The detrimental effect of mobile phone use on the driving competence of patients with neurological diseases affecting cognitive functions

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Abstract: Drivers with brain disorders have difficulties in their driving competence (motor, visual, cognitive or perceptual) which may lead to increased accident probability. Alongside, driver distraction is an important cause of vehicle accidents. The interaction of brain disorders and driver distraction, which has not been adequately investigated so far, makes the assessment of their driving competence a very challenging task. The objective of this paper is the analysis and quantification of the effect of mobile phone use on the driving competence of patients with neurological diseases affecting cognition diseases, through a large driving simulator experiment carried out by an interdisciplinary research team of civil engineers, neurologists and psychologists. 34 Controls, 43 MCI, 28 AD, and 20 PD patients, all older than 55 years old, were asked to drive in urban and rural driving simulated environment and under three distraction conditions: no distraction, conversation with a co-passenger and conversation through handheld mobile phone. Their mean speed, their reaction time and accident probability in unexpected incidents were under investigation. The regression analyses (24 generalized linear models) indicated several interesting results. The findings extracted from the patient groups' regression analyses highlighted the detrimental impact of the mobile phone use on their reaction time and accident probability.

1. Introduction

Road accidents constitute a major social problem in modern societies, accounting for more than one million road accidents per year in EU-28 (2.900 per day) with consequences 1,4 million injured and 26.000 fatalities (70 per day) [1]. Despite the fact that road traffic casualties presented a constantly decreasing trend during the last years, the number of fatalities in road accidents in several countries and in Greece in particular is still unacceptable and illustrates the need for even greater efforts with respect to better driving performance and increased road safety [2].

Driving is a complex task that requires possessing sufficient cognitive, visual and neurological state. 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, which involve 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 [3,4].

Human factors are the basic causes in 65-95% of road accidents [5,6,7]. The accurate evaluation of crash causal factors can provide fundamental information for effective transportation policy, vehicle design, and driver education. Dingus et al., [8] through a methodology developed at Virginia Tech Transportation Institute (VTTI), suggested that crash causation has shifted dramatically in recent years, with driver-related factors (i.e., error, impairment, fatigue, and distraction) present in almost 90% of crashes. The results also definitively showed that distraction is detrimental to driver safety, with handheld electronic devices having high use rates and risk. A critical driver-related human factor includes neurological diseases affecting cognition. A number of neurological diseases affecting cognitive functions may affect driving performance in the general population and particularly in the elderly. Older drivers generally exhibit a higher risk of involvement in a road accident [9,10].

Executive functions which decline over age are of critical importance regarding driving competence. Diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to neurological diseases affecting cognitive functions as Mild Cognitive Impairment - MCI, Alzheimer’s disease - AD, Parkinson’s disease - PD), may significantly impair the person's driving performance, especially when unexpected incidents occur. A number of prevalent neurological diseases may be involved, ranging from very mild to severe states that include Parkinson’s or Alzheimer’s disease, Cerebrovascular disease etc. [11,12,13,14].

Mild Cognitive Impairment (MCI), which is considered to be the predementia stage of various dementing diseases of the brain, is a common neurological disorder that may be observed in about 16% of individuals over 64 years old in the general population [15], 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 [14], as it is characterized by attentional and functional deficits, which are expected to affect the driver’s ability to handle unexpected incidents. Moreover, self-reported road accident involvement was correlated with future diagnosis of dementia [16]. Regarding Alzheimer’s disease, although research findings suggest that individuals with this disease may still be fit to drive in the early stages [17], they may show visual inspection and target identification disorders during driving [18]. Moreover, the associated impairment in executive functions appears to have a significant effect on driving performance [19], especially when unexpected incidents occur. Studies regarding Parkinson disease are less conclusive in terms of the impact of its clinical parameters on driving abilities [12,13]. Although these conditions have obvious impacts on driving performance, in mild cases and importantly in the very early stages, they may be imperceptible in one’s daily routine yet still impact one’s driving ability.

According to the review on the interaction between neurological diseases affecting cognition (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 [20,21,22,23]. 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 [24,25,26].

Thus, the interaction of brain disorders and driver distraction, which has not been adequately investigated so far, makes the assessment of their driving competence a very challenging task.

