Can driving at the simulator "diagnose" cognitive impairments?

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Background

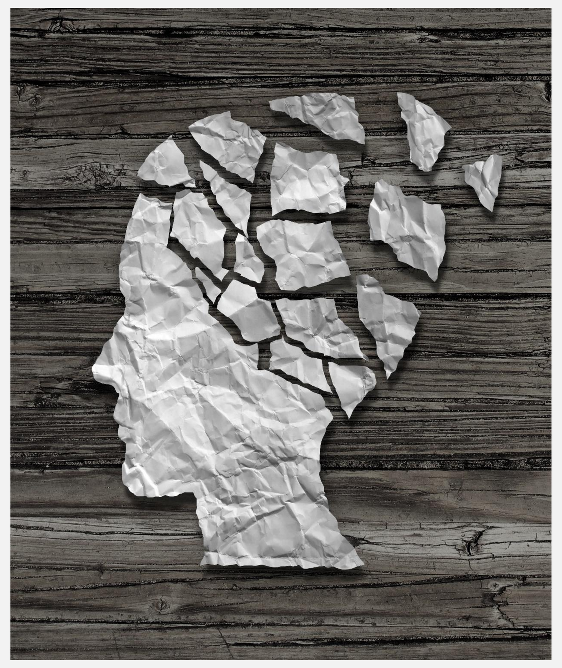
- Numerous studies associate cognitive impairments in the elderly with driving performance
- Particular focus has been placed on Alzheimer's disease (**AD**), and Mild Cognitive Impairment (**MCI**)
- Main purpose: to **assess fitness-to-drive** and identify **driving performance deficits and risks** due to the disease and the related cognitive impairments

Objectives

- In this paper, the question is reversed:

Can driving at the simulator assist in the screening for cognitive impairments, towards their diagnosis?

- In order to address this question, the simulated driving performance of 86 older drivers (healthy controls, MCI patients and AD patients) was associated with their clinical diagnosis, in order **to attempt to classify the drivers into healthy or cognitively impaired groups on the basis of their driving performance**.



Literature Review

- **Cognitive and driving impairments are strongly interrelated**, with critical impact on the mobility and quality of life of older individuals
- Results clearly establish that older drivers with cognitive impairments (MCI or AD) may:
  - drive at - often dangerously - lower speeds,
  - have difficulty in positioning the vehicle on the lane and maintaining that position,
  - have slower reaction time at unexpected events,
  - be more vulnerable to complex driving environments and
  - be more affected by in-vehicle or external distraction,
  - conduct more driving errors and unintentional traffic violations etc.
- However, they are often capable of **self-regulating**, and their driving impairments are partly balanced by their **reduced exposure**.

- There is strong need **for identifying sensitive tools** to measure cognitive and functional changes **in the early stages of the disease**.
- A driving simulation test, although often criticized for lack of fidelity, **might provide more detailed information on the types and importance of driving errors and could be repeated in other settings and with other samples**.

Data Collection

- This research was implemented by **an interdisciplinary team** including transportation engineers, neurologists and neuropsychologists.
- The study was approved by the **Ethics Committee of the "ATTIKON" University General Hospital**.
- All participants were recruited among patients of the 2nd Department of Neurology of the University of Athens Medical School at ATTIKON University General Hospital, Greece

