The impact of cognitive impairments on accident risk

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Abstract - The objectives of this paper are the analysis of the accident risk of drivers brain pathologies (Mild Cognitive Impairment, Alzheimer's disease, and Parkinson's disease), and the investigation of the impact of driver distraction on the accident risk of patients with brain pathologies, through a driving simulator experiment. The three groups of patients are compared to a healthy group of similar demographics, with no brain pathology. In particular, 125 drivers of more than 55 years old (34 "controls" and 91 "patients") went through a large driving simulator experimental process, in which incidents were scheduled to occur. They drove in rural and urban areas, in low and high traffic volumes and in three distraction conditions (undistracted driving, conversation with a passenger and conversation through a mobile phone). The statistical analyses indicated several interesting findings; brain pathologies affect significantly accident risk and distraction affects more the groups of patients than the control one.

INTRODUCTION

Road accidents constitute a major social problem in modern societies, accounting for more than 1 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].

Human factors are the basic causes in 65-95% of road accidents [3-5]. The accurate evaluation of crash causal factors can provide fundamental information for effective transportation policy, vehicle design, and driver education. Dingus et al., [6] 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 cerebral diseases. 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 [7, 8]. Executive functions which decline over age are of critical importance regarding driving performance. Diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to neurological diseases affecting cognitive functions as Alzheimer's disease, Parkinson's disease, cerebrovascular disorders (stroke), effect of pharmaceutical substances used for the treatment of various disturbances), 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. [9-12].

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 [13], 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 [12], 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 [14]. Regarding Alzheimer's disease, although research findings suggest that individuals with this disease may still be fit to drive in the early stages [15], they may show visual inspection and target identification disorders during driving [16]. Moreover, the associated impairment in executive functions appears to have a significant effect on driving performance [17], especially at unexpected incidents. Studies regarding Parkinson disease are less conclusive in terms of the impact of its clinical parameters on driving abilities [10, 11]. 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.

In summary, various parameters may affect the driving performance of individuals with neurological diseases affecting cognitive functions, including demographic, medical, neurological and neuropsychological parameters. The aforementioned neurological diseases affecting cognitive functions and other related parameters are rather common in the general population, especially in older adults, and may have an important effect on accident risk, especially at unexpected incidents, which has not been investigated sufficiently.

OBJECTIVES

Accident risk in case of unexpected incidents is considered to be of critical importance regarding road safety. The objectives of this paper are the analysis of the accident risk of drivers with cognitive impairments due to brain pathologies, through a large driving simulator experiment and then the investigation of the impact of driver distraction on the accident risk of patients with brain pathologies. The brain pathologies examined include Mild Cognitive Impairment (MCI), early Alzheimer's disease (AD), and early Parkinson's disease (PD) and the in-vehicle distraction conditions examined are conversation with a passenger and conversation through a hand-held mobile phone. The three groups of patients are compared to a healthy control group of similar age, driving experience and education, with no brain pathologies.

For that purpose 125 older drivers of more than 55 years of age (34 "controls" and 91 "patients") went through a driving simulator experimental process: 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 through a hand-held mobile phone) were examined in a full factorial within-subject design. Our research hypotheses are that the presence of a brain pathology affects significantly accident risk and secondly, that in-vehicle distraction affects more the groups of patients than the control one. Both these hypotheses, are not only confirmed by this paper but also quantified by appropriate statistical modeling techniques.

METHODOLOGY

This study was carried out by an interdisciplinary research team of engineers, neurologists and psychologists [18,19]. 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.

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.

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 [20].

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:

- 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. Unexpected incident in rural road

During each trial, 2 unexpected incidents were scheduled to occur during the drive (Figure 1). 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. 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 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.

Sampling scheme

For the purpose of this study 274 participants started the driving simulator experiment that was described 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 (”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 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 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 of the two groups.

Table 1. Comparison of patients with MCI, AD, and PD and of the Control group with the use of the Wilcoxon Rank Sum Test

	"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

RESULTS

In order to answer to our research questions, linear regression modeling was implemented to investigate the accident risk 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.

