Which are the effects of driver distraction and brain pathologies on reaction time and accident risk?

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Abstract

Driving is a complex task that requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses. Older drivers or drivers suffering brain pathologies may have deficits in their driving ability (motor, visual, cognitive or perceptual) and these deficits may lead to reduced driver fitness and increased accident probability. These particularities of impaired driver's behaviour and safety characteristics make the assessment of their driving ability a very challenging task especially regarding driver distraction which is an important cause of vehicle accidents. Especially in the elderly and people with brain pathologies, because of the degradation of cerebral function, they may be particularly vulnerable to the effects of distraction. The objective of this study is the analysis of reaction time and accident probability of drivers with cognitive impairments due to various brain pathologies, in combination with in-vehicle distraction, through a driving simulator experiment, which was carried out by an interdisciplinary research team of neurologists, neuropsychologists and transportation engineers. The driving scenario concerned driving in rural area, with and without distraction (conversation with passenger and mobile phone use). The brain pathologies examined include early Alzheimer's disease, Parkinson's disease, and Mild Cognitive Impairment. 140 participants (out of which 109 were patients) completed the experimental procedure. A statistical analysis was carried out by means of mixed generalized linear modelling and the results indicated significant differences between the driving performance of healthy drivers and patients. Patients with cerebral diseases reacted significantly slower at unexpected incidents than the healthy ones and were more likely to be involved in an accident. The mobile phone use had a significant negative effect on both reaction time and accident probability. Finally, effects of conversation with passengers were less pronounced, although several differences in driving behaviour and safety of group of patients were identifiable.

Keywords – brain pathologies, driver distraction, driving simulator, reaction time, accident risk

1. Introduction

1.1. General

Road accidents are considered to constitute a major social problem in modern societies around the world, accounting for more than 1.3 million fatalities per year worldwide (World Health Organization 2010 [1]). Although road traffic casualties presented a constantly decreasing trend during the last years, the number of fatalities in road accidents in several countries is still unacceptable and illustrates the need for even greater efforts with respect to better driving performance and increased road safety (OECD 2008 [2]). Driving is a complex activity, requiring several tasks to be performed simultaneously, and attention and perception are key determinants of the driving performance. This is not surprising, as complex driving situations require the simultaneous processing of numerous pieces of information and the taking of quick decisions. Unfortunately, the consequences of an error of judgment when driving can be major, even fatal.

A number of cerebral diseases may affect driving performance in the general population, particularly the elderly. Older drivers generally exhibit a higher risk of involvement in a road accident (Baldock et al. 2007 [3]). Simulated driving tasks have shown that older adults have greater difficulty in dividing attention than do younger adults (Brouwer et al. 1991 [4], Ponds et al. 1988 [5]). More specifically, diseases affecting a person's brain functioning may significantly impair the person's driving performance, especially when unexpected incidents occur (Wood et al. 2005 [6], Cordell et al. 2008 [7], Cubo et al. 2009 [8], Frittelli et al. 2009 [9]). For example, Mild Cognitive Impairment (MCI), which is considered to be the predementia stage of various types of dementia, is a common clinical condition that may be observed in about 16% of individuals over 64 years old in the general population (Ravaglia et al. 2008 [10]), a percentage that increases further if individuals with mild dementia are also included. Recent studies suggest that MCI is associated with impaired driving performance to some extent (Frittelli et al. 2009 [9]), as it is characterized by attentional and functional deficits, which are expected to affect the driver’s ability to handle unexpected incidents. Regarding Alzheimer’s disease, research findings indicate that individuals may show visual inspection and target identification deficits during driving (Uc et al. 2005 [11]). Moreover, the associated impairment in executive functions appears to have a significant effect on driving performance (Tomioka al. 2009 [12]), especially at unexpected incidents. Studies regarding Parkinson disease are less conclusive in terms of the impact of its clinical parameters on driving abilities (Cordell et al. 2008 [7], Cubo et al. 2009 [8]).

Although these conditions have obvious impacts on driving performance, in the very early stages, they may be imperceptible in one’s daily routine yet still impact one’s driving ability. Useful information can be obtained by sensitive neuropsychological tasks that are significantly associated with driving performance, both in the general population and in clinical groups. Popular measures reflect reaction time, visual attention, speed of perception and processing, general cognitive state and executive functioning. The tasks with the highest sensitivity to driving performance involve speed of visual processing, especially as measured by the Useful Field of View test (UFOV), attention (e.g. selective attention, divided attention, etc.) and executive functions (Bieliauskas 2005 [13], de Raedt et al. 2000 [14], Mathias et al. 2009 [15], Weaver et al. 2009 [16]). These tasks show considerable decline with age and are associated with the probability of accident involvement (Clay et al. 2005 [17], Lunsman et al. 2008 [18]), especially while being distracted.

1.2. Driver distraction

Human factors in total are considered to be the basic causes in 65-95% of road accidents (Sabey & Taylor 1980 [19], Salmon et al. 2011 [20]). Driver impairment or distraction factors appear to account for 12% of all road accident contributory factors, while in-vehicle distraction factors account for 2/3 of the total distraction factors (Department for Transport 2008 [21]). Driver distraction is therefore estimated to be an important cause of vehicle accidents. Although driver distraction can be considered as part of everyday driving, the penetration of various new technologies in the vehicle, and the expected increase of use of such technologies in the next years, makes the investigation of their influence on the behaviour of drivers and on road safety very essential (Olsen 2005 [22]).

There is a lack of consensus in the literature about what is meant by the terms “driver inattention” and “driver distraction”. Definitions of these two constructs, and thinking about the relationship between the two, vary enormously. The term distraction has been defined as “a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver’s awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes” (Hedlund et al. 2006 [23]). On the other hand, very few definitions of driver inattention exist in the literature, and those that do, like driver distraction, vary in meaning. Lee et al. (2008) [24], for example, define driver inattention as “diminished attention to activities critical for safe driving in the absence of a competing activity”. Regan et al. (2011) [25] summarise this discussion and suggest that: “Driver Inattention” means insufficient or no attention to activities critical for safe driving and “Driver distraction” is just one form of driver inattention, with the explicit characteristic of the presence of a competing activity.

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Several studies have examined the effect of external distraction sources that may attract the driver’s attention during the driving task. The results suggest that, although these sources do attract the driver's attention (e.g., in terms of eye glances towards the source of distraction), neither the drivers’ behaviour (e.g., in terms of speeding), nor safety are significantly affected. On the other hand, significant factors impacting driving performance and safety have been associated with in-vehicle sources of distraction, on which particular emphasis was put in the recent years. These include the use of a mobile phone or a navigation / recreation system, discussing with another passenger, smoking, eating or drinking etc. (Strayer et al. 2003 [26], Johnson et al. 2004 [27], Lesch & Hancock 2004 [28], Neyens & Boyle 2008 [29], Bellinger et al. 2008 [30], Yannis et al. 2010 [31]), and have been found to potentially influence both driver behaviour (e.g. in terms of driver speed, lateral position and headways) and road safety (e.g. in terms of reaction times and accident probability).

Hancock et al. (2003) [32] showed that the stopping accuracy of older drivers deteriorated statistically significantly more than that of younger drivers when exposed to the distracting effect of cellular phones. In addition, it was shown recently that the presence of passengers was associated with a reduced risk of some unsafe actions (e.g., driving on the wrong side of the road), but an increased risk of other unsafe actions (e.g., ignoring signs). These difficulties may explain why older drivers are often not aware of potential dangers while driving (Hakamies-Blomqvist 1993 [33]) and why deficits in attention and visuospatial ability are associated with poorer on-road driving test results (Hunt et al. 1993 [34], Richardson & Marottoli 2003 [35]) and with crashes (Ball et al. 1993 [36]).

1.3. Driver distraction and brain pathologies

According to the review on the interaction between cerebral diseases (MCI, Alzheimer’s, Parkinson’s etc.) and driver distraction, the majority of the studies indicate downgrade of driving performance and an increase in the likelihood of making a critical mistake in drivers suffering from neurodegenerative diseases. It is noted, however, that the literature on the relationship between driver distraction and brain pathology remains limited and there several fields of interest for further exploration. As far as MCI or AD patients are concerned, in the early stages of dementia they seem to retain their ability to perform a driving task, but as the disease proceeds, the driving ability deteriorates. There are indications of the cognitive functions that predict this deterioration, but much less is known about the performance of these patients under conditions of distraction (Parasuraman et al.1991 [37], Harvey et al. 1995 [38], Duchek et al. 1998 [39], Anderson et al. 2007 [40], Frank-Garcia et al. 2009 [41]). As far as Parkinson's disease is concerned, the findings do not show a stronger effect of distraction on PD patients than on controls. However, the greater fluctuation of driving errors due to distraction that was observed is a sign that this topic needs further investigation (Uc et al. 2006 [42], Uc et al. 2008 [43], Uitti 2009 [44]).

