Driving behaviour of drivers with Mild Cognitive Impairment and Alzheimer's Disease: A Driving Simulator Study

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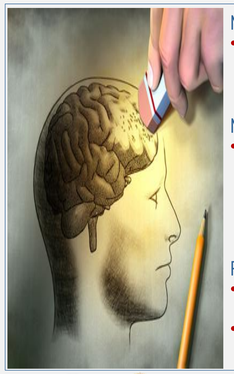
Introduction - Background

- The task of driving requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses.
- Various motor, visual, cognitive and perceptual deficits can affect the ability to drive and lead to reduced driver fitness and increased crash risk.
- More specifically, diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to neurological diseases as Alzheimer's disease) may significantly impair the person's driving ability.
- Neuropsychological parameters associated with driving performance are reaction time, visual attention, speed of perception and processing, and general cognitive and executive functions.
- These parameters show considerable decline with age or at the presence of cognitive impairments and are associated with the probability of accident involvement.



Main objective:

- Analyze the driving performance of drivers with Alzheimer's disease (AD) and Mild Cognitive Impairment (MCI), by means of a driving simulator experiment.

Methodology:

- Various driving performance measures are examined in both rural and urban environment and the driving performance of drivers impaired by the above pathologies is compared to that of healthy controls by means of Repeated Measures General Linear Modeling techniques.

Research questions:

- How MCI and AD affect various measures of driving performance
- How these diseases interact with road and traffic parameters.

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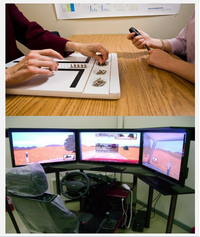
Driving simulator experiment

- Distract research project
- Neurologists - Medical/neurological assessment:
  - The first assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of these disorders.
- Neuropsychologists-Neuropsychological assessment:
  - The second assessment concerns the administration of a series of neuropsychological tests and psychological - behavioural questionnaires to the participants which cover a large spectrum of Cognitive Functions: visuospatial and verbal episodic and working memory, general selective and divided attention, reaction time, processing speed, psychomotor speed etc.
- Transportation Engineers - Driving at the simulator:
  - The third assessment concerns the driving behaviour by means of programming of a set of driving tasks into a driving simulator for different driving scenarios.



"Driving at the simulator" assessment

- quarter-cab driving simulator manufactured by the FOERST Company
  - 3 LCD wide screens 42" (full HD: 1920x1080pixels) - total field of view 170 degrees.
  - validated against a real world environment
- At first, one practice drive (usually 10-15 minutes)
- Afterwards, the participant drives two sessions (approximately 10 minutes each)
- Each session corresponds to a different road environment:
  - a rural route (2.1 km long), single carriageway, zero gradient, mild horizontal curves and
  - an urban route (1.7km long), at its bigger part dual carriageway, separated by guardrails. Two traffic controlled junctions, one stop-controlled junction and one roundabout are placed along the route.
- Two traffic scenarios examined:
  - Low traffic conditions (Q=300 vehicles/hour)
  - High traffic conditions (Q=600 vehicles/hour)
- Consequently, in total, each participant drives 4 trials of the simulated routes.
- During each trial, 2 unexpected incidents are scheduled to occur:
  - sudden appearance of an animal (deer or donkey) on the roadway (photo), and
  - sudden appearance of a child chasing a ball on the roadway or of a car suddenly getting out of a parking position and getting in the road.

Analysis data and methods

- Repeated Measures General Linear Model (GLM)
- 140 participants have participated in the experiment in 15 months time
- 30 eliminated due to simulator sickness issues
- 35 participants of age <55 years old eliminated too for age representativity reasons
- The analysis is thus based on 75 participants (49 males):
  - 38 healthy "controls" (mean age 66.4)
  - 14 AD patients (mean age 74.6)
  - 23 MCI patients (mean age 68.3)
- between-subject variable: the presence of a disease (AD or MCI)
- within-subject variables: the traffic scenario (low or high traffic volume).
- Driving performance measures examined:
  - Longitudinal control measures: Mean speed, Headway, Reaction time
  - Lateral control measures: lateral position and steering angle (+variability)

Results - Analysis of variance (Table 1)

- Traffic volume has a significant effect on mean speed, mean headway and lateral position in both road environments, whereas lateral position variability and steering angle variability only on rural road
- The presence of a cerebral disease affect mean speed and reaction time in both road environments
- The presence of a cerebral disease affect mean headway, lateral position variability and steering angle variability only in rural roads and lateral position only in urban road environment.

