RESULTS FROM A DRIVING SIMULATOR STUDY ON PERFORMANCE OF DRIVERS WITH CEREBRAL DISEASES IN RURAL ROADS

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ABSTRACT

The objective of this research is the analysis of the driving performance of drivers with cerebral diseases on the basis of a driving simulator experiment. The cerebral diseases examined are Alzheimer's disease (AD), Parkinson's Disease (PD), and Mild Cognitive Impairment (MCI). A driving simulator experiment is carried out, in which healthy "control" drivers and impaired drivers drive in different driving scenarios, following a thorough neurological and neuropsychological assessment of all participants. The driving scenarios include driving in rural area in low and high traffic volumes. The driving performance of drivers impaired by the examined pathologies is compared to that of healthy controls by means of repeated measures ANOVA techniques. This paper analyses a subset of early results from a smaller sample, while a larger sample will be available from the study in progress. Various driving performance measures are examined, including speed, lateral position, steering angle, headway, reaction time at unexpected events etc., both in terms of their mean values and their variability. The results suggest that cerebral diseases do affect driving performance, and there are common driving patterns for all cerebral diseases, as well as particular characteristics of specific pathologies. More specifically, drivers with cerebral diseases drive at lower speeds and with larger headway compared to healthy drivers, an effect which is more pronounced within PD patients than AD and MCI patients. Moreover, AD and MCI patients appear to have difficulties in driving-related dual tasking, especially as regards the use of the gearbox. On the other hand, PD patients were found to have difficulties in positioning the vehicle on the lane. Cerebral diseases also appear to affect reaction times at incidents.

Key-words: cerebral diseases; driving performance; driving simulator.

BACKGROUND AND OBJECTIVES

Driving is a complex task that requires possessing sufficient cognitive, visual and motor skills. The driver must have adequate motor strength, speed and coordination. Perhaps more importantly, higher cognitive skills including concentration, attention, adequate visual perceptual skills, insight and memory need to be present. Higher cortical functions required for driving include strategic and risk taking behavioural skills, including the ability to process multiple simultaneous environmental cues in order to make rapid, accurate and safe decisions. The task of driving requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses (*1, 2*).

The ability to drive can be affected by various motor, visual, cognitive and perceptual deficits which are either age-related or caused by neurologic disorders. More specifically, diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to neurological diseases as Alzheimer's disease, Parkinson's disease, or Cerebrovascular disease) may significantly impair the person's driving ability (*3, 4, 5, 6*). Moreover, the effect of the pharmaceutical substances used for the treatment of various neurological and/or psychiatric disturbances may have positive or negative effects on driving performance.

Although these conditions have obvious impacts on driving performance, in mild cases and importantly in the early stages, they may be imperceptible in one's daily routine yet still impact one's driving ability. Furthermore, 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 and are associated with the probability of accident involvement (*7*).

Taking into account that the percentage of the elderly in society is increasing (*8*), while at the same time the level of motorization also increases (*9*), the need to investigate the impact of these conditions on driver performance becomes quite critical. It is also underlined that relatively few studies exist analyzing the effect of a specific pathology on driving performance, and even fewer studies comparing different pathologies.

Within this framework, the objective of this paper 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), and Mild Cognitive Impairment (MCI). Various driving performance measures are examined, e.g. speed, lateral position, steering angle, headway, reaction time at unexpected events etc. The driving performance of drivers impaired by the above pathologies is compared to that of healthy controls by means of repeated measures ANOVA techniques.

The paper starts with a review of studies on cerebral diseases and driving performance. Then, a large driving simulator experiment is presented, in which the driving performance of drivers with cerebral diseases and healthy drivers was examined in different driving scenarios, following a thorough neurological and neuropsychological assessment of all participants. The existing sample size and characteristics are presented next, followed by a short description of the analysis methods, dependent and independent variables. The results are presented and discussed, and some concluding remarks are provided.

REVIEW OF CEREBRAL DISEASES AND DRIVING PERFORMANCE

Mild Cognitive Impairment and Alzheimers Disease

Mild cognitive impairment (MCI) is a brain function syndrome involving the onset and evolution of cognitive impairments beyond those expected based on the age and education of the individual, but which are not significant enough to interfere with their daily activities. It is often found to be a transitional stage between normal aging and dementia. Although MCI can present with a variety of cognitive symptoms, MCI with memory loss is the most prevalent type. This type is well-known under the term "amnestic MCI" and typically represents the prodromal stage of Alzheimer's dementia.