2. Objectives

The objective of this research is the analysis of two basic road safety parameters - reaction time and accident probability - of drivers with cognitive impairments due to various brain pathologies, in combination with in-vehicle distraction, using a driving simulator. The brain pathologies examined include early Alzheimer's disease (AD), early Parkinson's disease (PD), and Mild Cognitive Impairment (MCI). Group of patients is compared to a control group with no brain pathologies of similar age, driving experience and education. The two critical research questions are whether the presence of a brain pathology affects the reaction time and the accident probability of a driver and if in-vehicle distraction affects more the group of patients than the control one. Both these questions, are not only answered by this research but also quantified by appropriate statistical models.

For the purpose of this study, 140 participants of more than 55 years of age (31 "controls" and 109 "patients") went through a full neurological, a full neuropsychological assessments and a driving simulator task. They drove in rural and urban area and within each road type, two traffic scenarios (low and high traffic volumes) and three distraction conditions (undistracted driving, driving while conversing with a passenger and driving while conversing on a mobile phone) were examined in a full factorial within-subject design. The results carried out of the experiment between the 4 examined groups (Controls vs MCI vs AD vs PD), between the 3 examined distraction conditions (No distraction vs Conversation with passenger vs Mobile phone use) and between the 2 examined driving areas (Rural vs Urban) are compared to each other. But more importantly the interaction between the disease and the distractor is examined and significant results are carried out.

3. Methodology

3.1. Overview of the experiment

Road safety research often makes use of driving simulators, as they allow for the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. Driving simulators, however, vary substantially in their characteristics, and this can affect their realism and the validity of the results obtained. Despite these limitations, driving simulators are an increasingly popular tool for measuring and analyzing driver distraction, and numerous studies have been conducted, particularly in the last decade.

This study was carried out within the framework of two research projects: DriverBrain and Distract research project. They were carried out by an interdisciplinary research team of engineers, neurologists and psychologists (Yannis et al. 2013 [45], Pavlou et al. 2014 [46]). According to the objectives of the analysis, the experiment includes three types of assessment:

- 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.

- Neuropsychological assessment: The second assessment concerns the administration of a series of neuropsychological tests and psychological-behavioural questionnaires to the participants. The tests carried out 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.
- Driving at the simulator assessment: After clustering our sample scheme in two categories by the neuropsychological and the neurological teams (Control group and group of patients) all participants moved on to the third type of assessment. The third type of assessment concerns the programming of a set of driving tasks into the driving simulator for different driving scenarios.

The driving simulator experiment took place at the Department of Transportation Planning and Engineering of the National Technical University of Athens, where the Foerst Driving Simulator FPF is located. The NTUA driving simulator is a motion base quarter-cab manufactured by the FOERST Company. The simulator consists of 3 LCD wide screens 40" (full HD: 1920x1080pixels), driving position and support motion base. The dimensions at a full development are 230x180cm, while the base width is 78cm and the total field of view is 170 degrees. Research evidence from on-road testing supports the validity properties of the driving simulator that was applied in the current study (Yannis et al., 2015 [47]).

3.2. Driving at the simulator - Rural and Urban Driving Sessions

The design of the driving scenarios included driving in rural area with different traffic conditions (high and low traffic volume). More specifically, the driving simulator experiment started with one practice drive (usually 15-20 minutes), until the participant fully familiarized with the simulation environment. Afterwards, the participant moved on to the main part of the experiment which includes driving in two different sessions (~20 minutes each). Each session corresponded to a different road environment (Figure 1):

- A rural route that was 2.1km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves.
- An urban route that was 1,7km long, at its bigger part dual carriageway, separated by guardrails, and the lane width was 3.5m. Moreover, narrow sidewalks, commercial uses and parking were available at the roadsides.

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

- Q_L: Moderate traffic conditions - with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=12 sec, and variance σ^2=6 sec, corresponding to an average traffic volume Q=300 vehicles/hour.
- Q_H: High traffic conditions - with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=6 sec, 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 co-passenger and
- Driving while conversing on a handheld mobile phone

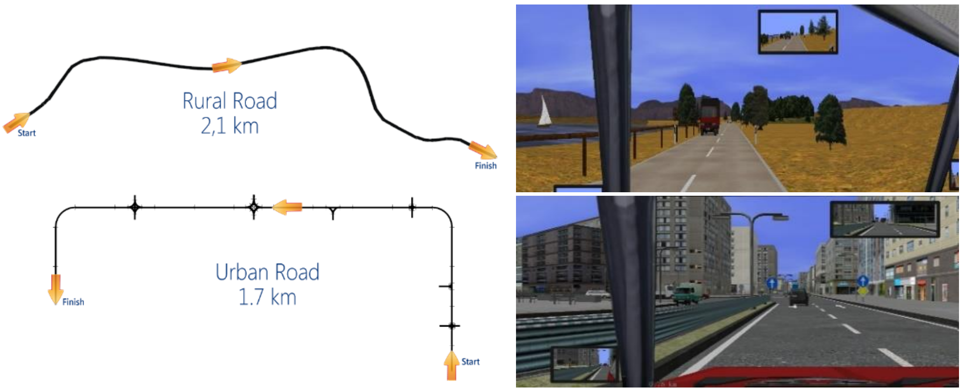


Figure 1. The two plans of the driving routes (rural and urban) and two screenshots for each driving environment

