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Results from a driving simulator study on performance of drivers with cerebral diseases in rural roads

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Introduction

- Driving requires sufficient cognitive, visual and motor skills
- Adequate motor strength, speed and coordination
- Higher cognitive skills including concentration, attention, adequate visual perceptual skills, insight and memory
- Ability to receive sensory information, process the information, and to make proper, timely judgments and responses
- The ability to drive can be affected by various motor, visual, cognitive and perceptual deficits, either age-related or caused by neurologic disorders
- Diseases affecting a person's brain functioning (e.g. Alzheimer's disease, Parkinson's disease, Cerebrovascular disease, Mild Cognitive Impairment)

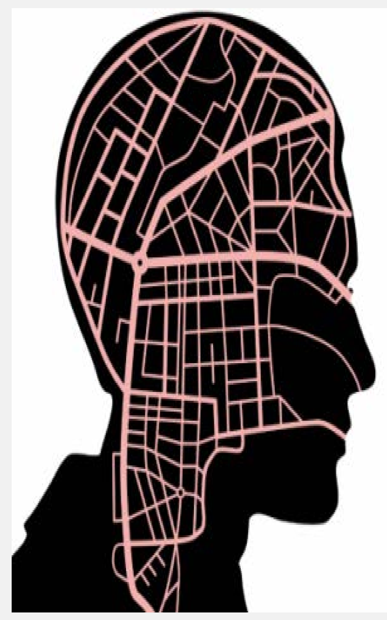
Objectives

The main objective of this study is to **analyze the driving performance of drivers with cerebral diseases by means of a driving simulator experiment**.

The cerebral diseases examined are:

- Alzheimer's disease (AD)
- Parkinson's Disease (PD)
- Mild Cognitive Impairment (MCI)

The driving performance of drivers impaired by the above pathologies is compared to that of healthy controls by means of repeated measures ANOVA techniques.



Overview of the experiment

Within this research, a large driving simulator experiment is carried out, common for two research projects:

✓The **DriverBrain** research project (http://www.nrso.ntua.gr/driverbrain/), entitled "Analysis of the performance of drivers with cerebral diseases", concerning drivers with Alzheimer's disease, Parkinson's disease, Cerebrovascular disease - both in their MCI (pre-dementia) stages, but also in their mild dementia stages.

✓The **DISTRACT** research project (http://www.nrso.ntua.gr/distract/), entitled "Analysis of causes and impacts of driver distraction", concerns endogenous and exogenous causes of driver inattention and distraction.

The experiment was designed and is carried out by an **interdisciplinary research team** consisting of:

✓Transportation Engineering of the Department of Transportation Planning and Engineering, of the National Technical University of Athens (NTUA)

✓Neurologists of the 2nd Department of Neurology, University of Athens Medical School, at Attikon University General Hospital, Athens

✓Neuropsychologists of the Department of Psychology, University of Athens, the 2nd Department of Neurology of Attikon University General Hospital, Haidari, Athens and the Aristotle University of Thessaloniki.

The experiment includes **three types of assessment**:

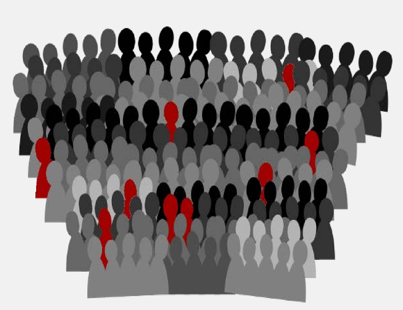
✓Medical / neurological assessment

✓Neuropsychological assessment

✓Driving at the simulator

Sampling scheme

- one group of participants with **a cerebral pathological condition** (AD, MCI or PD), explicitly selected by the neurology / neuropsychology research teams
- one **"control"** group of participants with no known pathological condition.
- A sample of at least 175 participants with a pathological condition is to be examined in approximately 2 years time and a similar control group of another 125 participants with no known pathological condition, of the same age groups.
- Currently, 39 participants (22 impaired) have gone through all assessments



Medical, Neurological & Neuropsychological Assessment

Medical, clinical and neurological evaluation including up to 16 exams:

✓a thorough neurological examination
✓ detailed background history
✓existence of disorders (e.g. AD, PD, Cerebrovascular Disease, MCI)
✓a full assessment of motor, cerebral and sensory systems and cranial and peripheral nerves.
✓clinical assessment of higher cortical functions (memory, language, attention, executive functions, perception) as well as behavioral and emotional state is conducted
✓a laboratory evaluation including blood tests, biochemistry, neuroimaging (Cerebral MRI or CT scan) and Electroencephalography (as needed).