TABLE 1 Tests of within and between subjects in rural and urban road environment

	Rural Road				Urban Road			
	Tests of Within-Subjects Contrasts (Source Traffic)		Tests of Between-Subjects Effects (Source Disease)		Tests of Within-Subjects Contrasts (Source Traffic)		Tests of Between-Subjects Effects (Source Disease)	
	F	p-value	F	p-value	F	p-value	F	p-value
Mean speed (km/h)	17,292	,000**	24,634	,000**	20,327	,000**	6,000	,004**
Mean headway (sec)	69,665	,000**	14,218	,000**	9,569	,003**	,294	,746
Reaction time (millisec)	1,785	,186	2,828	,066*	,466	,498	2,656	,078 *
Lateral position (m)	106,116	,000**	,375	,689	5,690	,021**	2,552	,085 *
Lateral position variability	29,125	,000**	4,840	,011**	,430	,515	1,374	,262
Steering angle (degrees)	1,368	,246	,358	,701	,051	,823	,381	,685
Steering angle variability	9,586	,003**	3,435	,038**	,037	,849	,313	,732

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

Results-Repeated measures GLM - Longitudinal control measures (Table 2):

- AD and MCI patients drive at significantly lower mean speed compared to healthy drivers, both at low and high traffic volumes, in both rural and urban areas
- AD drivers' speed is significantly lower than MCI, in both traffic volumes in rural road, whereas in urban road the two groups have almost the same speed
- AD patients have significantly longer mean headway compared to healthy drivers (and compared to MCI group) at both traffic volumes in rural area
- MCI patients seem to have significantly longer mean headway compared to healthy drivers only at high traffic volume in urban road
- In both traffic environments impaired drivers have about 0.5 sec longer reaction times than the healthy ones in rural road
- Reaction times in urban road are improved for the impaired drivers

TABLE 2 Parameter estimates of the repeated measures GLM - Longitudinal control measures

		Rural Road								Urban Road							
Parameter Estimates		Low Traffic Volume				High Traffic Volume				Low Traffic Volume				High Traffic Volume			
Dependent Variable		B	Std. Error	t	Sig.	B	Std. Error	t	Sig.		Std. Error	t	Sig.	B	Std. Error	t	Sig.
Mean speed (km/h)	Intercept	47,9	1,2	39,7	,000**	45,3	1,0	45,6	,000**	33,7	0,9	37,5	,000**	30,4	0,7	43,9	,000**
	MCI	-6,1	2,0	-3,1	,003**	-6,2	1,6	-3,9	,000**	-4,9	1,7	-2,8	,007**	-3,7	1,3	-2,8	,007**
	AD	-14,0	2,3	-6,0	,000**	-13,4	1,9	-7,0	,000**	-4,4	2,4	-1,8	,079*	-4,6	1,9	-2,5	,017**
	Control	0				0				0				0			
Mean headway (sec)	Intercept	46,6	4,8	9,8	,000**	22,4	4,7	4,7	,000**	48,6	5,2	9,4	,000**	23,8	2,3	10,3	,000**
	MCI	12,4	7,8	1,6	,120	12,0	7,7	1,6	,123	7,5	9,9	0,8	,460	12,0	4,5	2,7	,009**
	AD	40,4	9,2	4,4	,000**	51,3	9,1	5,6	,000**	4,3	13,9	0,3	,760	7,3	6,3	1,2	,250
	Control	0				0				0				0			
Reaction time (millisec)	Intercept	923,1	154,0	6,0	,000**	996,3	159,1	6,3	,000**	1294,5	66,6	19,4	,000**	1284,2	63,0	20,4	,000**
	MCI	481,9	250,7	1,9	,059*	532,6	259,1	2,1	,043**	198,1	116,0	1,7	,092*	139,1	121,4	1,2	,260
	AD	580,3	296,7	2,0	,054*	446,4	266,7	1,7	,097*	296,2	165,7	1,8	,078*	209,7	170,5	1,2	,220
	Control	0				0				0				0			

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

Results - Repeated measures GLM - Lateral control measures (Table 3):