In the early stages of Alzheimer's disease, the most common symptom is difficulty in remembering recent events (amnestic MCI). As the disease advances, symptoms can include confusion, behavioural disorders (e.g. irritability, aggression, mood swings), language deficits (e.g. naming difficulties), and long-term memory loss (*10*). The main factors affecting the driving ability and behaviour of AD patients are: age, dementia progress degree, education level, mental level, memory, and visuospatial perception. The most significant predictive cognitive factors concerning the accident risk and driving safety are: visuospatial perception, structure from motion, useful field of view, attention, visual processing and motor stimulation, mental level, memory (verbal and spatial), and executive functions (e.g. impaired judgment) (*11*).

Research results are not conclusive on the extent to which MCI is affecting driving behaviour and driving safety. MCI drivers seem to have statistically significant deviation, considering driving behaviour (maintaining speed, wheel stability, lane control), from the control driving population (*12*). Kawano et al. (*13*) tried to ascertain which cognitive features contribute to safe driving behaviour of MCI drivers. They drove using a driving simulator and seemed to have considerable difficulties in tracking a road and in following the vehicle ahead.

Dawson et al. (*14*) showed that AD drivers (especially the elderly) made many more safety errors (the most common errors were lane violations). Duchek et al. (*15*) provides longitudinal evidence for a decline in driving performance over time, primarily in early-stage dementia of the Alzheimer type. Mild AD significantly impaired simulated driving fitness, while MCI affected driving performance to a smaller extent (*6*).

Parkinson's disease

Parkinson's disease (PD) is a degenerative disorder of the central nervous system. Early in the course of the disease, the most obvious symptoms are movement-related. Later, cognitive and behavioural problems may arise, with dementia commonly occurring in the advanced stages of the disease, whereas depression is the most common psychiatric symptom. Other symptoms include sensory, sleep and autonomic deregulation.

The main factors affecting the driving ability and behaviour of PD patients are: age, notability and chronicity of disease, mobility problems (control of the wheel, reaction time), cognitive impairment (visuospatial skills, executive functions), dementia, excessive daytime sleepiness, and sudden onset of sleep. The most significant cognitive fields affecting the driving ability and behaviour of PD patients are: visual perception and memory, visuospatial perception, structure from motion, attention, and visual processing speed. Finally, the main factors determining the safe driving of PD patients are: cognitive abilities, motion function, ability to stay on alert, and self-perception of safe driving ability (*16*).

Meindorfner et al. (*17*) sent a questionnaire about sudden onset of sleep (SOS) and driving behaviour to 12.000 PD patients. Of the patients holding a driving license, 15% had been involved in and 11% had caused at least one accident during the past 5 years. The risk of causing accidents was significantly increased for patients who felt moderately impaired by PD.

DRIVING SIMULATOR EXPERIMENT

Overview

Within this research, a large driving simulator experiment is carried out, common for two research projects: the DriverBrain and the DISTRACT research project.

- The DriverBrain research project, 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, 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.

According to the objectives of the analysis, the experiment includes three types of assessment:

- Medical / neurological assessment: The first assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation.
- Neuropsychological assessment: The second assessment concerns the administration of a neuropsychological and psychological evaluation of the participants, with the use of appropriate tools.
- 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.

Sampling scheme

The sample of participants comprises two distinct groups: one group of participants with a cerebral pathological condition (AD, MCI or PD), explicitly selected by the neurology / neuropsychology research teams, and 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. Individuals older than 55 years are included with priority in the study, due to the increased likelihood of exhibiting such pathological conditions. A similar control group of another 125 participants with no known pathological condition, of

the same age groups should then be sufficient. Therefore, the sample of participants will total at least 300 individuals.

Medical, Neurological & Neuropsychological Assessment

The Medical / Neurological assessment concerns the administration of a full medical, clinical and neurological evaluation including a thorough neurological examination and taking of a detailed background history of all the participants, in order to identify the existence of disorders (e.g. Alzheimer's, Parkinson's, Cerebrovascular disease and the related MCI stages) as well as other related parameters of potential impact on driving (e.g. use of medication affecting the Central Nervous System). The medical and neurological assessment also includes a full assessment of motor, cerebral and sensory systems and cranial and peripheral nerves. During the medical interview a clinical assessment of higher cortical functions (memory, language, attention, executive functions, perception) as well as behavioral and emotional state is conducted. All patients have a comprehensive laboratory evaluation including blood tests, biochemistry, neuroimaging (Cerebral MRI or CT scan) and Electroencephalography (as needed).
The neuropsychological assessment concerns the administration of a neuropsychological and psychological evaluation of the participants, with the use of appropriate tools. The tests carried out cover a large spectrum of Cognitive Functions: visuo-spatial and verbal episodic and working memory, general selective and divided attention, reaction time, processing speed, psychomotor speed etc. More specifically, the following neuropsychological tests are administered to all participants:

- General Cognitive State tests: Mini Mental State Examination, MoCA (Montreal Cognitive Assessment)
- Other Cognitive screening tests: Clock Drawing Test, Semantic and Phonemic Fluency, Frontal Assessment Battery, Apraxia Examination
- Specific Cognitive Tests: Short-term & Working Memory (Letter-Number Sequencing (Wechsler Memory Scale -IV), Spatial Span (Wechsler Memory Scale-III)), Attention (Symbol Digit Modalities Test - Written & Oral, Neuropsychological Assessment Battery (NAB) – Driving Scenes Test, Useful Field of View (UFOV), Psychomotor Vigilance Test), Learning & Memory (Hopkins Verbal Learning Test, Brief Visuospatial Memory Test-Revised (BVMT)), Visual Perception (Judgment of Line Orientation-short form, Embedded Figure Test), Executive Functions (Wechsler Memory Scale-IV (WMS-IV) – Spatial Addition, Comprehensive Trail Making Test).

Driving at the simulator

The third type of assessment concerns the programming of a set of driving tasks into a driving simulator for different driving scenarios. The driving simulator experiment takes place in the NTUA Road Safety Observatory, where the Foerst Driving Simulator FPF is located. The Foerst GmbH is a DIN ISO 9001-certified company and this specific quarter-cab simulator has been manufactured by the FOERST Company in order to serve research purposes. The simulator consists of 3 LCD wide screens 40'', driving position and support motion base. The design of the driving scenarios is a central component of the experiment and includes driving in different road and traffic conditions, such as in a rural, urban area with high and low traffic volume, with or without external distraction.

The driving simulator experiment begins with one practice drive (usually 10-15 minutes), until the participant fully familiarizes with the simulation environment. Afterwards,

the participant drives two sessions (~20 minutes each). Each session corresponds to a different road environment:

- 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, and the lane width is 3.5m. Moreover, narrow sidewalks, commercial uses and parking are available at the roadsides. Two traffic controlled junctions, one stop-controlled junction and one roundabout are placed along the route.

Within each road / area type, two traffic scenarios and three distraction conditions are examined in a full factorial within-subject design. The traffic conditions examined include:

- Low 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.
- 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.

The distraction conditions examined concern undistracted driving, driving while conversing with a passenger and driving while conversing with a mobile phone.

Consequently, in total, each session (urban or rural) includes six trials, i.e. six drives of the simulated route. During each trial of the experiment, 2 unexpected incidents are scheduled to occur at fixed points along the drive (but not at the exact same point in all trials, in order to minimize learning effects). More specifically, incidents in rural area concern the sudden appearance of an animal (deer or donkey) on the roadway, and incidents in urban areas concern the sudden appearance of an adult pedestrian or of a child chasing a ball on the roadway. Due to the large number of parameters, 12 combinations of the parameters of interest were carefully selected and thus the experiment is counterbalanced concerning the number and the order of the trials on the basis of these combinations.

Impaired participants are to carry out the simulator experiment while under their usual medication, so that their driving performance corresponds to their everyday condition, as treated by their neurologist. This was particularly important with respect to PD patients, whose medication concern the treatment of motor deficits related to the disease.

ANALYSIS METHODS AND DATA

The present research aims to analyze and compare the driving performance of drivers with cerebral diseases. For that purpose, two trials of the simulator experiment are selected: the undistracted driving at low traffic volume and the undistracted driving at high traffic volume for the rural road, as the existing sample is too small for including additional parameters (e.g. area type, distracters etc.). Consequently, the driving performance of each of the participants (healthy or impaired) is recorded in two road and traffic scenarios.

The analysis method selected for type study is with the Repeated Measures General Linear Model (GLM). The repeated measures GLM (or repeated measures ANOVA) is the equivalent of the one-way ANOVA, but for related, not independent groups. A repeated measures GLM may be based on a within-subjects or a mixed design (*18*).