During each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive. More specifically, incidents in rural area concerned the sudden appearance of an animal (deer or donkey) on the roadway, and incidents in urban areas concerned the sudden appearance of an adult pedestrian or 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 (Figure 2). The hazard did appear at the same location for the same trial (i.e. rural area, high traffic) but not at the same location between the trials, in order not to have learning effects. Regarding the time that the hazard appeared, it depended on the speed and the time to collision, in order to have identical conditions for the participant to react, either they drove fast or slowly. Thus, there was no possibility for the incident to appear closely or more suddenly to a participant than to another.

The experiment was counterbalanced concerning the number and the order of the trials. However, rural drives were always first and urban drives were always second. This was decided for the following reasons: It was observed that urban area causes more often simulation sickness to the participants and thus it was decided to have the urban scenario second and secondly, counterbalancing in driving area means that we would have twice as much driving combinations which leads to much larger sample size requirements.

Figure 2. Two incidents screenshots - donkey entering the road in rural area and a child chasing a ball in urban area

3.3. Ethical issues

The study was approved by the Ethics Committee of the University General Hospital "ATTIKON". Informed consent was obtained from all individuals studied; it was explained to them that participation was on a voluntary basis and that they had the right to withdraw any time they wished to. Participants were informed on the nature of the study, the duration of their engagement and the type of information that they would be asked to give during the data collection process. Also, participants were ensured of the anonymity and confidentiality of the procedure. Finally, participation was voluntary and no compensation was offered.

4. Sampling scheme

For the purpose of this study 274 participants started the driving simulator experiment that was described analytically in the above chapters. 49 participants were eliminated from the study because they had simulator sickness issues from the very beginning of the driving simulator experiment. Thus, 225 subjects (both "patients" and "controls") have been through the whole experiment procedure. 25 participants had a brain pathology which is beyond the purpose of this paper and thus, they were eliminated from the analyses. Finally, 60 participants were of younger age (<55 years old) and they were eliminated from this study too, in order not to have age as a parameter that may affects the results, but only their cerebral condition.

Summarizing the above, the sampling scheme included 140 participants: 109 "patients" with a brain pathology with a mean age of 69.0 years (s.d.=8.1), 57% males: 25 AD patients (aver. 75.4 y.o.), 59 MCI patients (aver. 70.1 y.o.) and 25 PD patients (aver. 66.1 y.o.), and 31 cognitively intact "controls" with a mean age of 64.5 years (s.d.=7.2), 65% males. In Table 1, the between-group comparisons in age, driving experience, number of days driven per week and kilometers per week, in the number of years of education, the total accidents and accidents in the past two years, their self-reported levels of simulator sickness (caused by the driving simulator) and the Clinical Dementia Rating (CDR) score are presented. There were not statistically significant differences in the demographic characteristics of the two groups (Table 1).

Table 1. Comparison of patients with MCI and of a Control group without neurological history on various demographics with the use of the Wilcoxon Rank Sum Test

	"Patients" group	"Control" group	P-values
Age, y, mean±SD	69.0±7.1	64.5±7.9	0.189
N, M/F (Gender)	109, 62/47	31, 20/11	0.177
Driving experience, y, mean±SD	40.3±5.8	36.7±3.7	0.371
Days/week, median (range)	4 (2-7)	5 (2-7)	0.359
Kilometers driven/week[a], median (range)	3 (2-5)	3 (2-5)	0.416
Accidents (2 years) - reported, median (range)	0 (0-0)	0 (0-0)	1.000
Education, y, mean±SD	11.9±3.5	14.9±2.2	1.000
Simulator sickness[b] - reported, median (range)	0.23 (0-3)	0.18 (0-3)	1.000
CDR[c]	0.5	0	

[a]1=1-20km; 2=21-50km; 3=50-100km; 4=100-150 and 5>150
[b]Question: Did you feel dizzy at the simulator? 0=Not at all, 1=Just a little, 2=To some extent, 3=A lot
[c]Clinical Dementia Rating

The following inclusion criteria were required for participation in the current study: a) valid driving license, b) more than 3 years of driving experience, c) driving more than 2500km during the last year, d) driving at least 10km/week during the last year, e) no history of psychosis, f) absence of any significant kinetic disorder that prevents them from basic driving movements, g) absence of dizziness or nausea while driving, either as a driver or as a passenger, h) absence of alcohol or any other drug addiction, i) absence of any significant eye disorder that prevents them from driving safely. Also, because one of the driving conditions included the use of hand-held mobile phone, an essential requirement for all participants was that this specific driving practice is part of their everyday driving routine.