- There are no significant differences in lateral position except for high traffic volume in urban area where impaired groups drive at longer distance from the central road axis compared to healthy ones
- MCI drivers in rural area and AD drivers in high traffic volume in urban road have a significant increase in the variability of the lateral position
- Statistically significant differences are not observed for mean steering angle, or for the variability in the steering angle between control group and impaired drivers, except for the rural road and the high traffic volume for both impaired groups

TABLE 3 Parameter estimates of the repeated measures GLM – Lateral control measures

		Rural Road								Urban Road							
Parameter Estimates		Low Traffic Volume				High Traffic Volume				Low Traffic Volume				High Traffic Volume			
Dependent Variable		B	Std. Error	t	Sig.	B	Std. Error	t	Sig.		Std. Error	t	Sig.	B	Std. Error	t	Sig.
Lateral position (m)	Intercept	1,49	0,02	61,98	,000**	1,61	0,02	72,60	,000**	2,96	0,10	28,86	,000**	3,06	0,10	29,69	,000**
	MCI	0,03	0,04	0,75	,458	0,03	0,04	0,83	,410	0,31	0,18	1,76	,099*	0,33	0,19	1,76	,083*
	AD	0,01	0,05	0,22	,823	0,01	0,04	0,33	,744	0,17	0,28	0,62	,541	0,51	0,28	1,84	,071*
	Control	0,00				0				0				0			
Lateral position variability	Intercept	0,30	0,01	31,52	,000**	0,27	0,01	29,16	,000**	1,56	0,10	15,84	,000**	1,52	0,10	15,35	,000**
	MCI	-0,04	0,02	-2,33	,023**	-0,03	0,02	-1,82	,073*	0,21	0,19	1,11	,273	0,20	0,19	1,02	,312
	AD	0,02	0,02	1,31	,194	0,02	0,02	0,99	,324	0,17	0,27	0,64	,525	0,48	0,27	1,80	,078*
	Control	0,00				0				0				0			
Steering angle (degrees)	Intercept	-1,79	0,08	-21,99	,000**	-1,95	0,09	-21,68	,000**	6,97	0,20	34,37	,000**	7,34	0,29	24,96	,000**
	MCI	-0,10	0,13	-0,77	,444	0,23	0,15	1,57	,121	0,14	0,39	0,35	,729	-0,38	0,57	-0,67	,506
	AD	0,05	0,16	0,28	,777	-0,13	0,17	-0,76	,452	0,55	0,55	1,00	,324	0,20	0,80	0,25	,807
	Control	0,00				0				0				0			
Steering angle variability	Intercept	17,75	0,31	57,74	,000**	17,65	0,26	67,98	,000**	22,87	0,75	30,37	,000**	22,46	1,33	16,92	,000**
	MCI	-0,76	0,50	-1,51	,135	-1,09	0,42	-2,57	,012**	0,37	1,45	0,25	,801	1,65	2,56	0,64	,523
	AD	-0,51	0,59	-0,85	,397	-1,56	0,50	-3,11	,003**	-0,82	2,04	-0,40	,689	0,10	3,60	0,03	,978
	Control	0				0				0				0			

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

Conclusions -Discussion

- Summarizing the results, AD and MCI drivers were found to drive at significantly lower speeds compared to the healthy control group drivers in every examined condition
- AD drivers in rural environment have even lower mean speed compared to the MCI drivers, but in urban roads their speed is approximately the same
- This reduced speed results under given ambient traffic conditions in increased headways in rural roads, however in urban environment there are statistically significant differences in mean headways only for MCI drivers in high traffic volume
- MCI and AD drivers have significantly longer reaction times in rural road in both traffic volumes compared to the control group
- In urban area, they have longer reaction times, but only in low traffic volume this difference is significant
- MCI drivers have slightly better reaction times than the AD group in most cases
- MCI patients drive more closely to the right border of the road in urban area and in both traffic volumes, whereas AD drivers only in high traffic volume in urban area
- A significantly higher variability of the lateral position is highlighted for AD divers in high traffic volume in urban area
- The more complex is the driving environment the more the AD drivers have difficulty in maintaining the position of the vehicle on the lane
- In rural area impaired groups have low steering variability in high traffic volume that is a result of their conservative driving
- The age and gender distributions of the populations seem balanced at the present time, however sample representativity should be improved in the next steps of the ongoing experiment, in order to eliminate the possibility that the differences of the diving behaviour are a result of age distribution.

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