Neuropsychological evaluation (up to 19 tests) of the participants, with the use of appropriate tools:

✓visuospatial and verbal episodic and working memory
✓general selective and divided attention
✓reaction time
✓processing speed
✓psychomotor speed

Driving at the simulator

The driving simulator experiment takes place in the NTUA Road Safety Observatory, where the Foerst Driving Simulator FPF is located. (quarter-cab Simulator and support motion base).

- Practice drive (15-20 minutes)
- **Two road environments:**

✓A rural route that is 2.1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves.
✓An urban route that is 1.7km long, at its bigger part dual carriageway, separated by guardrails, lane width is 3.5m. narrow sidewalks, commercial uses and parking at the roadsides. Two traffic controlled junctions, one stop-controlled junction and one roundabout.

- **Two traffic scenarios**:

✓Q_M: Moderate traffic conditions - ambient vehicles' arrivals are drawn from a Gamma distribution with mean m=12sec, and variance σ^2=6 sec, corresponding to an average traffic volume Q=300 vehicles/hour.
✓Q_H: High traffic conditions - ambient vehicles' arrivals are drawn from a Gamma distribution with mean m=6sec, and variance σ^2=3 sec, corresponding to an average traffic volume of Q=600 vehicles/hour.

- **Three distraction conditions:**

✓undistracted driving
✓driving while conversing with a passenger and
✓driving while conversing with a mobile phone.

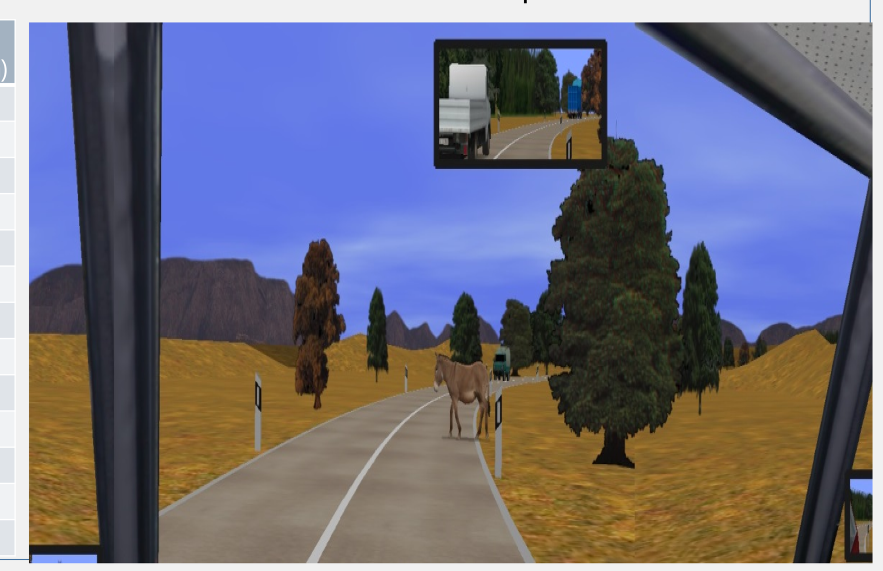
- **Two unexpected incidents** are scheduled to occur at fixed points along the drive :

✓in rural area sudden appearance of an animal (deer or donkey) on the roadway
✓in urban areas the sudden appearance of an adult pedestrian or of a child chasing a ball on the roadway.

- **Two driving sessions** (urban and rural) includes up to six trials each, in total.

✓full factorial within-subject design
✓counterbalanced between and within session-trials on the basis of 12 combinations of the parameters of interest.