The accident risk of the 3 groups of patients was compared to the healthy controls' accident risk. In Figure 2 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the accident risk in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM

Dependent variable: Accident Probability

Model: (Intercept), Disease, No distraction Condition

	Low Traffic					High Traffic					
			Hypothesis Test					Hypothesis Test			
Parameter	B	Std. Error	Wald Chi-Square	df	Sig.	B	Std. Error	Wald Chi-Square	df	Sig.	
(Intercept)	0,13	0,0	11,2	1	0,001	0,04	0,0	1,4	1	0,238	Rural Area
MCI	-0,01	0,1	0,0	1	,916	0,09	0,0	3,2	1	,072	
AD	0,15	0,1	5,4	1	,020	0,19	0,1	11,6	1	,001	
PD	-0,03	0,1	0,2	1	,691	0,04	0,1	0,4	1	,521	
Controls	0[a]					0[a]					
(Scale)	,068[b]	0,0				,055[b]	0,0				
			Hypothesis Test					Hypothesis Test			
Parameter	B	Std. Error	Wald Chi-Square	df	Sig.	B	Std. Error	Wald Chi-Square	df	Sig.	
(Intercept)	0,07	0,0	2,8	1	0,095	0,10	0,0	4,7	1	0,030	Urban Area
MCI	0,16	0,1	6,2	1	,013	0,15	0,1	4,4	1	,037	
AD	0,23	0,1	9,6	1	,002	0,20	0,1	5,3	1	,021	
PD	0,12	0,1	2,0	1	,156	0,19	0,1	4,2	1	,042	
Controls	0[a]					0[a]					
(Scale)	,066[b]	0,0				,076[b]	0,0				

a. Set to zero because this parameter is redundant.

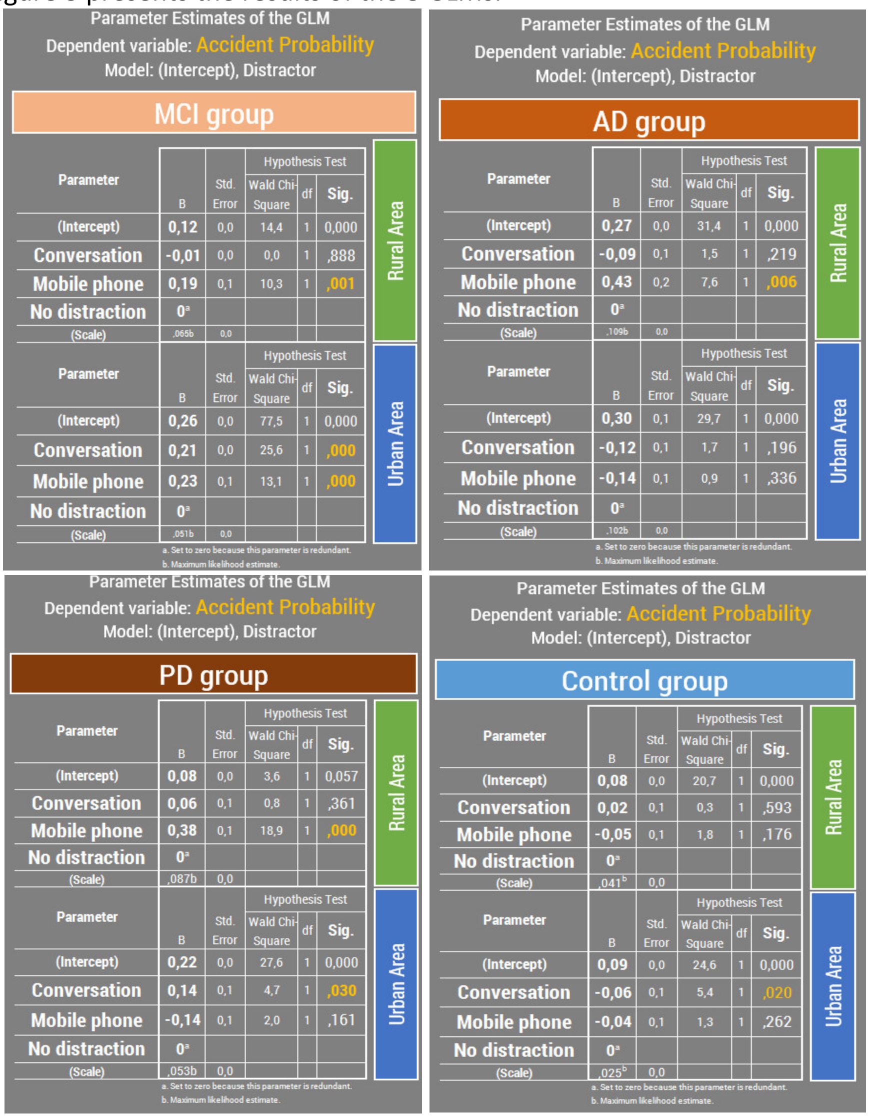
b. Maximum likelihood estimate.

