In-vehicle distraction and brain pathologies: Effects on reaction time and accident probability

Dimosthenis Pavlou
5 Heroon Polytechniou str.,
GR-15773, Athens, Greece
dpavlou@central.ntua.gr

Panagiotis Papantoniou
5 Heroon Polytechniou str.,
GR-15773, Athens, Greece
ppapant@central.ntua.gr

Eleonora Papadimitriou
5 Heroon Polytechniou str.,
GR-15773, Athens, Greece
nopapadi@central.ntua.gr

Sophia Vardaki
5 Heroon Polytechniou str.,
GR-15773, Athens, Greece
sophiav@central.ntua.gr

George Yannis
5 Heroon Polytechniou str.,
GR-15773, Athens, Greece
geyannis@central.ntua.gr

Constantinos Antoniou
5 Heroon Polytechniou str.,
GR-15773, Athens, Greece
antoniou@central.ntua.gr

John Golias
5 Heroon Polytechniou str.,
GR-15773, Athens, Greece
igolias@central.ntua.gr

Sokratis G. Papageorgiou
75 Mikras Asias str.,
GR-11527, Athens, Greece
sokpapa@med.uoa.gr

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.

Driver distraction is estimated to be 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; however, relatively few studies have examined the effect of cerebral diseases on distracted driving behaviour.

The objective of this research is the analysis of two basic driving behaviour and 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.

An interdisciplinary research team of civil engineers, neurologists and psychologists is carrying out an experiment with three assessments for healthy and impaired drivers: a medical/neurological assessment, a neuropsychological assessment and a driving simulator task. The driving scenario examined concerns driving in rural area, with and without in-vehicle distraction (conversation with passenger and mobile phone use). The brain pathologies examined include early Alzheimer's disease (AD), early Parkinson's disease (PD), and Mild Cognitive Impairment (MCI).

140 participants (out of which 109 have some brain pathology) have completed the experiment. A statistical analysis was carried out by means of mixed generalized linear modelling (mixed GLM) and the results suggest that there are significant differences in the driving performance and safety of healthy drivers and drivers with cognitive impairments. Impaired drivers appear to react significantly slower at unexpected incidents than the healthy ones and are more likely to be involved in an accident. More specifically, AD and PD drivers seem to have the longest reaction times among the examined group. The mobile phone use seems to have a statistically significant negative effect on both reaction time and accident probability, especially in the AD participants. Finally, effects of conversation with passengers are less pronounced, although several differences in driving behaviour and safety of impaired drivers are identifiable.

KEYWORDS

Brain pathologies, drivers' distraction, driving simulator, reaction time, accident probability

INTRODUCTION

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). 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). 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, OECD 2008). Simulated driving tasks have shown that older adults have greater difficulty in dividing attention than do younger adults (Brouwer et al. 1991, Ponds et al. 1988). 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, Cordell et al. 2008, Cubo et al. 2009, Frittelli et al. 2009). 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), 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), 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). Moreover, the associated impairment in executive functions appears to have a significant effect on driving performance (Tomioka al. 2009), 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, Cubo et al. 2009).

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, de Raedt et al. 2000, Mathias et al. 2009, Weaver et al. 2009). These tasks show considerable decline with age and are associated with the probability of accident involvement (Clay et al. 2005, Lunsman et al. 2008), especially while being distracted.

Driver distraction

Human factors in total are considered to be the basic causes in 65-95% of road accidents (Sabey & Taylor 1980, Salmon et al. 2011). 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). 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).

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. 2005). 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), 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)

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, Johnson et al. 2004, Lesch & Hancock 2004, Neyens & Boyle 2008, Bellinger et al. 2008, Yannis et al. 2010), 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) 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) and why deficits in attention and visuospatial ability are associated with poorer on-road driving test results (Hunt et al. 1993, Richardson & Marottoli 2003) and with crashes (Ball et al. 1993).

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, Harvey et al. 1995, Duchek et al. 1998, Anderson et al. 2007, Frank-Garcia et al. 2009). 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, Uc et al. 2008, Uitti 2009).

OBJECTIVES

The objective of this research is the analysis of two basic 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. Reaction time and accident probability in case of unexpected incidents are considered to be the most representative safety parameters. The brain pathologies examined include early Alzheimer’s disease (AD), early Parkinson’s disease (PD), and Mild Cognitive Impairment (MCI). Impaired groups are compared with 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 impaired group than the control one. Both these questions, are not only answered by this research but also quantified by appropriate statistical models.