Session	Area Type	Trial	Traffic	Distractor	~ Length (Km)	~ Duration(Min)
1	Urban	1	Moderate	None	1,7	3:30
		2	High	None	1,7	3:30
		3	Moderate	Cell Phone	1,7	3:30
		4	High	Cell Phone	1,7	3:30
		5	Moderate	Conversation	1,7	3:30
		6	High	Conversation	1,7	3:30
2	Rural	7	Moderate	None	2,1	3:30
		8	High	None	2,1	3:30
		9	Moderate	Cell Phone	2,1	3:30
		10	High	Cell Phone	2,1	3:30
		11	Moderate	Conversation	2,1	3:30
		12	High	Conversation	2,1	3:30
				Total	22,8	42:00



Analysis Methods and Data

Two trials of the simulator experiment are selected:

✓the undistracted driving at **low traffic volume for the rural road** and

✓the undistracted driving at **high traffic volume for the rural road** - the existing sample is too small for including additional parameters (e.g. area type, distractors etc.).

- **39 participants (27 males):** 17 healthy "controls" (48 years old on average), 15 AD and MCI patients (72 years old on average and 7 PD patients (63 years old on average).
- The variables examined in the present research include a **between-subject variable**, namely the presence of a cerebral disease (AD and MCI pathologies are for the moment grouped together)
- They also include **two within-subject variables**, namely the traffic scenario (low or high traffic volume) and the unexpected event number.
- The analysis method is the **Repeated Measures General Linear Model** (GLM).

Driving performance measures

✓**Longitudinal control measures**: mean speed, Speed variability (the standard deviation of speed), mean Headway (in seconds), driver reaction time at unexpected incidents (in milliseconds), as well as the gear in use (from 0: idle to 6: reverse) and the motor revolutions per minute.

✓**Lateral control measures**: Lateral position (vehicle distance from the central road axis in meters), Lateral position variability (the standard deviation of lateral position), the mean wheel steering angle (in degrees) and the Steering angle variability (the standard deviation of steering angle).

TABLES 1, 2. Parameter estimates of the repeated measures GLM - Longitudinal and lateral control measures

	Dependent Variable		Low traffic B	Low traffic p-value	High traffic B	High traffic p-value
Longitudinal driving performance measures	Mean speed (km/h)	Intercept	51.998	.000**	47.039	.000**
		AD or MCI	-7.580	.083*	-5.865	.021**
		PD	-9.699	.091*	-9.200	.007**
		Control	0	.	0	.
	Speed variability (st.dev. of speed - km/h)	Intercept	15.580	.000**	12.703	.000**
		AD or MCI	-0.460	.826	-0.289	.839
		PD	-1.471	.593	-0.897	.631
		Control	0	.	0	.
	Mean headway (sec)	Intercept	349.446	.000**	112.322	.002**
		AD or MCI	90.570	.164	124.547	.015**
		PD	152.454	.078*	218.768	.002**
		Control	0	.	0	.
	Gear in use (0:idle - 6:reverse)	Intercept	3.241	.000**	3.128	.000**
		AD or MCI	-0.741	.003**	-0.747	.002**
		PD	-0.068	.821	-0.361	.230
	Revolutions per minute	Intercept	2821.517	.000**	2782.417	.000**
		AD or MCI	408.329	.139	473.149	.081*
		PD	-449.856	.212	-285.545	.412
		Control	0	.	0	.
			Event #1			
	Reaction time (millisec)	Intercept	1441.083	.000**	1766.083	.000**
		AD or MCI	285.667	.422	121.750	.733
		PD	356.717	.442	-2.083	.996
		Control	0	.	0	.
			Event #2			
		Intercept	1549.583	.000**	1621.833	.000**
		AD or MCI	424.000	.237	634.917	.095*
		PD	-112.983	.807	615.167	.210
		Control	0	.	0	.

* significant at 90%, ** significant at 95%

	Dependent Variable		Low traffic B	Low traffic p-value	High traffic B	High traffic p-value
Lateral driving performance measures	Lateral position (m)	Intercept	1.543	.000**	1.658	.000**
		AD or MCI	-0.030	.569	0.000	.997
		PD	-0.115	.100*	-0.119	.056*
		Control	0	.	0	.
	Lateral position variability (st.dev of lateral position - m)	Intercept	0.331	.000**	0.269	.000**
		AD or MCI	0.015	.631	0.004	.831
		PD	-0.004	.930	0.024	.371
		Control	0	.	0	.
	Steering angle (degrees)	Intercept	-2.049	.000**	-2.209	.000**
		AD or MCI	-0.352	.300	0.065	.743
		PD	0.902	.049**	-0.210	.419
		Control	0	.	0	.
	Steering angle variability (st.dev of steering angle - degrees)	Intercept	18.416	.000**	17.821	.000**
		AD or MCI	-0.255	.787	-0.451	.467
		PD	0.167	.893	-0.713	.383
		Control	0	.	0	.