2. Objectives

The objective of this paper is the analysis and quantification of the effect of mobile phone use on the driving competence of patients with neurological diseases affecting cognitive functions, through a large driving simulator experiment carried out by an interdisciplinary research team of civil engineers, neurologists and psychologists. Participants with MCI, AD, PD and Controls were asked to drive in driving simulated environment and under distraction conditions (conversation with a co-passenger and conversation through a handheld mobile phone), and their mean speed, their reaction time and accident probability in unexpected incidents were under investigation. The basic research hypothesis is that the effect of the mobile phone use is detrimental on their driving performance and the question is to what extend their driving competence is compromised by this type of distraction. In order to deal with the research hypothesis, regression analysis techniques were developed.

3. Experimental methodology

This study was carried out by an interdisciplinary research team of engineers, neurologists and psychologists [27, 28]. 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 (MCI, AD and PD).
- 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 into four categories by the neuropsychological and the neurological teams (Control group and MCI, AD and PD groups) 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 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. It's worth mentioning that the simulator is validated against a real world environment [29].

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

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 included driving in two different sessions (~15 minutes each). Each session corresponded to a different road environment: a rural route 2.1km long, single carriageway, lane width is 3m, with zero gradient and mild horizontal curves, and an urban route 1,7km long, at its bigger part dual carriageway, separated by guardrails, lane width 3.5m. Within each road / area type, three distraction conditions were examined: a) undistracted driving, b) driving while conversing with a passenger and c) driving while conversing on a mobile phone. During each trial, two unexpected incidents were scheduled to occur during 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 1).

a *b*

Fig. 1. *Unexpected incidents*
a Deer crossing the lane ("over the shoulder" view)
b Child with ball crossing the road ("POV" view)

Regarding the time that the hazard appeared, it depended on the speed and the time to collision, in order to have identical conditions for all the participants to react, either they drove fast or slowly. The accident risk was calculated as the proportion of the total incident crashes to the total incidents happened. 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.

3.2. Sample

For the purpose of this study, 274 participants started the driving simulator experiment that was described in the previous chapter. 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 ("patients" and "controls") have been through the whole experiment procedure. 30 participants had a brain pathology which is beyond the purpose of this paper and thus, they are eliminated from the analyses. Finally, 70 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 of this research is 125 participants of more than 55 years of age. Out of the 125 participants, 34 are controls (aver. 64.1 y.o., 25 males), and 91 are patients (aver. 71.2 y.o., 59 males): 28 AD patients (aver. 75.4 y.o.), 43 MCI patients (aver. 70.1 y.o.) and 20 PD patients (aver. 66.1 y.o.). 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, and their self-reported levels of simulator sickness (caused by the driving simulator) are presented for the group of older drivers (> 55 years old). There were not statistically significant differences in the demographic characteristics between any of the patients group and the control group.

Table 1 Comparison of patients with neurological diseases affecting cognitive functions and of the Control group without neurological history on various demographics with the use of the Wilcoxon Rank Sum Test (age >55 y.o.)

	"MCI, AD, PD Patients" group	"Control" group	**P-values**
Age, y, mean±SD	71.2±7.2	64.1±6.6	0.122
N, M/F (Gender)	91, 59/32	34, 25/9	0.141
Driving experience, y, mean±SD	41.3±5.8	38.7±2.8	0.271
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	12.1±3.5	13.5±2.2	0.812
Simulator sickness[b] - reported, median (range)	0.23 (0-3)	0.18 (0-3)	0.726

[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

The following inclusion criteria were required for participation in this study: a) valid driving license, b) driving experience of at least 3 years, c) driving exposure more than 2500km and at least 10km/week during the last year, d) absence of any significant motor disorder that prevents them from basic driving movements, e) absence any drug addiction, f) absence of any significant eye disorder that prevents them from driving safely and g) absence of severe neurological disease affecting cognition (only mild AD and mild PD patients were included in the study). Also, because one of the driving distractors included the use of mobile phone, a requirement for all participants was that this specific driving practice is part of their everyday driving routine.

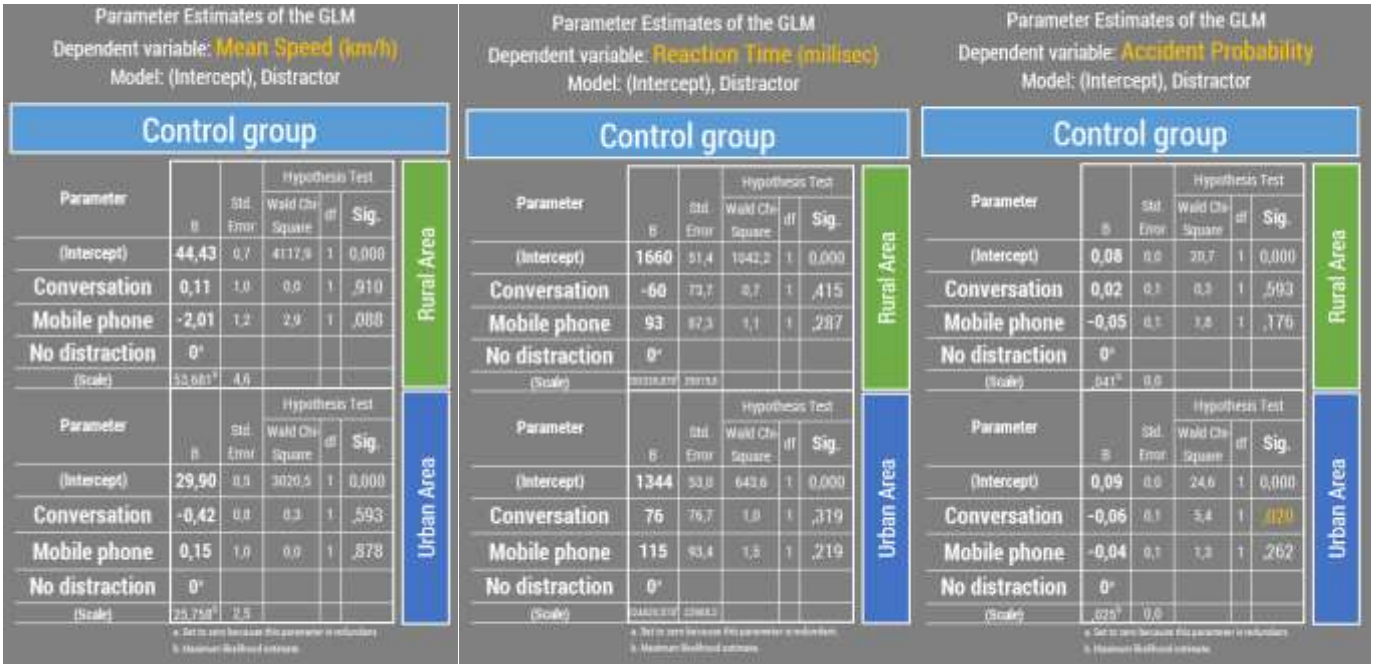
4. Analysis methods

In order to deal with the research hypothesis, linear regression modelling was implemented to investigate the driving competence of the participants. Linear regression is used to model a linear relationship between a continuous dependent variable and one or more independent variables. Furthermore, the generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for inclusion of dependent 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. It also allows the magnitude of the variance of each measurement to be a function of its predicted value. No distraction condition, conversation with passenger and conversation through handheld mobile phone were examined regarding the following critical driving competence measures in rural and urban areas: a) Mean speed, b) Reaction time at unexpected incidents, and c) Accident probability. The aim of these regression analyses is to examine the effect of in-vehicle distraction in the three clinical groups with neurological diseases affecting cognition and the control group, regarding the driving performance measures in which they have significant differences with the undistracted driving of each group.

5. Results

5.1. Control group

In Figure 2 the parameter estimates of six generalized linear models (GLM), on the 3 dependent driving performance variables regarding the group of controls in rural area and urban area, are presented.



Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

Control group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	44,43	0,7	4117,9	1	0,000
Conversation	0,11	1,0	0,0	1	,910
Mobile phone	-2,01	1,2	2,9	1	,088
No distraction	0ª				
(Scale)	53,681ᵇ	4,6			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	29,90	0,5	3020,5	1	0,000
Conversation	-0,42	0,8	0,3	1	,593
Mobile phone	0,15	1,0	0,0	1	,878
No distraction	0ª				
(Scale)	25,758ᵇ	2,5			

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

a

Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

Control group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1660	51,4	1042,2	1	0,000
Conversation	-60	73,7	0,7	1	,415
Mobile phone	93	87,3	1,1	1	,287
No distraction	0ª				
(Scale)	[illegible]	[illegible]			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1344	53,0	643,6	1	0,000
Conversation	76	76,7	1,0	1	,319
Mobile phone	115	93,4	1,5	1	,219
No distraction	0ª				
(Scale)	[illegible]	[illegible]			

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

b

Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

Control group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,08	0,0	20,7	1	0,000
Conversation	0,02	0,1	0,3	1	,593
Mobile phone	-0,05	0,1	1,8	1	,176
No distraction	0ª				
(Scale)	,041ᵇ	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,09	0,0	24,6	1	0,000
Conversation	-0,06	0,1	5,4	1	,020
Mobile phone	-0,04	0,1	1,3	1	,262
No distraction	0ª				
(Scale)	,025ᵇ	0,0			

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

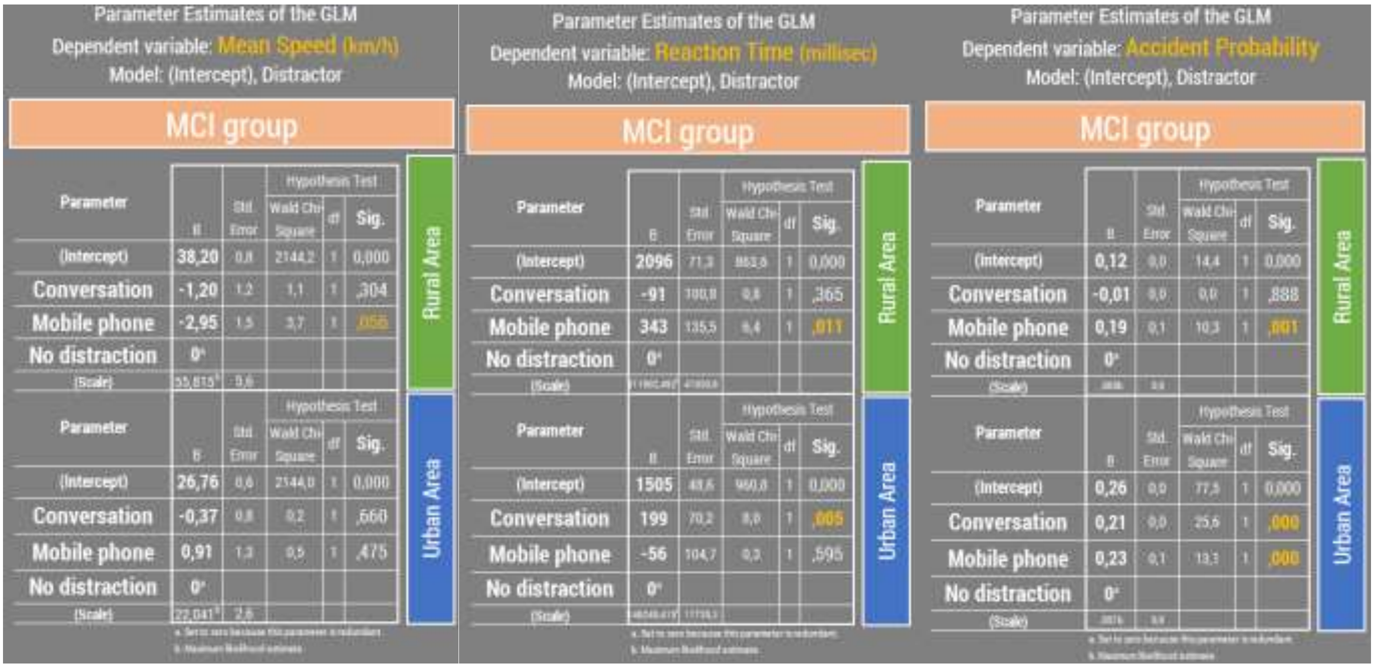
c

Fig. 2. *GLM regarding the effect of distraction on driving competence of the control group in rural and urban areas*
a Mean Speed
b Reaction Time
c Accident Probability

Investigating the effect of distraction in the group of healthy controls of similar demographics with the groups of patients, significant differences were detected only in one condition: The conversation with passenger lead to slightly lower accident probability in urban area. It appears that, in general terms, the distraction conditions (even the mobile phone use while driving) don't have a significant impact on mean speed, reaction time and accident probability in the group of controls overall, compared to their undistracted driving performance.

5.2. MCI group

In Figure 3 the parameter estimates of six generalized linear models (GLM), on the 3 dependent driving performance variables regarding the group of MCI patients in rural area and urban area, are presented.


Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

MCI group

Area	Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
Rural Area	(Intercept)	38,20	0,8	2144,2	1	0,000
	Conversation	-1,20	1,2	1,1	1	,304
	Mobile phone	-2,95	1,5	3,7	1	,056
	No distraction	0^a				
	(Scale)	55,815^b	0,6			
Urban Area	(Intercept)	26,76	0,6	2144,0	1	0,000
	Conversation	-0,37	0,8	0,2	1	,660
	Mobile phone	0,91	1,3	0,5	1	,475
	No distraction	0^a				
	(Scale)	22,041^b	2,8			

Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

MCI group

Area	Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
Rural Area	(Intercept)	2096	71,3	863,6	1	0,000
	Conversation	-91	100,8	0,8	1	,365
	Mobile phone	343	135,5	6,4	1	,011
	No distraction	0^a				
	(Scale)	[illegible]	[illegible]			
Urban Area	(Intercept)	1505	48,6	960,8	1	0,000
	Conversation	199	70,2	8,0	1	,005
	Mobile phone	-56	104,7	0,3	1	,595
	No distraction	0^a				
	(Scale)	[illegible]	[illegible]			

Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

MCI group

Area	Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
Rural Area	(Intercept)	0,12	0,0	14,4	1	0,000
	Conversation	-0,01	0,0	0,0	1	,888
	Mobile phone	0,19	0,1	10,3	1	,001
	No distraction	0^a				
	(Scale)	[illegible]	[illegible]			
Urban Area	(Intercept)	0,26	0,0	77,5	1	0,000
	Conversation	0,21	0,0	25,6	1	,000
	Mobile phone	0,23	0,1	13,3	1	,000
	No distraction	0^a				
	(Scale)	[illegible]	[illegible]			

a *b* *c*

Fig. 3. *GLM regarding the effect of distraction on driving competence of the MCI group in rural and urban areas*
a Mean Speed
b Reaction Time
c Accident Probability

Investigating the effect of distraction in the group of MCI several interesting results are extracted. Mobile phone use has a significant impact on all three examined driving performance measures namely mean speed, reaction time and accident probability. More specifically, in rural area mobile phone use leads to lower speeds (approximately 8% lower speeds), to worse reaction time (0,34 sec worse reaction time) and higher accident probability (20% higher) in a significant level compared to their undistracted driving. It is of great interest that although in urban area mobile phone use doesn't lead to worse reaction time, it leads to 23% higher accident probability. On the other hand, the effect of conversation with passenger isn't that detrimental as it leads to larger reaction time and higher accident risk only in urban driving environment.

5.3. AD group

In Figure 4 the parameter estimates of six generalized linear models (GLM), on the 3 dependent driving performance variables regarding the group of AD patients in rural area and urban area, are presented.

Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

AD group

Area	Parameter	B	Std. Error	Wald Chi-Square	df	Sig.
Rural Area	(Intercept)	33,89	1,2	864,0	1	0,000
	Conversation	0,06	1,6	0,0	1	,969
	Mobile phone	-3,82	3,4	1,2	1	,265
	No distraction	0ª				
	(Scale)	62,480ᵇ	8,8			
Urban Area	(Intercept)	24,80	0,9	772,7	1	0,000
	Conversation	-1,06	1,4	0,6	1	,440
	Mobile phone	-0,11	2,4	0,0	1	,962
	No distraction	0ª				
	(Scale)	28,655ᵇ	4,9			

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

a

Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

AD group

Area	Parameter	B	Std. Error	Wald Chi-Square	df	Sig.
Rural Area	(Intercept)	2489	126,5	387,5	1	0,000
	Conversation	-33	181,9	0,0	1	,857
	Mobile phone	1246	403,9	9,5	1	,002
	No distraction	0ª				
	(Scale)	[illegible]	[illegible]			
Urban Area	(Intercept)	1782	81,9	473,3	1	0,000
	Conversation	65	135,5	0,2	1	,629
	Mobile phone	164	208,8	0,6	1	,431
	No distraction	0ª				
	(Scale)	[illegible]	[illegible]			

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

b

Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

AD group

Area	Parameter	B	Std. Error	Wald Chi-Square	df	Sig.
Rural Area	(Intercept)	0,27	0,0	31,4	1	0,000
	Conversation	-0,09	0,1	1,5	1	,219
	Mobile phone	0,43	0,2	7,6	1	,006
	No distraction	0ª				
	(Scale)	[illegible]	[illegible]			
Urban Area	(Intercept)	0,30	0,1	29,7	1	0,000
	Conversation	-0,12	0,1	1,7	1	,196
	Mobile phone	-0,14	0,1	0,9	1	,336
	No distraction	0ª				
	(Scale)	[illegible]	[illegible]			

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

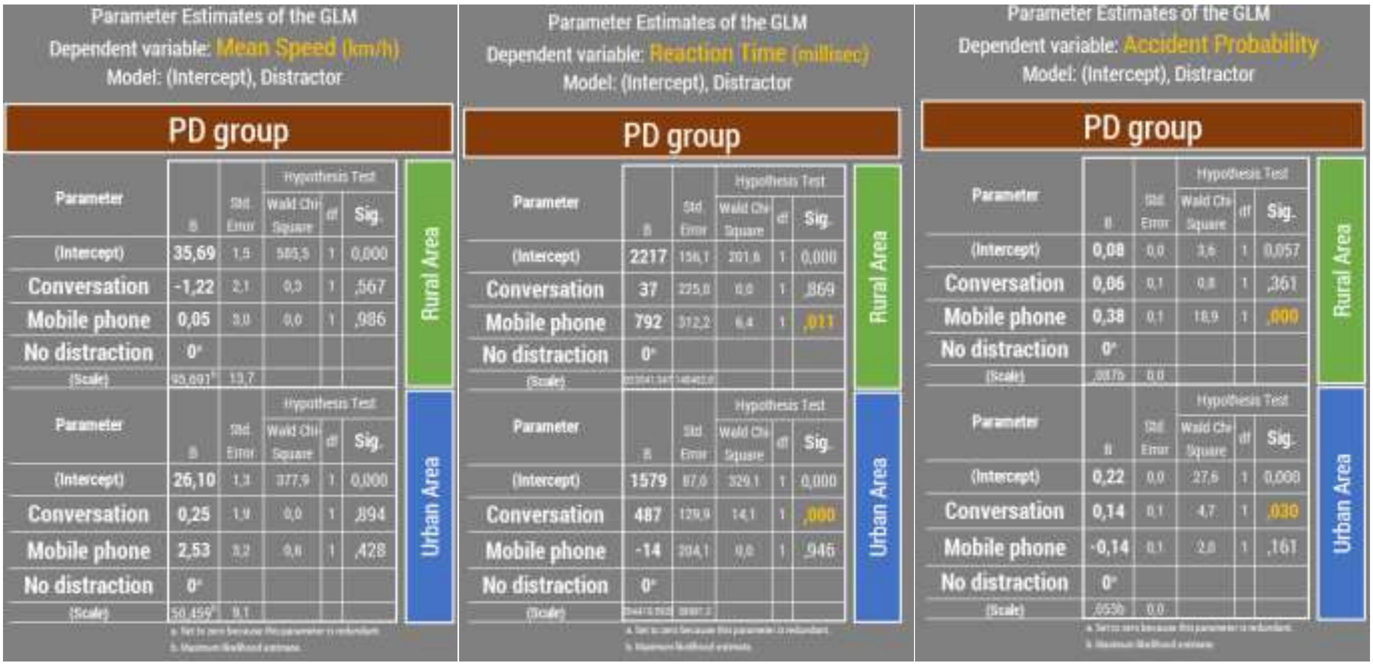
c

Fig. 4. *GLM regarding the effect of distraction on driving competence of the AD group in rural and urban areas*
a Mean Speed
b Reaction Time
c Accident Probability

Investigating the effect of distraction in the group of AD several interesting results are extracted but less than of the MCI group. More specifically, significant differences were detected only in rural area, where AD patients when using the mobile phone while driving have significantly larger reaction time and higher accident probability compared to their undistracted driving. Mobile phone use worsen the reaction times of AD patients by 1.2 sec and more importantly catapults their accident probability to more than 40%. In urban area no significant differences were detected regarding the effect of distraction to the driving competence of the AD group.

5.4. PD group

In Figure 5 the parameter estimates of six generalized linear models (GLM), on the 3 dependent driving performance variables regarding the group of PD patients in rural area and urban area, are presented.



Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

PD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	35,69	1,5	585,5	1	0,000
Conversation	-1,22	2,1	0,3	1	,567
Mobile phone	0,05	3,0	0,0	1	,986
No distraction	0a				
(Scale)	95,691b	13,7			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	26,10	1,3	377,9	1	0,000
Conversation	0,25	1,9	0,0	1	,894
Mobile phone	2,53	3,2	0,6	1	,428
No distraction	0a				
(Scale)	50,459b	9,1			

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

Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

PD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	2217	156,1	201,6	1	0,000
Conversation	37	225,0	0,0	1	,869
Mobile phone	792	312,2	6,4	1	,011
No distraction	0a				
(Scale)	[illegible]	[illegible]			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1579	87,0	329,1	1	0,000
Conversation	487	129,9	14,1	1	,000
Mobile phone	-14	204,1	0,0	1	,946
No distraction	0a				
(Scale)	[illegible]	[illegible]			

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

Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

PD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,08	0,0	3,6	1	0,057
Conversation	0,06	0,1	0,8	1	,361
Mobile phone	0,38	0,1	18,9	1	,000
No distraction	0a				
(Scale)	,0876b	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,22	0,0	27,6	1	0,000
Conversation	0,14	0,1	4,7	1	,030
Mobile phone	-0,14	0,1	2,0	1	,161
No distraction	0a				
(Scale)	,0530b	0,0			

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

Fig. 5. *GLM regarding the effect of distraction on driving competence of the PD group in rural and urban areas*
a Mean Speed
b Reaction Time
c Accident Probability

Investigating the effect of distraction in the group of PD significant differences were detected in their reaction time and their accident probability. More specifically, PD patients in rural area when using the mobile phone while driving they have significantly larger reaction time (0.8 sec larger) and higher accident probability (approximately 40%) compared to the undistracted driving. Finally, in urban area, less pronounced differences were detected; when conversing with passenger, PD patients have significantly larger reaction time and higher accident probability compared to the undistracted driving, but not when using their mobile phone.

6. Discussion and conclusions

The goal of this study is the analysis and the quantification of the impact of in-vehicle distraction on the driving competence of drivers suffering a brain pathology such that of MCI, AD or PD, through a large driving simulator experimental procedure. The sample scheme was divided in four categories of similar demographics: 34 Controls, 43 MCI, 28 AD and 20 PD drivers. No distraction condition, conversation with passenger and conversation through handheld mobile phone were examined regarding the following driving performance measures in rural and urban areas: Mean speed, Reaction time and Accident probability, with the use of a validated driving simulator. It is important to note that road safety research often uses driving simulators because they allow the investigation 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.

Summarizing the results extracted from this paper, in Figure 6 the results of the regression analyses regarding the effect of distraction on driving performance of the participants are presented and then discussed.