Figure 2. GLM - Accident risk / undistracted driving

The 4 GLM models indicated several interesting results. It is observed that, overall, control drivers had a small accident risk compared to the group of patients in both rural and urban driving environments and in both low and high traffic volumes. All 3 groups of patients in almost every condition examined had significantly higher accident probability that the controls. In urban area, it seems more likely for the groups of patients to have an accident, because of its complexity as a driving environment. AD patients had significantly higher accident probability than the controls in every examined condition. More specifically, AD group had 15% and 19% accident probability in low and high traffic volumes respectively in rural area, whereas they had 23% and 20% in urban area (slightly higher). MCI group had significant differences with the control group only in urban area, where they had approximately 16% accident probability. Finally, regarding the PD group, they had 19% accident probability in urban area in high traffic volume. The MCI and PD groups in rural area didn't have significant differences regarding accident risk with the control group.

Summarizing the results, AD participants in all 4 driving conditions had significantly higher accident probability by more than 15% compared to healthy controls of similar demographics. Then, PD participants had significantly worse accident probability than the controls only in urban area in high traffic volume (the most complex driving environment of all four). MCI patients didn't have significant differences with the control group in rural road, but on the other hand they had higher accident probability in urban driving environment.

Moving on to the effect of the in-vehicle distraction on the accident risk of drivers with cognitive impairments, figure 3 presents the results of the 8 GLMs.



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

MCI group

Area	Parameter	B	Std. Error	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)	,065b	0,0			
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	13,1	1	,000
	No distraction	0[a]				
	(Scale)	,051b	0,0			

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

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	0[a]				
	(Scale)	,109b	0,0			
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	0[a]				
	(Scale)	,102b	0,0			

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

Area	Parameter	B	Std. Error	Wald Chi-Square	df	Sig.
Rural Area	(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	0[a]				
	(Scale)	,087b	0,0			
Urban Area	(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	0[a]				
	(Scale)	,053b	0,0			

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

Control group

Area	Parameter	B	Std. Error	Wald Chi-Square	df	Sig.
Rural Area	(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	0[a]				
	(Scale)	,041[b]	0,0			
Urban Area	(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	0[a]				
	(Scale)	,025[b]	0,0			

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

Figure 3. GLM - Accident risk / distracted driving

Several interesting findings were extracted by this GLM analysis too. Firstly, it is easily detected that the hand-held mobile phone use didn't have any significant impact on the accident risk of the healthy drivers. On the other hand, mobile phone use had a detrimental impact on the accident risk of all patient groups in almost every examined condition. The conversation with passenger had only significant impact on the accident risk in urban area for the PD group. MCI drivers had more than 20% accident risk while conversing through mobile phone, AD drivers had 43% and PD drivers 38% accident risk in rural area while conversing through mobile phone.

CONCLUSIONS

The objectives of this paper were the analysis of the accident risk of drivers with cognitive impairments due to brain pathologies (MCI, AD, and PD), and then the investigation of the impact of driver distraction on their accident risk. The in-vehicle distraction conditions examined, were conversation with a passenger and conversation through a hand-held mobile phone. The three groups of patients were compared to a healthy control group of similar demographics, with no brain pathologies. 125 older drivers of more than 55 years of age (34 "controls" and 91 "patients") went through the experimental procedure. Our research hypotheses were that the presence of a brain pathology affects significantly accident risk and secondly, that in-vehicle distraction affects more the groups of patients than the control one.

The GLMs regarding the undistracted driving, indicated that there are significant differences between the accident risk of patients with cognitive impairments and the control group. The presence of a brain disease had a detrimental impact on accident risk and especially the presence of AD leads to significantly higher accident risk (AD group had accident approximately in 1 out of 5 incidents) in comparison to the healthy group. The traffic volume didn't have any significant effect on the accident risk of all examined groups, whereas the driving area had. More specifically, the more complex driving environment of the urban area leads to increased accident risk for the group of patients with brain pathologies (especially for the PD patients).

Regarding the effect of distraction, it is notable that the control group seemed unaffected regarding their accident risk when conversing with a passenger or when they converse through a handheld mobile phone. On the other hand, the use of the mobile phone had a significant effect on the accident risk of all three groups of patients in almost every examined condition (accident risk of drivers with AD climbed to 43% and for PD drivers to 38% in rural area while conversing through mobile phone).