For that purpose 140 participants of more than 55 years of age (31 “controls” and 109 “impaired”) completed a driving simulator experiment. 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.

METHODOLOGY

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 is carried out within the framework of the Distract research project. It is carried out by an interdisciplinary research team of engineers, neurologists and psychologists (Yannis et al. 2013, Pavlou et al. 2014). 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 (e.g. MCI, Alzheimer's disease, Parkinson's disease, Cerebrovascular disease (stroke) as well as other related parameters of potential impact on driving (e.g. use of medication affecting the Central Nervous System).
- 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 PD group) all participants continue with 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 takes 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. It's worth mentioning that the simulator is validated against a real world environment (Nikas 2014).

Driving at the simulator - Rural and Urban Driving Sessions

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

- A rural route that is 2.1km 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.

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

- 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 passenger and
- Driving while conversing on a mobile phone

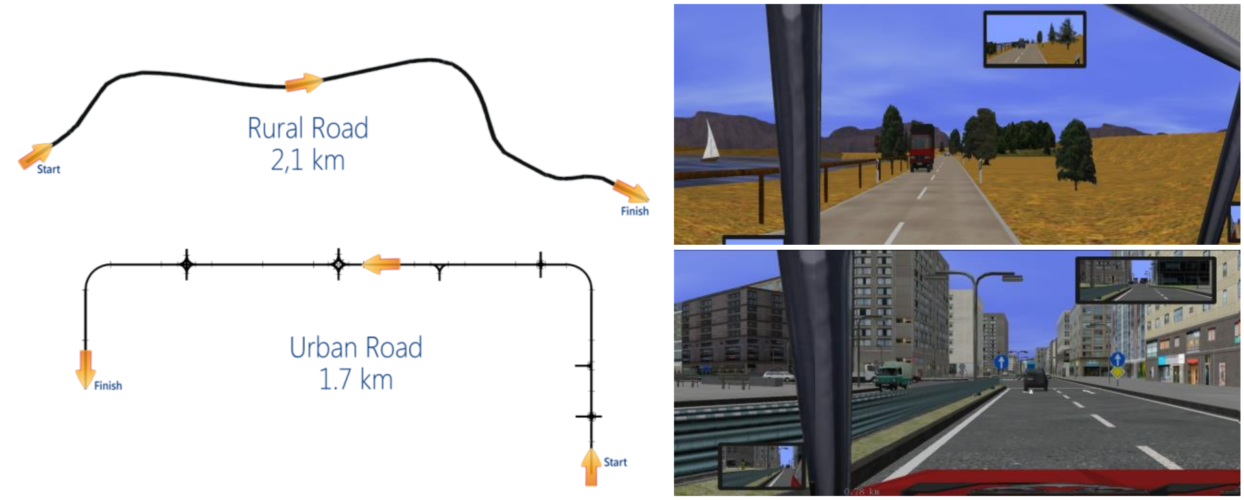


Figure 1. The two plans of the driving routes (rural and urban) and two screenshots for each driving environment

Consequently, in total, each session (urban or rural) includes six trials of the simulated route. During each trial, 2 unexpected incidents are scheduled to occur at fixed points along the drive. 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 or of a car suddenly getting out of a parking position and getting in the road (Figure 2). The hazard does 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 appears, it depends on the speed and the time to collision in order to have identical conditions for the participant to react, either they drive fast or slowly. Thus, there is no possibility for the incident to appear closely or more suddenly to a participant than to another.

The experiment is 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.

Finally, 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.

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

Sampling scheme

For the purpose of this research 274 participants have, at least, 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 impaired and "controls") have been through the whole experiment procedure. 25 participants have a brain pathology which is beyond the purpose of this paper and thus, they are eliminated from the analyses. Finally, 60 participants are of younger age (<55 years old) and they are 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 of this research is 140 participants of more than 55 years of age. Out of the 140 participants, 31 are controls (aver. 64.5 y.o., 20 males), and 109 are impaired (aver. 69.0 y.o., 80 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.) (Figure 3 - box and whisker plots).

A box plot (also known as a box-and-whisker chart) is a convenient way to show groups of numerical data, such as minimum and maximum values, upper and lower quartiles, median values, outlying and extreme values. The spacing between the different parts of the box plot indicate the degree of dispersion (spread) and skewness in the data and identify outliers. More specifically, regarding box plots: The line in the middle of the boxes is the median. The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile, whereas the top of the box represents the 75th percentile. Twenty-five percent of case have values above the 75th percentile (50% of the cases lie within the box).