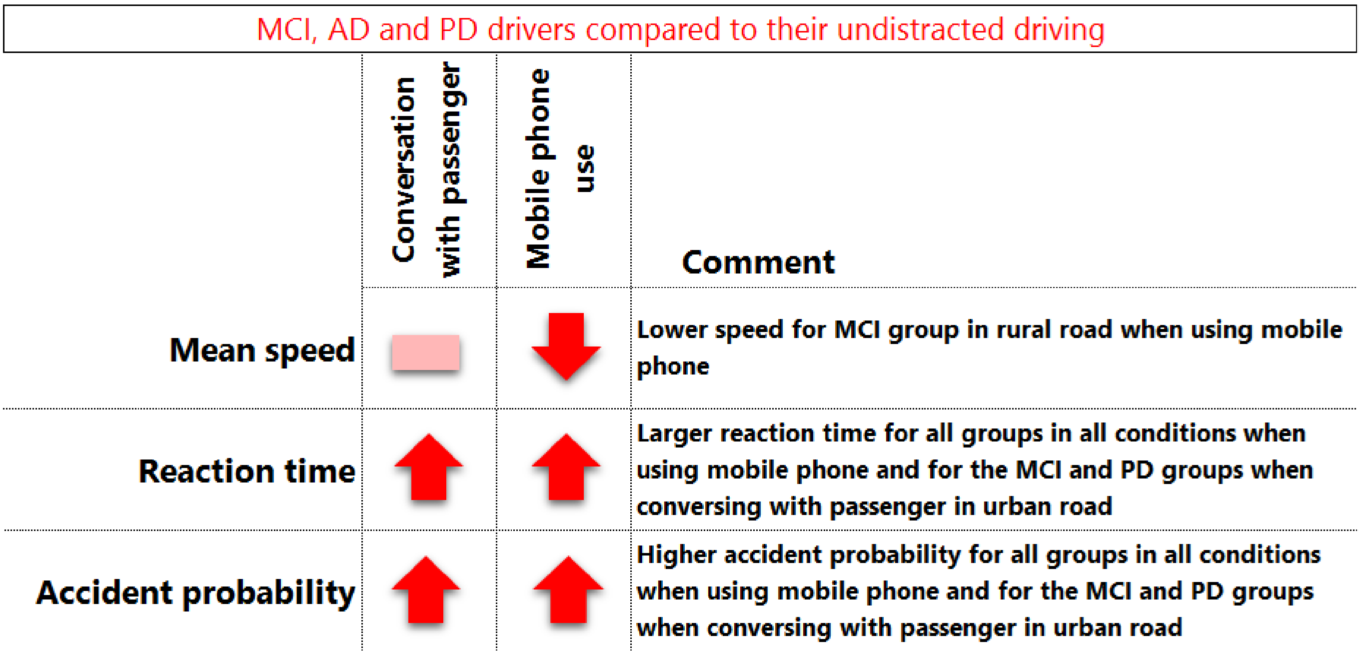


Fig. 6. *Summary figure regarding the effect of distraction on driving competence of the examined groups*

The use of mobile phone had the most pronounced negative effect on the driving behaviour of individuals with neurological diseases affecting cognitive functions as compared to a group of cognitively intact individuals of similar demographics. Overall, it appears that the distraction conditions don't have such a significant impact on several driving performance measures in the group of controls, in contrast with the findings extracted from the patients' groups regression analyses in whom the impact of distraction and especially the mobile phone use, was detrimental.

In particular, the reaction time in unexpected incidents of drivers with brain pathologies increased on more than 30% under the driving condition with the use of mobile phone (significant) whereas in the group of cognitively intact drivers the equivalent increase was only about 10% (and not in a significant level). Moreover, the group of drivers with neurological diseases affecting cognitive functions had a striking increase of the risk of being engaged in a car accident when using a mobile phone.

Notably, the aforementioned findings were detected despite the fact that the drivers with neurological diseases affecting cognitive functions tried to compensate their driving behaviour by reducing, at an important extent, their speed when using a mobile phone. Nevertheless, this self-regulated driving behaviour was unsuccessful; i.e. although in urban area mobile phone use didn't lead to worse reaction time for the MCI patients, it lead to 23% higher accident probability. Also, the presence of a conversation with a passenger had an impact on the driving performance of the patients, but of a smaller magnitude as compared to the case of the mobile phone. In particular, under this distraction condition there was an accentuation of the difference on reaction time and accident probability between group of patients and controls, but only for the MCI and the PD groups in urban area, in line with previous literature review [24]. Overall, the conversation with passenger didn't have a detrimental effect on the majority of the examined conditions.

The driving profile of individuals with neurological diseases affecting cognitive functions changed significantly under the more demanding driving condition that included the use of a hand-held mobile phone. The detection of this strong effect of the mobile phone on the driving fitness of individuals with neurological impairments could be explained by their reduced cognitive resources [30,31], especially during the performance of divided attention procedures [32]. Following this perspective, it seems that the execution of two tasks simultaneously, namely of driving and using a hand-held mobile phone, placed the group of drivers with neurological diseases affecting cognition in a vulnerable position due to the need to effectively divide their attention under this demanding driving condition, confirming our initial research hypothesis.

To sum up, the presence of an in-vehicle distractor while driving such as conversing through a handheld mobile phone, has a significantly deleterious effect on accident probability of drivers with cognitive impairments (AD, PD and in a lesser extend MCI). Overall, all these quantified observations that were extracted from the present study, even with the limitation of the large heterogeneity within and between group, could have considerable practical importance; they provide quite 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.), especially in a sensitive and vulnerable group of car drivers, such that of drivers with MCI, AD or PD.

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- "**DISTRACT** - Causes and impacts of driver distraction: a driving simulator study" within the Research Program THALES.
- "**DriverBRAIN** - Performance of drivers with cerebral diseases at unexpected incidents" within the Research Program ARISTEIA.

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