* significant at 90%, ** significant at 95%

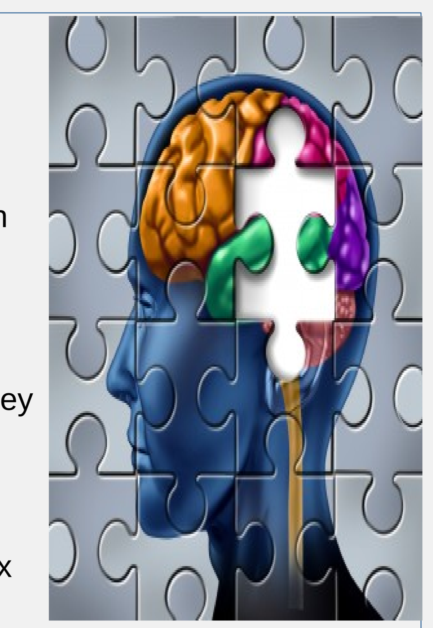
Longitudinal control measures - Results

- AD and MCI patients drive at **significantly lower mean speed** compared to healthy drivers, both at low and high traffic volumes.
- PD patients drive at even lower mean speed compared to healthy drivers both at low and high traffic volumes.
- AD and MCI patients have significantly **higher mean headway** compared to healthy drivers at high traffic volumes. PD patients have even higher mean headway compared to healthy drivers, both at low and at high traffic volumes.
- AD and MCI patients were found to **drive with lower gear** compared to healthy drivers, in fact with almost one gear lower compared to healthy drivers. As a consequence, the motor revolutions per minute of AD and MCI patients' driving **are significantly higher** compared to healthy drivers' (although the effect is significant at 90% confidence level only in urban areas).
- Although the data suggest a tendency of impaired drivers to have **higher reaction times at events** than healthy drivers, no statistically significant relationship was established.

Lateral control measures - Results

- PD patients appear to drive **at lower distance from the central road axis** compared to healthy drivers, both at high and at low traffic volumes.
- Additionally, a significantly **higher mean steering angle** is observed for PD patients compared to healthy drivers - a positive mean steering angle means more counter-clockwise steering movements, which is in accordance with a lateral position closer to the central road axis.

Conclusions - Discussion



- Drivers with cerebral diseases were found to drive at significantly lower speeds and had increased headways, compared to the healthy control group drivers, both at low and at high traffic volume.
- PD patients drive at lower speeds and with larger headways compared to AD and MCI patients, both at low and at high traffic volumes.
- Mean speed and mean headway, appear to be the only driving performance measures for which a comparison between cerebral diseases can be carried out with the existing sample of drivers.
- AD and MCI patients appear to be less efficient in the use of the gearbox of the simulator vehicle; they drive at lower gear compared to healthy drivers, and consequently at increased motor revolutions per minute as well.
- It is possible that the cognitive workload of the simulated drive in these patients in particular is excessive, due to their memory and attention deficits, leading them to neglect the use of the gearbox and focus on observing the road and traffic environment.
- PD patients have difficulty in positioning the vehicle on the lane. This may be due to poorer visuospatial skills of PD patients compared to other drivers, as well as to the procedural learning deficits encountered with these patients. However, PD patients were not found to have difficulties in maintaining their lateral position.
- This research in progress is one of the few which attempt to compare different pathologies in terms of their effect on driving performance.
- From these results, it is not possible to conclude on which cerebral disease impairs driving performance to a larger extent. Nevertheless, there appear to be specific driving patterns corresponding to each one of the pathologies.
- The above results suggest that cerebral diseases may have considerable impact on longitudinal driving performance measures, but less identifiable impact on lateral driving performance measures.
- This may be partly attributed to the road geometric design of the simulated drive (undivided two-lane rural road with narrow lanes).
- Relatively small sample size and representativity of the sample also needs improvement.
- The above results are quite promising and it is likely that once a larger and more representative sample is available, the analysis may be enhanced (urban road environment, under distracted driving conditions, in conjunction with the medical, neurological and neuropsychological parameters of drivers).

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