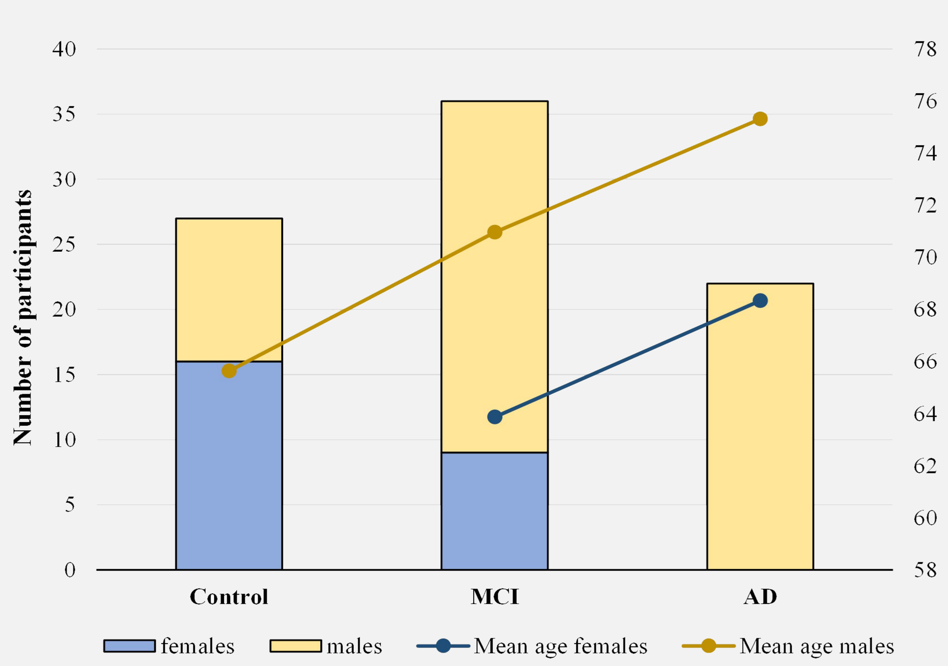


Figure 1 Sample size, gender and age of MCI, AD and healthy controls

Sampling frame

- **86 individuals >55 years old**:
  - 27 healthy controls,
  - 38 MCI patients
  - 21 AD patients
- **59 males and 25 females**.
- The mean age of the control group was 65 years, while for the MCI and the AD groups the mean age was 70 and 75 years respectively.
- **Females had slightly lower mean age in all groups**, with the same general trend of increasing age with the presence of pathology (Fig. 1).

*The distributions of gender and age groups in this sample **are representative of the prevalence of these pathologies in the general population**.*

Driving simulator assessment

- **Quarter-cab driving simulator** manufactured by the FOERST Company

- **1 practice drive** (usually 10-15 minutes)
- Afterwards, the participant drives **two sessions** (approximately 15 minutes each)

- Each session corresponds to a different road environment:
  - **a rural route** (2.1 km long), single carriageway, zero gradient, mild horizontal curves
  - **an urban route** (1.7km long), dual carriageway, separated by guardrails. Two traffic controlled junctions, one stop-controlled junction and one roundabout along the route.
- **2 traffic scenarios** examined:
  - Low traffic conditions (Q=300 vehicles/hour)
  - High traffic conditions (Q=600 vehicles/hour)
- **3 distraction conditions** for each route:
  - Undistracted driving
  - Driving while conversing with a passenger
  - Driving while conversing on a hand-held mobile phone
- During each trial, **2 unexpected incidents are scheduled to occur**:
  - sudden appearance of an animal (deer or donkey) on the roadway, and
  - sudden appearance of a child chasing a ball on the roadway.

- Within the framework of this research, **the driving data of the rural area, low traffic and undistracted conditions are used for the analysis**, being the least demanding condition in terms of road environment and participants' mental workload.

Research hypotheses

- **A "conservative" hypothesis:** the simulator may be a screening tool for the **presence of cognitive impairments in general**, so that further medical and neuropsychological tests may diagnose a specific pathology.
- **A more ambitious hypothesis:** driving at the simulator may identify different pathologies.

Discriminant Analysis

- A discriminant analysis **uses a linear combination of predictors** that separates two or more classes of individuals, and explicitly models the difference between the classes.
- Discriminant analysis **is broken into a 2-step process**: first, testing significance of a set of discriminant functions, and second, classification of individuals.

- The discriminant function score for the i^{th} function is: $D_i = \sum_{i=1}^{p} d_i Z_i$ (1)
- For unequal sample sizes n_j in each group the classification function has the following form: $C_j = c_{j0} + \sum_{i=1}^{p} c_{ij} x_i + \ln\left(\frac{n_j}{N}\right)$ (2)

The medical diagnosis was used as the dependent variable and the simulator driving measures were used as independent variables.

Results

Identification of cognitive impairments (conservative hypothesis)

- The only variables that significantly distinguished impaired from controls were **age and reaction time**.
- The simulator metrics did not add to the identification of cognitive impairments (reaction time is measured by several neuropsychological tests).

