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Sign recall in a fixed-base simulator as a measure of fitness-to-drive

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Introduction

The increasing number of older drivers will produce a higher prevalence of decline in specific cognitive abilities that predict crash risk, such as working memory. This increasing prevalence may be anticipated because of changes due to normal aging and the various age-related pathologies that are more common among older adults, as well as the medications used to treat them. Low fidelity (fixed-base) driving simulators may be effective tools to discriminate drivers at risk due to such cognitive decline.

This research recognizes 'working memory' as the only one of the primary memory systems (semantic, episodic, procedural, perceptual, and working) involved in "short term" memory function; it requires temporarily holding and processing information in order to perform complex cognitive tasks. A sign recall task requires drivers to draw upon working memory in an exploratory study using a fixed-base driving simulator.

Study Objectives

1. To provide evidence of whether there are main effects of health (cognitive) status and time elapsed between presentation and recall of sign information, as well as interactions between these variables, on drivers' recall of traffic safety messages.

2. To determine (in the absence of a main effect of time) whether varying levels of operational and tactical driving task demands would differentially affect healthy controls versus medically at-risk older drivers in terms of message recall.

General Information

The study was part of a large driving simulator experiment. Key elements:

- Designed for the purposes of the **DriverBrain** project ("Analysis of the performance of drivers with cerebral diseases") and the **DISTRACT** project ("Analysis of causes and impacts of driver distraction");
- Used a FOERST Driving Simulator FPF with3 LCD screens (40°wide), a total field of view=170 degrees; driver's seat and controls; and support base. Display resolution for the LCD screens was full HD (1920x1080pixels).

Participants in the larger experiment 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 CDR score <2;
- ✓ 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.

distRACT driverBRAIN

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Study Participants

Two driver groups**: a medically at-risk (MAR) group and a control group (C)**

- The MAR group: nine subjects; mean age of 70.3 years (s.d.=12.1); all males; 5 with Parkinson's disease (PD) and 4 with mild cognitive impairment (MCI)
- The C group: seven subjects; mean age of 55.6 years (s.d.=12.5); 4 men and 3 women; with no pathological condition.

Demographics and functional status of study sample

- The two groups were statistically different (a=0.05) in terms of age, driving experience and driving exposure (number of kilometers driven per week).
- The groups were not statistically different in terms of years of education (mean number of years of education: MAR: 14.7 (2.9), C: 15.7 (2.7)), frequency of driving and number of recent accidents.
- The drivers with PD had mild to moderate disease severity.
- Preliminary analysis of performance in cognitive tests revealed between-group differences in visual search, psychomotor speed, spatial skills, verbal learning and memory, visuospatial working memory, executive control (mental flexibility and task shifting), and speed of information processing.
- On the basis of diagnoses and differences in functional abilities, we assumed that those drivers in the medically at-risk group had higher potential for working memory impairment than controls.

TABLE 1. Comparison of Medically at-risk group (patients with Parkinson's disease and MCI) and Control group. Values represent mean ± SD (Median)- Demographic information

	MAR group (MCI or PD)	Control group	P-values
Driving experience[a]	46.8±11.7(43)	30.1±6.5(32)	0.002
Driving exposure			
Days/week	4.0±1.9(3.5)	5±1.7(5)	0.336
Kilometers driven/week[a]	53.1±48.0(40.0)	102.9±48.7(85.0)	0.029
Accidents (2 years)	0.3±0.7(0.0)	0.3±0.5(0.0)	0.694
CDR[b]	0.6± 0.5(1.0)	0.00± 0.00(0.00)	0.071
Parkinsonism(n=5)			
Disease duration	10±5.6(13)		
UPDRS[c]	12.8 ±6.3(14)		
H&Y[d]	1.8±0.4(2)		

[a] Statistically significant between-group difference at the 0.05 level
[b] Clinical Dementia Rating
[c] Unified Parkinson's disease Rating Scale – motor scores
[d] Hoehn & Yahr stage

TABLE 2. Comparison of patients with Parkinson's disease and MCI. Values represent mean ± SD (Median)-Functional tests

	MAR group (MCI or PD)	Control group	P-values
General cognitive state			
MMSE	27.8±2.2(29.0)	29.4±0.8(30)	0.071
Cognitive screening			
Clock Drawing Test	6.0±1.7(7.0)	7.0±0.00(7.00)	
Semantic fluency Test	16.2±2.8(17.0)	17.9±0.4(18.00)	0.071
Phonemic Fluency	9.0± 4.5(11.0)	13.3± 3.6()	0.055
Frontal Assessment Battery[a] (FAB) (executive-related)	12.6±4.2(14)	16.7±1.4(17.0)	0.023
Upper limb apraxia screening Test	16.2±2.8(17.0)	17.9±0.4(18)	0.142
Learning and memory			
Hopkins Verbal Learning Test-Revised Trial 1[a] (HVLT-1)	4.3±1.2(4)	6.9±1.8(7.0)	0.012
Hopkins Verbal Learning Test-Revised Trial 2[a] (HVLT-2)	5.6±1.2(6.0)	8.3±1.8(8.0)	0.003
Hopkins Verbal Learning Test-Revised Trial 3 (HVLT-3) (immediate recall of verbal information)	6.78±2.0(6.0)		0.055
Hopkins Verbal Learning Test-Revised Delayed Recall (HVLTDR)	4.2±3.7(5.0)	6.4±3.6(5)	0.408
Brief Visuospatial Memory Test –Trial 1 (BVMT1)	2.78±2.4(2.0)	5.0±2.6(4.0)	0.114
Brief Visuospatial Memory Test –Trial 2 (BVMT2)	5.3±3.3(4.0)	8.6±2.6(9.0)	0.091
Brief Visuospatial Memory Test –Trial 3 (BVMT3) (immediate recall of visuospatial material)	6.8±3.7(6.0)	10.1±2.9(11.0)	0.055
Brief Visuospatial Memory Test Delayed Recall[a] (BVMTDR) (delayed recall of visuospatial material)	5.2±3.8(6.0)	10.0±2.0(11.0)	0.008
Executive functions			
Trail Making Test Part A[a] (TMTA) (psychomotor speed, visual search)	73.9±42.2(59.0)	34.6±8.9(35.0)	0.002
Trail Making Test Part B[a] (TMTB) (mental flexibility, executive-related)	157.2±76.5(137)	75.4±33.2(64.0)	0.008
Spatial Addition Test[a] (visuospatial working memory)	6.0±1.2(6.0)	14.1±4.9(16.0)	0.001
Visual and Spatial Perception			
Judgment of Line Orientation Test (visuospatial perception)	14.8±3.8(16.0)	17.0±3.3(19.0)	0.252
Short-term & Working Memory tests			
Spatial Span Forward (visuospatial working memory)	6.4±2.8(7.0)	8.4±1.4(8.0)	0.174
Spatial Span Backward[a] (visuospatial working memory)	5.0±2.2(5.0)	6.1±2.2(6.0)	0.031
Attention			
Symbol Digit Modalities Test Oral[a] (SDMTo)	23.2±17.2(22.0)	49.4±11.2(52.0)	0.005
Symbol Digit Modalities Test Written[a] (SDMTw) (information processing speed)	22.8±11.9(26.0)	48.0±10.9(51.0)	0.001

[a] Statistically significant between-group difference at the 0.05 level

Study Procedure

- The drivers with PD were tested during periods of optimal symptom control.
- All subjects gained a degree of familiarity with the simulator through participation in a prior experiment (45 minutes); they were afforded a rest period of at least 15 minutes before participating 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.

Two Experiments

- Experiment 1
  - ✓ A repeated measures design including two test conditions (TC1 and TC2) of two min duration each (short-term memory span between 0.5 and 2 min).
  - ✓ The effect of varying the delay between the presentation and recall of safety information on a message sign-holding constant a low level of demand for intervening, operational-level driving tasks-was measured for drivers in the MAR and C study groups.
  - ✓ The delay in sign message recall in TC1 was 10 seconds and in TC2 80 seconds; the order of presentation was counterbalanced, with half of the subjects randomly assigned to each order.
- Experiment 2
  - ✓ A repeated measures design including two test conditions, TC3 and TC4.
  - ✓ The effect of different levels of intervening driving task demand (i.e., between message presentation and recall) on the recall of the sign information by the MAR and C subjects was measured, with the amount of time between the presentation and recall of the safety message held roughly equivalent across conditions (~80sec).
  - ✓ Driving task demand increased from test condition TC3 to TC4; TC3 and TC4 were presented in this (fixed) order to all subjects.

Instructions

In both experiments, before each of the four drives (TC1 – TC4), subjects were:

- Instructed to respond to traffic control information and always maintain safe gaps with other vehicles just as they would when actually driving.
- Instructed to maintain a constant speed at the posted speed limit unless they were forced to slow down due to road conditions (specifically, a road section where barriers were present). "In this situation, drive at what you feel is the maximum safe speed for conditions."
- Required to execute a lane change in response to a discriminative stimulus (activation of the flashers on a lead vehicle).
- told, "At some point during this drive you will see a sign with a safety message displayed in white letters on a blue background. I will ask you to recall it at the end of the drive."

Safety Message

- The letter size on the sign was calculated on the basis of legibility specifications to provide a viewing time within the range of 5 to 7.5 sec.
- Alternate messages were constructed for use in each test condition, each with three units of information:
  - ✓ the type of situation ahead
  - ✓ a distance
  - ✓ a driver action that is required
- Immediately after the end of each drive, the experimenter assigned a score 0-3, indicating none, 1, 2 or all 3 information units that are recalled.

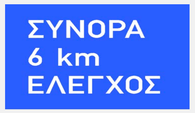


FIGURE 1. Example message sign indicating a border crossing in 6 km where drivers should stop for inspection

Driving Tasks

- Across all test conditions, driving scenarios involved driving along straight sections and gentle curves on a limited access, divided roadway.
- The research design required subjects to remember and apply rules for car following and lane changes throughout the drives.

Experiment 1

TC1 and TC2: These test conditions differed according to *when* the message sign was presented.

Experiment 2

TC3 and TC4: These test conditions varied the level of demand by imposing different types of operational and tactical driving tasks, following an initial period of low-demand driving that was constant for all subjects:

- ✓ TC3-Demand Level 1: 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).
- ✓ TC4-Demand Level 2: Drivers met the same steering requirements as in TC3, and in addition, they were required to execute a lane change in response to a discriminative stimulus (activation of the flashers on a lead vehicle).

FIGURE 2. Test condition TC3, with open road immediately ahead of the driver.

FIGURE 3. Test condition TC3, as barriers narrow the road to a single lane.

Results

- A two-way mixed ANOVA was conducted for the dependent variable (recall scores) for two groups to analyze the data from each of the two experiments.
- The dependent variable was expressed as percentages of the information units that are recalled, on a scale of 0 to 100.

Experiment 1

A 2x2 ANOVA tested for main effects of medical/health status (between-subjects variable) and amount of delay (within-subjects variable) on recall of the safety information, and for a possible two-way interaction between these variables.

- On average, the recall score was slightly higher under the longer delay than under the shorter delay conditions, but this effect was not significant, F (1,14)=0.49, p=0.497.
- There was a significant main effect of group membership on safety message recall (F (1,14)=21.03, p<0.001):Without regard to the amount of delay, medically at-risk subjects performed worse in the recall of safety information than controls.
- The interaction effect was non-significant (F (1,14)<1, p=0.936).

TABLE 3. Descriptive Statistics of Recall Scores in Experiment 1

Descriptive Statistics				
	Group	Mean	Std. Deviation	N
Delay Level 1 (shorter)	Controls	66.71	38.54	7
	Medically at-risk	14.78	24.24	9
	Combined	37.50	40.20	16
Delay Level 2 (longer)	Controls	76.14	31.84	7
	Medically at-risk	22.22	37.31	9
	Combined	45.81	43.72	16

FIGURE 4. Mean recall scores for each group under longer and shorter delay

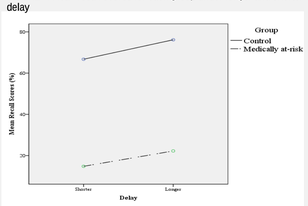
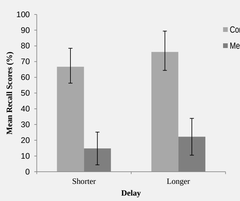


FIGURE 5. Error bars denoting one standard error around the mean of recall scores for each group under longer and shorter delay



Experiment 2

A 2x2 ANOVA tested for main effects of medical/health status (between-subjects variable) and level of demand for intervening driving tasks (within-subjects variable) on the recall of the safety message, and for a possible two-way interaction between these variables.

- On average, at Level 1 for intervening driving task demand (a steering task), recall scores were higher than recall scores in Level 2 (where a steering task was followed by a lane change contingent upon a discriminative stimulus).
- The effect of group membership on recall was non-significant (F (1,14)=0.48, p=0.499).
- Differences in recall performance associated with the level of intervening task demand were reliable (F (1,14) = 25.36, p<0.001): Disregarding group membership, subjects performed worse in the recall of safety information under a higher (Level 2) versus a lower (Level 1) level of driving task demand following message presentation.
- Interaction effect: While recall scores decreased for both groups in task demand Level 2 relative to Level 1, they dropped more sharply for the medically at-risk drivers; however, this interaction was not statistically significant (F (1,14)=1.24, p=0.285).

TABLE 5. Descriptive Statistics of Recall Scores in Experiment 2

Descriptive Statistics				
	Group	Mean	Std. Deviation	N
Demand Level 1	Controls	76.14	31.84	7
	Medically at-risk	70.44	42.30	9
	Combined	72.94	36.99	16
Demand Level 2	Controls	57.29	16.59	7
	Medically at-risk	40.89	32.57	9
	Combined	48.06	27.32	16

FIGURE 6. Mean recall scores for each group with varying levels of task demand.

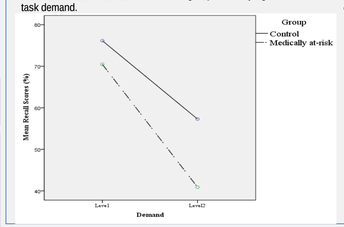
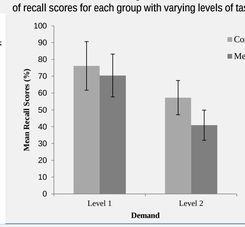


FIGURE 7. Error bars denoting one standard error around the mean of recall scores for each group with varying levels of task demand



Conclusions

- **First experiment**: Drivers with neurological disease have increased difficulty when attempting to recall safety information presented to them for only a limited time (e.g., as viewed on a sign) while driving. There was a significant main effect of medical/health status on the recall of safety information presented on a sign in this experiment, with the medically at-risk subjects performing worse than controls; at the same time, a longer versus shorter delay before message recall had no significant effect on message recall for either group.
- **Second experiment**: When drivers with or without neurological disease are faced with increased demands for operational/tactical driving tasks, their ability to recall safety information presented to them for only a limited time is diminished. A statistically significant main effect for task demand was found which had an inverse impact on recall performance across both groups of study participants. Further, increasing the level of driving task demand between message presentation and recall resulted in a disproportionally greater drop in recall performance for the medically at-risk group compared to the controls, although this effect was not statistically significant.
- The results from this small sample study are encouraging with regard to the use of a fixed-base driving simulator to identify performance differences related to medical conditions that have clear implications for fitness-to-drive.
- These conclusions are tentative, given the various limitations noted below.

Study Limitations

Confounding factors

- The MAR drivers were not matched with controls with respect to age, gender, driving experience or driving exposure (kilometers driven per week); nor were results analyzed in relation to individual characteristics associated with driving competence.

Study design limitations

- Lack of precise control over the time the message was displayed to the subjects.
- The particular experimental condition did not resemble a usual driving situation (implications for the external validity of the experiment).

Other complications

- Important functional tests of vision (visual acuity, contrast sensitivity), visual cognition (UFOV) and motor performance were not available to characterize the functional status of the MAR and C study samples.
- Older drivers are more likely to experience simulator sickness.
- Driving skills that are overlearned by older persons are perhaps less likely to be manifested by individuals with cognitive impairment than by healthy controls under the artificial conditions of a simulator.

Future Work

- Our future research agenda will address these challenges:
  - ✓ Improved control over the time the safety message is displayed to each driver – a fixed interval (~8 sec) that is constant across subjects – at the beginning of each trial.
  - ✓ Application of models suitable for our discrete (categorical) data sets to analyze the combination of within and between-subjects variables, incorporating key covariates (e.g., driver age, individual differences in functional status).
- There is a need to analyze the extent to which performance differences may be attributed to actual differences in functional abilities of vision and cognition
- With an understanding of its limitations, we wish to demonstrate the practical value of such driving simulation in combination with functional-assessment batteries measuring physical, visual and cognitive abilities as one component of a multi-tiered system to evaluate medical fitness-to-drive