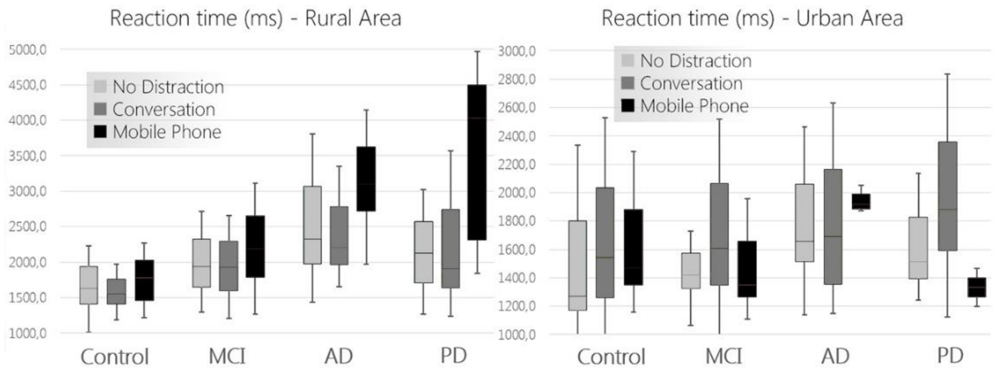
5. Analyses and results

The results carried out from the experiment between the 4 examined groups (Controls vs MCI vs AD vs PD), between the 3 examined distraction conditions (No distraction vs Conversation with passenger vs Mobile phone use) and between the 2 examined driving areas (Rural vs Urban) were compared. But more importantly the interaction between the disease and the distractor was examined and significant results carried out. Both road safety key measures were analyzed by descriptive statistics at first and then appropriate mathematical models were developed. The statistical analysis method selected was the mixed generalized linear model (GLM). In statistics, the generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for response variables that have error distribution models other than a normal distribution. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value. It is worth mentioning that the traffic volume effect was analyzed and had no significant effect on reaction time and accident probability in any examined group of participants, thus this variable was eliminated from the study.

5.1. Reaction Time

At first reaction time was examined and is presented per distractor (no distraction, conversation, mobile phone use) and per cognitive condition (control, MCI, AD, PD) by descriptive statistics (Figures 3 and 4) and then by appropriate mathematical models (Tables 2 and 3). It was observed that controls had the best reaction times overall in rural area, whereas AD and PD groups had the worst reaction times (more than 40% worse reaction times than the control group). Then, the mobile phone use had a significant effect on reaction time for AD and PD groups. Finally, conversing with passenger didn't seem to have an important effect on reaction time in all examined groups.

On the other hand, in urban area the differences in reaction times between the groups were less pronounced, yet detectable. It seemed that the conversation with passenger distraction task had an effect in all groups. AD participants seemed to have the worst reaction times in urban area. Finally, AD and PD sample in mobile phone use in urban areas was very small (less than 5 participants), thus the mobile phone use results for these two groups were not significant. It is important to mention that the reaction times in urban area cannot be compared to the ones in rural area, because of the fact that the incidents are totally different between the two driving environments and because of the fact that urban session was always second for representativeness reasons (thus it is obvious that the reaction times are getting better through driving time for the majority of the participants).



Figures 3, 4. Reaction times in rural and urban area for all groups in all distraction conditions

Moving on to the mixed GLM analysis for the rural driving area (Table 2), statistically significant differences were detected between control group and all impaired groups. AD group had the worst reaction times compared to all other groups. Then the interaction between disease and distractor was inserted in the model too (no distraction was the reference) and interesting results arise: although conversing with a passenger didn't seem to affect reaction time in any examined group, the use of the mobile phone had a significantly negative impact on all groups of patients. Especially for the AD and PD groups, the mobile phone use deteriorated the reaction time by at least 1 second. The driver distraction presence wasn't statistically significant for the control drivers.