The analysis is based on the existing sample of the (ongoing) simulator experiment, which consists of 39 participants (27 males): 17 healthy "controls" (48 years old on average), 15 AD and MCI patients (72 years old on averageand 7 PD patients (63 years old on average). It is noted that the age and gender distributions of healthy and impaired drivers are currently not balanced: the proportion of females is slightly lower in the impaired drivers

group (which is in any case representative of the general population). Moreover, the impaired group drivers have slightly higher mean age than the healthy "controls" and this needs to be kept in mind in the interpretation of the results.

The variables examined in the present research include a between-subject variable, namely the presence of a cerebral disease. It is noted that AD and MCI pathologies are for the moment grouped together (as is often the case in existing studies with small samples). They also include two within-subject variables, namely the traffic scenario (low or high traffic volume) and the unexpected event number. The latter is only applicable in case the driver reaction time is examined.

The driving performance measures examined with respect to the cerebral diseases include both longitudinal control measures and lateral control measures (*19*). More specifically:

- Longitudinal driving performance 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 driving performance 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).

RESULTS

Effect of cerebral diseases on longitudinal measures of driving performance

A repeated measures general linear model was developed for each one of the driving performance measures considered. Within-subject variables were the traffic volume and the unexpected event number, while between-subject variable was the cerebral disease. The analysis of variance for the within subject variables indicated that traffic volume has a significant effect on mean speed ($F=15.5$, p-value=0.001), standard deviation of speed ($F=81.5$, p-value<0.001), and on mean headway ($F=9.2$, p-value=0.05). Moreover, the event number appears to have a significant effect on driver reaction time ($F=5.6$, p-value=0.026); reaction times were lower at the second event compared to those of the first event in both traffic scenarios. As regards the between-subject variable, the presence of a cerebral disease was found to significantly affect mean speed ($F=3.6$, p-value=0.04), mean headway ($F=4.4$, p-value=0.026), the use of the gearbox ($F=6$, p-value=0.07) and the motor revolutions ($F=3.4$, p-value=0.048).

The results of the GLMs fitted to the data for the various driving performance measures, in terms of parameter estimates and their statistical significance, are presented in Table 1.

Cerebral diseases appear to have a significant effect on driver mean speed. 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. It is also noticed that PD patients have practically equal and very low mean speed both at low and high traffic volumes. On the other hand, cerebral diseases were not found to have a significant effect on speed variability (i.e. the standard deviation of speed) in none of the conditions examined.

Moreover, cerebral diseases appear to have a significant effect on mean headway. 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. These results are intuitive, given that lower speeds naturally result in larger headways, with a given distribution of ambient traffic on the road network. It is also noted that headways at low traffic volumes are higher for all driver groups, which is also intuitive.

TABLE 1 Parameter estimates of the repeated measures GLM – Longitudinal driving performance measures

		Low traffic					High traffic				
Dependent Variable		**B**	**Std.Error**	**t**	**p-value**		**B**	**Std.Error**	**t**	**p-value**	
Mean speed (km/h)	Intercept	51,998	2,916	17,834	,000	**	47,039	1,656	28,404	,000	**
	AD or MCI	-7,580	4,208	-1,801	,083	*	-5,865	2,390	-2,454	,021	**
	PD	-9,699	5,532	-1,753	,091	*	-9,200	3,142	-2,928	,007	**
	Control	0	.	.	.		0	.	.	.	
Speed variability	Intercept	15,580	1,435	10,857	,000	**	12,703	0,974	13,038	,000	**
(st.dev. of speed - km/h)	AD or MCI	-0,460	2,071	-0,222	,826		-0,289	1,406	-0,205	,839	
	PD	-1,471	2,723	-0,540	,593		-0,897	1,849	-0,485	,631	
	Control	0	.	.	.		0	.	.	.	
Mean headway (sec)	Intercept	349,446	43,905	7,959	,000	**	112,322	33,280	3,375	,002	**
	AD or MCI	90,570	63,372	1,429	,164		124,547	48,036	2,593	,015	**
	PD	152,454	83,304	1,830	,078	*	218,768	63,145	3,465	,002	**
	Control	0	.	.	.		0	.	.	.	
Gear in use	Intercept	3,241	0,158	20,485	,000	**	3,128	0,155	20,194	,000	**
(from 0: idle to 6: reverse)	AD or MCI	-0,741	0,228	-3,244	,003	**	-0,747	0,224	-3,343	,002	**
	PD	-0,068	0,300	-0,228	,821		-0,361	0,294	-1,229	,230	
	Control	0	.	.	.		0	.	.	.	
Revolutions per minute	Intercept	2821,517	185,566	15,205	,000	**	2782,417	180,690	15,399	,000	**
	AD or MCI	408,329	267,841	1,525	,139		473,149	260,804	1,814	,081	*
	PD	-449,856	352,087	-1,278	,212		-285,545	342,836	-0,833	,412	
	Control	0	.	.	.		0	.	.	.	
		Event #1									
Reaction time (millisec)	Intercept	1441,083	247,681	5,818	,000	**	1766,083	249,653	7,074	,000	**
	AD or MCI	285,667	350,274	0,816	,422		121,750	353,063	0,345	,733	
	PD	356,717	456,701	0,781	,442		-2,083	460,337	-0,005	,996	
	Control	0	.	.	.		0	.	.	.	
		Event #2									
	Intercept	1549,583	247,955	6,249	,000	**	1621,833	259,332	6,254	,000	**
	AD or MCI	424,000	350,662	1,209	,237		634,917	366,750	1,731	,095	*
	PD	-112,983	457,207	-0,247	,807		615,167	478,184	1,286	,210	
	Control	0	.	.	.		0	.	.	.	