All above results are considered as quite promising and not only confirm but also quantify our initial hypotheses. The results are to be considered, though, within the limiting context of driving simulator studies, as driving performance is known to be more reliably estimated by means of on-road studies. However, the relative effects of patients vs. healthy drivers are known to be quite identifiable in driving simulator studies. Especially, when investigating the accident risk in unexpected incidents, which is very difficult to assess and examine in on-road studies, the driving simulator provides a reliable and safe environment to assess accident risk.

To conclude, the take-home message of the present paper is that drivers with cognitive impairments had difficulty in avoiding the crash when an unexpected incident happened in front of them, and thus they had significantly increased accident risk, in comparison with the healthy controls of similar demographic characteristics. In particular, in undistracted condition, AD drivers had the worst "accident risk profile" in all examined conditions among all groups, followed by the PD group but only in urban area which constitutes a more complex driving environment. MCI group had an overall lower accident risk compared to the other two groups of patients, but not compared to the healthy drivers.

What is more, the presence of an in-vehicle distractor while driving such as conversing through a handheld mobile phone, has a significantly deleterious effect on accident risk of drivers with cognitive impairments (AD, PD and in a lesser extend MCI). Overall, all these observations that were extracted from the present study 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 group of car drivers, such that of drivers with MCI, AD or PD.

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REFERENCES

1 WHO, 2015. Global status report on Road Safety 2014, supporting a decade of action, World Health Organisation.
2 OECD (2013). IRTAD Road Safety Annual Report 2013.
3 Sabey, B.E., Taylor, H., 1980. The known Risks We Run: The Highway. TRRL Report SR 567, Crowthorne, TRRL.
4 Salmon, P., Young, K., Lenné, M., Williamson, A., Tomasevic, N., 2011. The Nature of Errors made by Drivers. Austroads Publication No. AP–R378/11. Austroads Ltd., Australia.
5 Treat, J.R., 1980. A study of precrash factors involved in traffic accidents. HSRI Research Review 10(6)/11(1), 1-36.
6 Dingus T.A., Guo F., Lee S., Antin J.F., Perez M., Buchanan-King M., Hankey J., (2016), "Driver crash risk factors and prevalence evaluation using naturalistic driving data", PNAS, vol. 113 no. 10, pg. 2636–2641, doi: 10.1073/pnas.1513271113
7 Baldock, M. R. J., Mathias, J., McLean, J., & Berndt, A. (2007). Visual attention as a predictor of on-road driving performance of older adults. Australian Journal of Psychology, 59, 159-168.
8 OECD (2008). Towards Zero: Ambitious Road Safety Targets and the Safe System Approach. OECD, Paris, October 2008.
9 Wood, J. M., C. Worringham, et al. (2005). Quantitative assessment of driving performance in Parkinson's disease. J Neurol Neurosurg Psychiatry 76(2): 176-80.
10 Cordell, R., H. C. Lee, et al. (2008). Driving assessment in Parkinson's disease - a novel predictor of performance? Mov Disord 23(9): 1217-22.
11 Cubo, E., P. Martinez Martin, et al. (2009). "What contributes to driving ability in Parkinson's disease." Disabil Rehabil.
12 Frittelli, C., D. Borghetti, et al. (2009). Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test. Int J Geriatr Psychiatry 24(3): 232-8.
13 Ravaglia, G., Forti, P., Montesi, F., Lucicesare, A., Pisacane, N. Rietti, E. et al. (2008). Mild Cognitive Impairment: Epidemiological and dementia risk in an elderly Italian population. Journal of the American Geriatrics Society, 56, 51-58.
14 Lafont, S., Laumon, B., Helmer, C., Dartigues, J. F., & Fabrigoule, C. (2008). Driving cessation and self-reported car crashes in older drivers: The impact of cognitive impairment and dementia in a population-based study. Journal of Geriatric Psychiatry and Neurology, 21, 171-182.
15 Ott, B. R., W. C. Heindel, et al. (2008). A longitudinal study of drivers with Alzheimer disease. Neurology 70(14): 1171-8.
16 Uc, E. Y., M. Rizzo, et al. (2005). Driver landmark and traffic sign identification in early Alzheimer's disease. J Neurol Neurosurg Psychiatry 76(6): 764-8.
17 Tomioka, H., B. Yamagata, et al. (2009). Detection of hypofrontality in drivers with Alzheimer's disease by near-infrared spectroscopy. Neurosci Lett 451(3): 252-6.
18 Yannis G., Golias J., Antoniou C., Papadimitriou E., