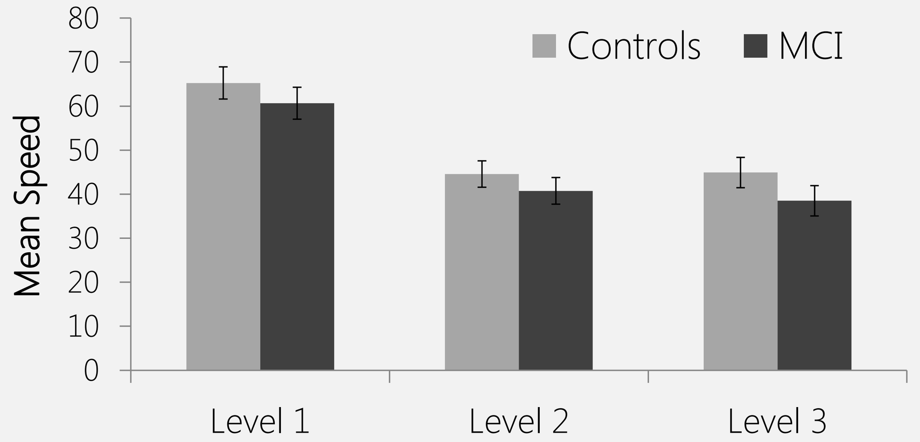


FIGURE 1 Mean speed for each group under varying levels of task demand

Differences in sign recall scores

Data analyses examined differences in sign recall to evaluate the hypothesized deficit for MCI drivers versus controls, and a potential interaction of sign message recall with task demand level.

- MCI group performed more poorly in message recall, demonstrating higher percentages of low recall scores (0 and 1) than the control group.
- 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 inter-correlations among sign recall task for each participant at the three test conditions.
- 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).
- Disregarding group membership, subjects performed better in the recall of sign information in TC1 versus TC3, although this difference was not significant.
- Performance in the sign recall task was more likely to be higher in TC2 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 significant and were not included in the final model specification.

TABLE 3 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						

Prediction of MCI diagnosis

A stepwise logistic regression was used to explore the extent to which such driving simulator measures 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.

- The dependent variable was group membership and the independent variables were age; self-reported changes in global driving proficiency; self-reported frequency of avoiding driving; and recall score in the high demand test condition, TC3.
- Self-reported changes in global driving ability was the only statistically significant predictor.
- 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.

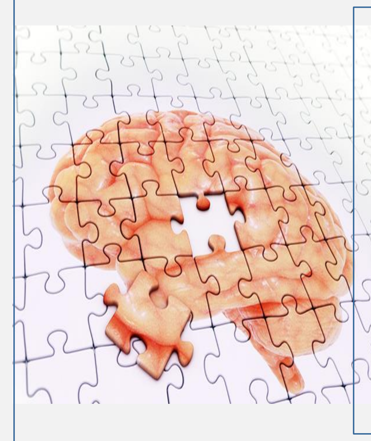
TABLE 4 Logistic Regression Predicting Whether a Driver Will Be Diagnosed With MCI: Final Model

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.forExp(B) Lower	95% C.I.forExp(B) 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

- This research showed a reliable main effect of group membership indicating that drivers with MCI performed significantly more poorly on a sign recall task across varying levels of driving task demand than a cognitively-intact comparison group.
- 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.
- The results suggest that (older) drivers with MCI will be at a disadvantage when new information is presented, e.g., 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 suggest that this effect will be exaggerated as driving task demand increases.
- The results suggest 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.



Study Limitations

- Results were not analyzed in relation to individual characteristics associated with driving competence such as driving experience, etc., nor functional status.
- Informant or self-reported measures may become less useful the older the target population and the greater the extent of cognitive impairment.
- Questionnaire data analysis was based on consolidated responses.
- Older drivers are more likely to experience simulator sickness, so an effect of sampling bias on study results cannot be ruled out.
- This must be characterized as an exploratory study due to its small sample size.

Future Work

- 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.
- Larger samples with appropriate measurement techniques could better account for the influence on driving behaviors and performance of confounding variables such as age, and individual characteristics (driving experience and driving exposure, that are associated with driving competence).
- There is a need to analyze the extent to which performance differences may be attributed to actual differences in visual and cognitive functional abilities.
- 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.
- Fixed-base driving simulators may become even more important as connected/automated vehicle (C/AV) technologies are introduced, to delineate the conditions under which healthy as well as (cognitively) impaired drivers may retain control of their vehicles.

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