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

Significant differences in the driving behaviour of healthy and impaired drivers were also identified as regards the use of the gearbox. More specifically, 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).

Concerning the drivers' reaction time at unexpected incidents, an extended repeated measures design was design, on the basis of two factors: traffic volume (low / high) and event

number, given that two unexpected events occurred within each traffic scenario. 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. For example, the mean reaction time at the first event of the low traffic scenario was 1.46 sec for healthy drivers, 1.73 for AD and MCI patients and 1.94 for PD patients, while a similar pattern was observed in all other conditions as well. However, the difference was found to be statistically significant only for AD and MCI patients at the second event of the high traffic scenario (and only at 90% confidence level).

Effect of cerebral diseases on lateral measures of driving performance

A similar statistical analysis procedure was implemented with respect to the examined lateral measures of driving performance. Within-subject variable was the traffic volume and between-subject variable was the cerebral disease. The analysis of variance for the within subject variable indicated that traffic volume has a significant effect on mean lateral position (F=28.5, p-value=<0.001), on the standard deviation of lateral position (F=9.9, p-value=0.004), marginally on the mean steering angle (F=3.35, p-value=0.08) and on the standard deviation of the steering angle (F=5.1, p-value=0.033). The presence of a cerebral disease (between-subject variable) was found not found to significantly affect any of the lateral control measures examined at 90% confidence interval – although in a couple of cases this desirable confidence level was only marginally missed.

The results of the GLMs fitted to the data for these driving performance measures, in terms of parameter estimates and their statistical significance, are presented in Table 2.

TABLE 2 Parameter estimates of the repeated measures GLM – Lateral driving performance measures

Parameter Estimates		Low traffic					High traffic				
Dependent Variable		**B**	**Std.Error**	**t**	**p-value**		**B**	**Std.Error**	**t**	**p-value**	
Lateral position (m)	Intercept	1,543	0,035	43,532	,000	**	1,658	0,031	52,761	,000	**
	AD or MCI	-0,030	0,051	-0,577	,569		0,000	0,045	-0,003	,997	
	PD	-0,115	0,067	-1,705	,100	*	-0,119	0,060	-1,995	,056	*
	Control	0	.	.	.		0	.	.	.	
Lateral position	Intercept	0,331	0,022	15,049	,000	**	0,269	0,014	19,012	,000	**
variability	AD or MCI	0,015	0,032	0,486	,631		0,004	0,020	0,215	,831	
(st.dev of lateral position - m)	PD	-0,004	0,042	-0,088	,930		0,024	0,027	0,910	,371	
	Control	0	.	.	.		0	.	.	.	
Steering angle (degrees)	Intercept	-2,049	0,230	-8,896	,000	**	-2,209	0,135	-16,353	,000	**
	AD or MCI	-0,352	0,332	-1,058	,300		0,065	0,195	0,332	,743	
	PD	0,902	0,437	2,063	,049	**	-0,210	0,256	-0,821	,419	
	Control	0	.	.	.		0	.	.	.	
Steering angle	Intercept	18,416	0,647	28,466	,000	**	17,821	0,423	42,094	,000	**
variability	AD or MCI	-0,255	0,934	-0,273	,787		-0,451	0,611	-0,737	,467	
(st.dev of steering angle - degrees)	PD	0,167	1,227	0,136	,893		-0,713	0,803	-0,887	,383	
	Control	0	.	.	.		0	.	.	.	