Identification of MCI or AD patients (ambitious hypothesis, Table 1)

- The dependent variable here had three groups (controls, MCI, AD).
- The variables most likely to discriminate groups are: **speed, gearbox position, mean headway, reaction time, accident occurrence and age.**

Table 1 MANOVA for the simulator metrics

	Wilks' Lambda	F	df	p-value
Age	,761	13,042	2	,000*
AverageSpeed	,870	6,184	2	,003*
StdevAverageSpeed	,961	1,666	2	,195
LateralPositionAverage	,968	1,378	2	,258
StdLateralPosition	,948	2,286	2	,108
GearAverage	,840	7,909	2	,001*
StdGearAverage	,974	1,089	2	,341
RpmAverage	,999	,059	2	,942
StdRpmAverage	,998	,069	2	,934
HWayAverage	,910	4,093	2	,020*
WheelAverage	,987	,555	2	,576
StdWheelAverage	,990	,399	2	,672
EngineStops	,973	1,158	2	,319
HitOfSideBars	,997	,114	2	,892
OutsideRoadLines	,974	1,095	2	,339
SuddenBrakes	,957	1,874	2	,160
SpeedLimitViolation	,972	1,214	2	,302
HighRoundsPerMinute	,994	,255	2	,775
ReactionTime 1	,781	11,634	2	,000*
Acc.Prob.1	,906	4,314	2	,017*

Results (cont.)

Table 2 presents **the discriminant functions coefficients and the respective structure matrix**, interpreted in the same way that factor loadings are interpreted in a factor analysis:

- age, average speed, gearbox position, reaction time and accident occurrence at incidents are strongly correlated with discriminant function 1,
- mean headway and lateral position variability are strongly correlated with discriminant function 2.

Classification results are presented in Table 3.

Table 2 Canonical discriminant function coefficients (left panel) and structure matrix (right panel)

Variables	Coefficients		Correlations (structure matrix)	
	Function 1	Function 2	Function 1	Function 2
Age	0,492	-0,844	,645*	-0,546
AverageSpeed	-0,497	-0,348	,636*	0,156
GearAverage	-0,293	-0,035	-,525*	-0,116
ReactionTime 1	0,396	0,008	-,465*	-0,025
Acc.Prob.1	0,103	0,544	,379*	0,023
HWayAverage	-0,138	0,048	0,353	,442*
StdLateralPosition	0,268	0,644	0,231	,440*

Table 3. Original vs. predicted group membership classification results

		Diagnosis	Predicted: Control group	Predicted: MCI	Predicted: AD	Total
Original	Count	Control group	18	8	1	27
		MCI	10	26	2	38
		AD	1	8	12	21
	%	Control group	66,7	29,6	3,7	100
		MCI	26,3	68,4	5,3	100
		AD	4,8	38,1	57,1	100

Cross-validation

- **First cross-validation step**: a leave-one-out classification, the discriminant function estimated on the basis of all other cases except one.

- **In the second step**, the sample was split in two parts on the basis of a random (Bernoulli) case selection process: a part of the sample (70%) was selected for developing the model, while the remaining 30% was kept for prediction on the basis of the model developed.

Table 4 Model cross-validation - Original vs. predicted group membership classification results - leave-one-out classification (top panel), unselected cases (top panel).

Observed		Diagnosis	Predicted: Control group	Predicted: MCI	Predicted: AD	Total
Leave-one-out cross-validation*	Count	Control group	16	10	1	27
		MCI	10	24	4	38
		AD	1	10	10	21
	%	Control group	59,3	37	3,7	100
		MCI	26,3	63,2	10,5	100
		AD	4,8	47,6	47,6	100
Unselected cases**	Count	Control group	3	2	0	5
		MCI	4	6	4	14
		AD	0	4	2	6
	%	Control group	60	40	0	100
		MCI	28,6	42,9	28,6	100
		AD	0	66,7	33,3	100

*.Each case is classified by the functions derived from all cases other than that case.

**. 30% of the initial sample not used to derive the functions.

Discussion - Conclusions

- The results of the discriminant analysis **did not support the conservative hypothesis**.
- The more ambitious analysis attempting to discriminate between MCI and AD pathologies surprisingly resulted in more robust models and satisfactory classification of individuals.
- The classification results are encouraging (**correctly "diagnosed" nearly 65% of the cases**), but they lead to returning to the conservative hypothesis:
- The misclassification occurs almost exclusively **between "neighboring" groups** (MCI classified as AD, healthy classified as MCI).
- Driving performance measures that can successfully classify drivers are average speed, headways, lateral position variability, reaction time, accident occurrence at incidents, and gearbox position.

The model may be most useful for a general classification in cognitively impaired or not, with an indication of specific pathology.

- There is promising indication that **the simulator may be used as a "neuropsychological tool"** revealing the presence of cognitive impairments and might have a two-fold added value:
  - to assist clinicians in the screening and examination process
  - To assist clinicians in the provision of more targeted and substantiated advice as regards driving.

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