Table 2. GLM Reaction time in rural area

Parameter Estimates

	Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
				Lower	Upper	Wald Chi-Square	df	Sig.
Disease	(Intercept)	1679,1	71,3	1539,3	1819,0	554,1	1	,000
	MCI	372,8	100,4	176,1	569,5	13,8	1	**,000****
	AD	884,4	129,8	630,0	1138,7	46,4	1	**,000****
	PD	575,9	134,5	312,4	839,5	18,3	1	**,000****
	Control	0[a]						
Disease*Distractor	MCI Mobile Phone	338,4	135,4	73,1	603,8	6,2	1	**,012****
	MCI Conversation	-46,1	100,1	-242,4	150,1	0,2	1	,645
	MCI No distraction	0[a]						
	AD Mobile Phone	1171,8	332,4	520,4	1823,2	12,4	1	**,000****
	AD Conversation	-74,5	154,2	-376,9	227,8	0,2	1	,629
	AD No distraction	0[a]						
	PD Mobile Phone	1014,1	240,5	542,6	1485,6	17,8	1	**,000****
	PD Conversation	108,8	164,6	-213,8	431,4	0,4	1	,509
	PD No distraction	0[a]						
	Control Mobile Phone	91,6	122,3	-148,1	331,3	0,6	1	,454
	Control Conversation	-109,3	103,4	-312,0	93,4	1,1	1	,291
	Control No distraction	0[a]						
	(Scale)	493591,955[b]	27571,1	442406,6	550699,3			

Dependent Variable: Reaction Time (Rural area)
Model: (Intercept), Disease, Disease * Distraction

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Moving on to the mixed GLM analysis for the urban driving area (Table 3), statistically significant differences were detected between control group and all groups of patients too (statistically significant at 90% confidence level for MCI drivers, but 95% for the other two). AD group had the worst reaction times compared to all examined groups, a finding that was noticed in the rural results too. Then concerning the interaction between disease and distractor (no distraction condition was the reference) it is worth mentioning that there was very small sample size for the AD and PD drivers using the mobile phone while driving (it is mentioned before that if a participant claimed they didn't use the mobile phone while driving, they didn't do so in the experiment). In contrast with the rural results, in urban roads all participants (except for the MCI group) were affected by the "conversation with passenger" task, and their reaction time was significantly deteriorated; even the control group.

Table 3. GLM Reaction time in urban area

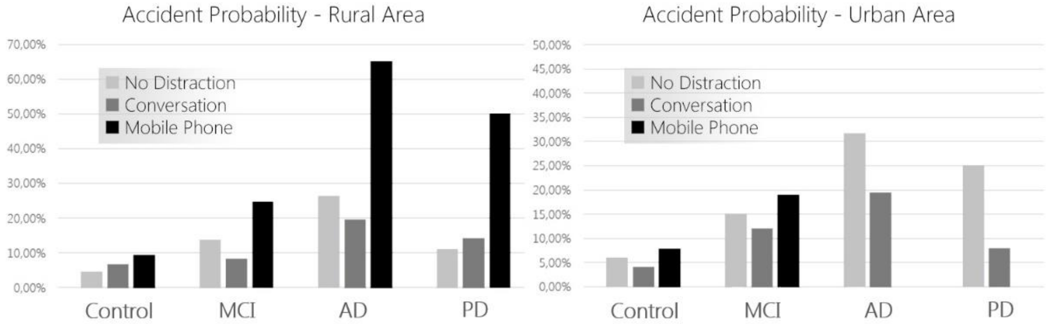
Parameter Estimates

	Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
				Lower	Upper	Wald Chi-Square	df	Sig.
Disease	(Intercept)	1341,9	52,8	1238,4	1445,3	646,5	1	,000
	MCI	130,6	73,6	-13,6	274,8	3,2	1	,076
	AD	463,4	94,4	278,4	648,5	24,1	1	**,000****
	PD	262,2	100,7	64,9	459,6	6,8	1	**,009****
	Control	0[a]						
Disease*Distractor	MCI Mobile Phone	55,8	110,9	-161,6	273,1	0,3	1	,615
	MCI Conversation	247,5	74,2	102,1	392,8	11,1	1	**,001****
	MCI No distraction	0[a]						
	AD Mobile Phone	141,0	191,7	-234,8	516,8	0,5	1	,462
	AD Conversation	4,6	127,8	-246,0	255,1	0,0	1	,971
	AD No distraction	0[a]						
	PD Mobile Phone	-257,6	230,9	-710,1	194,9	1,2	1	,265
	PD Conversation	438,0	128,6	185,9	690,1	11,6	**1**	**,001****
	PD No distraction	0[a]						
	Control Mobile Phone	147,9	96,7	-41,7	337,4	2,3	1	,126
	Control Conversation	160,2	76,5	10,3	310,0	4,4	1	**,036****
	Control No distraction	0[a]						
	(Scale)	183824,602[b]	12838,9	160307,2	210792,0			

Dependent Variable: Reaction Time (Urban area)
Model: (Intercept), Disease, Disease * Distraction
a. Set to zero because this parameter is redundant.
b. Maximum likelihood estimate.