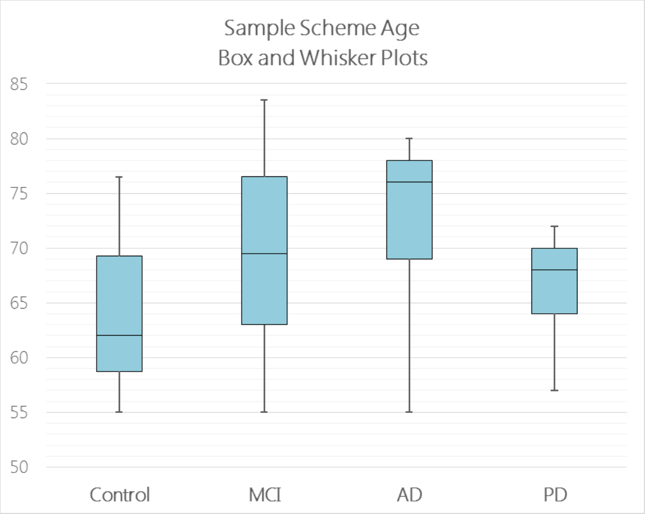
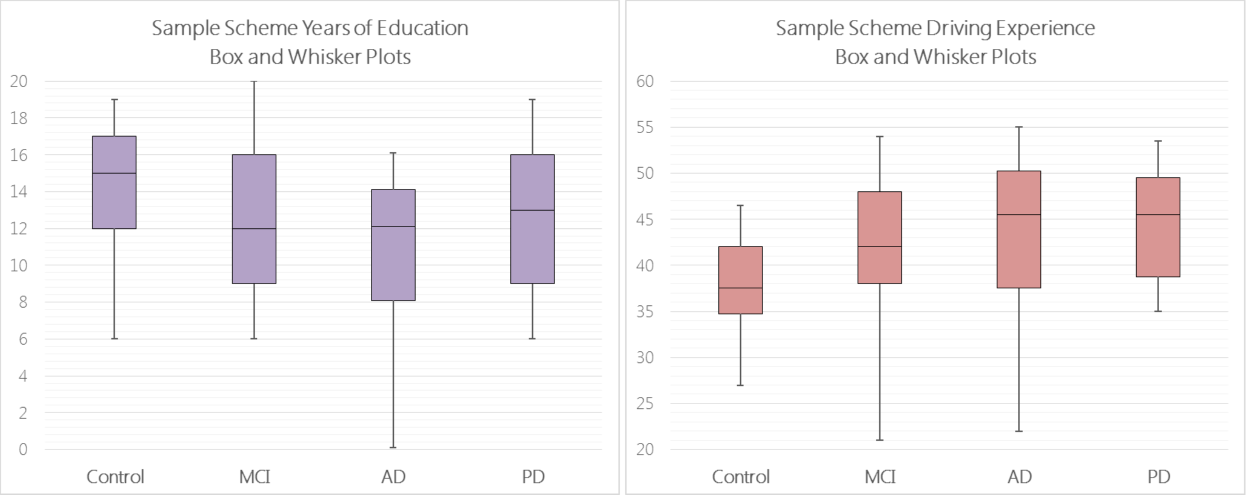


Figure 3. Sample scheme age distribution, through box and whisker plots

In Figures 4 and 5, there are some more demographics characteristics of the participants, concerning the years of education and the driving experience in years. It is observed that the majority of the participants have at least 12 years of education and are considered to be experienced drivers (more than 35 years). The similarities in all these demographic characteristics within the participants are significant and the sampling scheme can be safely considered to be representative.



Figures 4, 5. Sample scheme years of education and driving experience distribution, through box and whisker plots

ANALYSES AND RESULTS

The objective of this research is the analysis of two key driving behaviour and safety measures of drivers with cognitive impairments due to various brain pathologies, in combination with in-vehicle distraction, using a driving simulator: reaction time and accident probability in specific incident. 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[1]) 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 key measures analyzed by descriptive statistics at first and then appropriate mathematical models were developed. The statistical analysis method selected is 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.

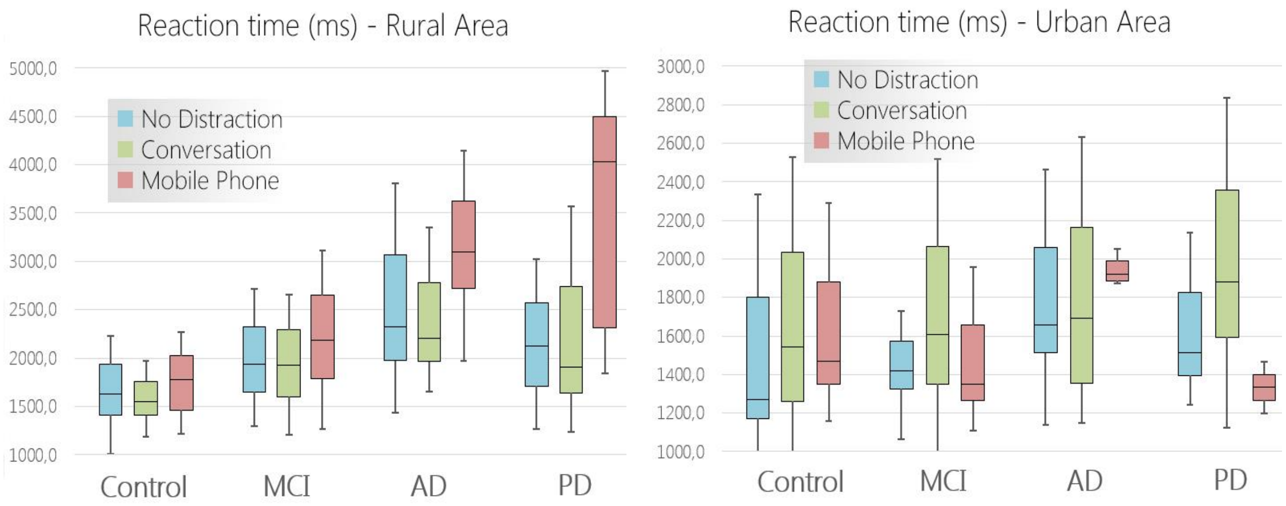
It is worth mentioning that the traffic volume effect was analyzed and had no significant effect on reaction time and accident probability in any examined group of participants, thus this variable was eliminated from the study.

All results are presented and discussed below.

Reaction Time

At first reaction time was analysed and presented per distraction factor (no distraction, conversation, mobile phone use) and per cognitive condition (control, MCI, AD, PD) by descriptive statistics (Figures 6 and 7) and then by appropriate mathematical models (Tables 1 and 2). It is observed that controls have the best reaction times overall in rural area, whereas AD and PD groups have the worst reaction times (more than 40% worse reaction times than the control group). Then, the mobile phone use seems to have a significant effect on reaction time for AD and especially PD groups. Finally, conversing with passenger doesn'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 are less pronounced, yet detectable. It seems that the conversation with passenger distraction task have an effect in all groups. AD participants seem 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 are 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 6, 7. Reaction times in rural and urban area for all groups in all distraction conditions

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[1] only those participants who do so in real driving conditions - all other didn't drive under this kind of distraction because the results wouldn't be reliable

Moving on to the mixed GLM analysis for the rural driving area (Table 1), statistically significant differences are detected between control group and all impaired groups. AD group has the worst reaction times compared to all other groups. Then the interaction between disease and distractor was inserted in the model too (no distraction condition was the reference) and interesting results arise: Although conversing with a passenger doesn't seem to affect reaction time in any examined group, the use of the mobile phone has significant effect on all impaired groups. Especially for the AD and PD groups, the mobile phone use deteriorates the reaction time by at least 1 second. The driver distraction presence isn't statistically significant for the control drivers.

Table 1. 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 2), statistically significant differences are detected between control group and all impaired groups too (statistically significant at 90% confidence level for MCI drivers, but 95% for the other two). AD group has the worst reaction times compared to all examined groups, something that came out from 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 don'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 2. 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**								