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

It may be interesting to note that all the (few) statistically significant parameter estimates concern PD patients. In particular, 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. As a consequence, 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.

On the other hand, no statistically significant variability in the lateral control measures was observed for none of the cerebral diseases examined.

DISCUSSION

Summarizing the above results, drivers with cerebral diseases were found to drive at significantly lower speeds compared to the healthy control group drivers, both at low and at high traffic volume. As would be expected, this reduced speed results under given ambient traffic conditions in increased headways, both at low and at high traffic volumes. Moreover, PD patients drive at lower speeds and with larger headways compared to AD and MCI patients, both at low and at high traffic volumes.

These two measures, i.e. 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. However, several other driving performance measures were found to reveal particular characteristics of drivers with a specific cerebral disease.

More specifically, 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. It is noted that variables related to the use of the gearbox are often not included in the recommended driving performance measures e.g. speed, lateral position, reaction time etc. (*18*); however the above results suggest that these variables may be equally insightful as regards impaired drivers.

PD patients were found to have difficulty in positioning the vehicle on the lane, as they were found to drive significantly closer to the central road axis. 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. Interestingly, 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. All cerebral diseases considered appear to affect speed and headway. Nevertheless, there also appear to be specific driving patterns corresponding to each one of the pathologies, something which was not identified in previous studies.

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. It should be kept in mind, however, that this may be partly attributed to the road geometric design of the simulated drive: it may not be surprising that no lateral control variability was found in an undivided two-lane rural road with narrow lanes.

The small sample may be another reason for other effects not being identifiable. This may be the case for reaction time at unexpected events in particular. Although the data clearly suggest that drivers with cerebral diseases have higher reaction times at events than healthy drivers – a difference that was even detectable by merely observing drivers while driving at the simulator – no significant difference could be identified by the statistical analysis.

A final remark concerns the effect of the sample representativity; the age and gender distributions of the impaired and control populations are currently somewhat unbalanced. The larger proportion of female drivers in the control group may result in lower speeds in that group. On the other hand, the lower mean age of the control group may result in higher speeds in that group. Although it is most likely that the effects of cerebral diseases are stronger than the effects of age and gender, they need to be fully control for in the next steps of the analysis, once the sample size increases adequately.

CONCLUSIONS

This paper analysed the driving performance of drivers with cerebral diseases, with focus on the comparative assessment of AD, MCI and PD pathologies. Such comparative assessments are seldom available in the international literature. Two trials were selected from a large driving simulator experiment including twelve trials in total, namely those concerning undistracted driving in rural areas with low or high traffic volume. These two trials were based on a mixed (within- and between-subject) counterbalanced design, as was the entire simulator experiment. Both longitudinal and lateral driving performance measures are examined, e.g. speed, lateral position, steering angle, headway, reaction time at unexpected events etc. by means of repeated measures ANOVA techniques.

The main findings suggest that cerebral diseases do affect driving performance, and there are common driving patterns for all cerebral diseases, as well as particular characteristics of specific pathologies. More specifically, drivers with cerebral diseases drive at lower speeds and with larger headway compared to healthy drivers, an effect which is more pronounced within PD patients than AD and MCI patients. Moreover, AD and MCI patients appear to have difficulties in driving-related dual tasking, especially as regards the use of the gearbox. On the other hand, PD patients were found to have difficulties in positioning the vehicle on the lane. Cerebral diseases also appear to affect reaction times at incidents, although no statistically significant relationship could be established.

It is possible that the relatively small sample size does not allow for all potential effects of cerebral diseases on driving performance to be identified. The representativity of the sample also needs improvement. However, 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 in several ways.

In particular, the effect of cerebral diseases will also be examined in urban road environment, and under distracted driving conditions. At the same time, the medical, neurological and neuropsychological parameters of cerebral diseases will be more thoroughly examined and associated with driving performance measures.

Two final remarks may be outlined: first, these results are to be considered within the limiting context of driving simulator studies – driving performance is known to be more accurately and reliably estimated by means of on-road studies. However, the relative effects of impaired vs. healthy drivers are known to be quite identifiable in simulator studies. Second, the translation of driving performance measures to a driver safety context may be a most challenging question for further investigation. The driving patterns identified may correspond to more or less safe behaviours, and the integration of all these elements into a global driving performance assessment may be very complex.

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