5.2. Accident probability

Then accident probability in specific incident was analysed and is presented per distractor (no distraction, conversation, mobile phone use) and per cognitive condition (control, MCI, AD, PD) (Figures 5 and 6). It is observed that, overall, control drivers had a small accident probability compared to the group of patients in both rural and urban driving environments. It is easily detectable that AD drivers had, in all conditions, the higher accident probability, and especially when conversing on the mobile phone. In that case their accident probability was more than 60%. Participants with PD had also a significantly higher accident probability when using the mobile phone. In rural road environment, it seemed that conversation with passenger didn't increase the possibility of causing an accident. In urban area the differences between the groups were approximately the same with the rural area. Controls had the smaller accident probability overall and conversation with passenger didn't seem to have any impact on it. Finally, AD and PD sample size in "mobile phone use" trials in urban areas was very small (less than 5 participants), thus the mobile phone use results for these two groups are not significant and are not presented.



Figures 5, 6. Accident probability in rural and urban area for all groups in all distraction conditions

The mixed GLMs concerning accident probability in specific incident are confirming what was indicated before (Tables 4 and 5). There were statistically significant differences in accident probability between the control group and the MCI and the AD groups in rural area and between the control group and all groups of patients in urban area. Moreover, the interaction between the disease and the distractor indicated that mobile phone use had a significant effect in increasing the accident probability of causing an accident in the MCI and the PD groups in rural area. Finally, in urban area, the effect of the presence of distraction was not significant, probably because of the small sample size of the drivers with cerebral diseases; they avoid to use mobile phone in such an environment in their normal lives, thus they were not through this session.

Table 4 GLM Accident probability in rural area

Parameter Estimates

	Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
				Lower	Upper	Wald Chi-Square	df	Sig.
Disease	(Intercept)	0,077	0,026	0,026	0,128	8,819	1	,003
	MCI	0,068	0,027	0,016	0,120	6,607	1	**,010****
	AD	0,185	0,047	0,092	0,277	15,187	1	**,000****
	PD	0,015	0,049	-0,081	0,111	0,091	1	,763
	Control	0^a						
Disease*Distractor	MCI Mobile Phone	0,125	0,049	0,029	0,222	6,446	1	**,011****
	MCI Conversation	-0,055	0,037	-0,126	0,017	2,248	1	,134
	MCI No distraction	0^a						
	AD Mobile Phone	0,438	0,121	0,200	0,676	13,042	1	**,000****
	AD Conversation	-0,067	0,056	-0,177	0,044	1,407	1	,236
	AD No distraction	0^a						
	PD Mobile Phone	0,362	0,088	0,190	0,535	17,042	1	**,000****
	PD Conversation	0,051	0,060	-0,067	0,168	0,714	1	,398
	PD No distraction	0^a						
	Control Mobile Phone	0,051	0,060	-0,067	0,168	0,714	1	,398
	Control Conversation	0,025	0,038	-0,049	0,099	0,437	1	,509
	Control No distraction	0^a						
	(Scale)	$,066^b$	0,0	0,1	0,1			

Dependent Variable: Accident Probability (Rural area)
Model: (Intercept), Disease, Disease * Distraction

a. Set to zero because this parameter is redundant.
b. Maximum likelihood estimate.

Table 5. GLM Accident probability in urban area

Parameter Estimates

	Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
				Lower	Upper	Wald Chi-Square	df	Sig.
Disease	(Intercept)	0,068	0,027	0,016	0,120	6,607	1	,010
	MCI	0,182	0,037	0,109	0,254	24,183	1	**,000****
	AD	0,248	0,047	0,155	0,341	27,423	1	**,000****
	PD	0,172	0,051	0,073	0,271	11,527	1	**,001****
	Control	0[a]						
Disease*Distractor	MCI Mobile Phone	-0,197	0,056	-0,307	-0,088	12,536	1	**,000****
	MCI Conversation	-0,219	0,037	-0,292	-0,146	34,450	1	**,000****
	MCI No distraction	0[a]						
	AD Mobile Phone	-0,150	0,096	-0,339	0,039	2,423	1	,120
	AD Conversation	-0,094	0,064	-0,220	0,031	2,161	1	,142
	AD No distraction	0[a]						
	PD Mobile Phone	-0,115	0,116	-0,342	0,112	0,982	1	,322
	PD Conversation	-0,140	0,065	-0,267	-0,013	4,690	1	**,030****
	PD No distraction	0[a]						
	Control Mobile Phone	-0,015	0,049	-0,110	0,081	0,090	1	,764
	Control Conversation	-0,035	0,038	-0,110	0,040	0,822	1	,365
	Control No distraction	0[a]						
	(Scale)	,046[b]	0,0	0,0	0,1			

Dependent Variable: Accident Probability (Urban area)
Model: (Intercept), Disease, Disease * Distraction
a. Set to zero because this parameter is redundant.
b. Maximum likelihood estimate.