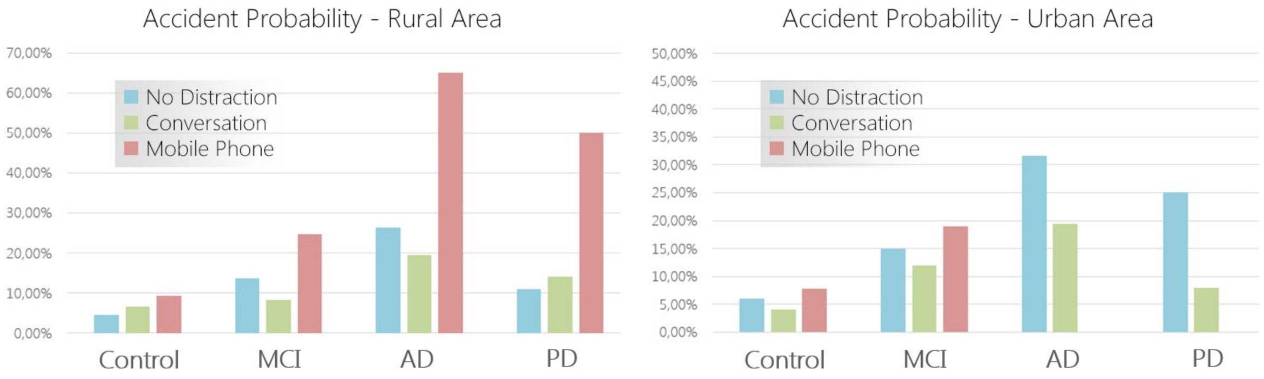
a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Accident probability

Then accident probability in specific incident was analysed and presented per distraction factor (no distraction, conversation, mobile phone use) and per cognitive condition (control, MCI, AD, PD) (Figures 8 and 9). It is observed that, overall, control drivers have a small accident probability compared to the impaired group in both rural and urban areas. It is easily detectable that AD drivers have in all conditions the higher accident probability, and especially when conversing on the mobile phone. In that case their accident probability is more than 60%. PD participants have also a significant effect in accident probability when using the mobile phone. In rural road environment, it seems that conversation with passenger doesn’t increase the possibility of causing an accident.

In urban area the differences between the groups are approximately the same with the rural area. Controls have the smaller accident probability overall and conversation with passenger doesn’t seem to affect 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 8, 9. 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 3 and 4). There are 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 impaired groups in urban area. Moreover, the interaction between the disease and the distraction condition indicates that mobile phone use has a significant effect in increasing the accident probability of causing an accident in the MCI and the PD groups in rural driving environment. Finally, in urban area, the effect of the presence of distraction is not significant, probably because of the small sample size of the impaired participant who use mobile phone in such an environment.

Table 3. 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 4. 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.

DISCUSSION AND CONCLUSIONS

The objective of this research is the analysis of two basic driving behaviour and 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). Impaired groups are compared with 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 impaired group than the control one. Both these questions, are not only answered by this research but also quantified by appropriate statistical models.

For that purpose 140 participants of more than 55 years of age (31 "controls" and 109 "impaired") were through a driving simulator experiment. 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 reaction time and the accident probability, which are considered to be the most significant safety parameters, were studied through a large driving simulator experiment.

Summarizing the results, all findings suggest difficulties in safe driving of the impaired group in both driving performance measure examined (reaction time and accident probability). More specifically, regarding the reaction time statistically significant differences are detected between control group and all impaired groups in both rural and urban driving environments. AD group seems to have 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 has statistically significant effect on all impaired groups in rural road. Especially for the AD and PD groups, the distraction through mobile phone use deteriorates their reaction time by at least 1 second, whereas driver distraction presence isn'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 impaired groups in urban area were carried out. The accident probability for the impaired group is significantly higher than the control drivers. Moreover, the interaction between the disease and the distraction condition indicates that the distraction through mobile phone use has a significant effect in increasing the accident probability of causing an accident in the MCI and the PD groups in rural driving environment.

It seems that both research questions are sufficiently confirmed and mathematically quantified. Overall, the brain pathologies examined (MCI, AD and PD) lead to important deterioration in road safety. 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%). It is worth mentioning that the "mobile phone use" scenario was carried out for only those participants who claimed they do so in read driving conditions too; thus this condition is considered to be familiar for all participants. Another interesting finding, is that control group doesn't seem to be affected by the distraction conditions regarding either reaction time or accident probability.

All above results are 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.

Finally, taking into account that the percentage of the elderly in society is increasing (Baldock et al. 2007), while at the same time the level of motorization also increases (Yannis et al. 2011), 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.

ACKNOWLEDGMENTS

This paper was carried out within the framework of the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF), namely the Research Funding Program: **THALES**. Investing in knowledge society through the European Social Fund, co-financed by the European Union (European Social Fund - ESF) and Greek national funds.

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