6. Conclusions

The objective of this research was the analysis of two basic driving behaviour and road safety parameters, namely the reaction time and accident probability, of drivers with cognitive impairments due to various brain pathologies, in combination with in-vehicle distraction, using a driving simulator. The brain pathologies examined include early Alzheimer's disease (AD), early Parkinson's disease (PD), and Mild Cognitive Impairment (MCI). The two critical research questions were whether the presence of a brain pathology affects the reaction time and the accident probability of a driver and if in-vehicle distraction affects more the impaired group than the control one. Both these questions, were not only answered by this research but also quantified by appropriate statistical models.

For the purpose of this research 140 participants of more than 55 years of age (109 patients with cerebral diseases and 31 cognitively intact individuals of similar demographics) were through a driving simulator experiment. They drove in rural and urban area and within each road type, three distraction conditions (undistracted driving, driving while conversing with a passenger and driving while conversing on a handheld mobile phone) were examined in a full factorial within-subject design.

Summarizing the results, all findings suggest difficulties in safe driving of the group of patients in both driving performance measure examined (reaction time and accident probability). More specifically, regarding the reaction time statistically significant differences were detected between control group and all groups of drivers with cerebral diseases in both rural and urban driving environments. AD group had the worst reaction times compared to all other groups. Then, regarding the interaction between disease and distractor, very interesting findings were carried out. The use of the mobile phone had a significantly negative impact on all groups of patients in rural road. Especially for the AD and PD groups, the distraction through mobile phone use worsened their reaction time by at least 1 second, whereas driver distraction presence wasn't statistically significant for the control drivers. On the other hand, in urban roads all participants (except for the MCI group) were affected by the "conversation with passenger" task, and their reaction time was significantly deteriorated; even the control group.

Moving on to the accident probability results, statistically significant differences in accident probability between the control group and the MCI and the AD groups in rural area and between the control group and all groups of patients in urban area were extracted. The accident probability of 3 groups of patients with a brain pathology was significantly higher than the control drivers. Additionally, the interaction between the disease and the distraction condition indicated that the distraction through mobile phone use had a significant impact in increasing the probability of causing an accident in the MCI and the PD groups in rural driving environment.

It seems that both research questions were sufficiently confirmed and mathematically quantified. Overall, the brain pathologies examined (MCI, AD and PD) lead to important deterioration in key road safety measures. Especially, the AD and PD drivers have the worst driving performance overall; very large reaction times, even with in-vehicle no distraction, higher accident probability even with no distraction too. Of course, as expected, when using the mobile phone, their driving performance is getting even more deteriorated (reaction times over 3 seconds and accident probability approximately 50%). Another interesting finding, was that control group wasn't affected by the distraction conditions regarding either reaction time or accident probability.

All above results were quite promising and confirm the initial hypotheses of the research that brain pathologies may deteriorate driving performance in several ways. Finally, the 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.

In conclusion, the take-home message of the current work is that drivers with brain pathologies had serious difficulties in their driving performance in comparison with the healthy controls and their road safety indexes deviated significantly from the healthy controls.

What is more, the presence of an in-vehicle distractor while driving such as conversing with a co-passenger, but more importantly conversing through a handheld mobile phone, has a significantly deleterious effect on key driving performance measures of drivers with cerebral diseases (AD, PD and in a lesser extend MCI) regarding road safety. Overall, all these observations that were extracted from the present study could have considerable practical importance; they provide quite useful information for the formulation of efficient driving recommendations which have the capacity to reduce the accident probability, and thus to reduce road fatalities in a sensitive group of car drivers, such that of drivers with MCI, AD or PD.

Considering that the percentage of the elderly in society is increasing (Baldock et al. 2007 [3]), while at the same time the level of motorization also increases (Yannis et al. 2011 [48]), the need for the investigation and comparative assessment of the impact of these conditions on driving performance becomes a high priority, especially when they interact with driver distraction parameters. The analysis of the distracted driving performance of individuals with cerebral diseases could provide useful information for the development of policies that aim at reducing the risk for car accidents and at improving aspects of driving performance e.g. restrictive measures, training and licensing, information campaigns, medical and neuropsychological monitoring etc.

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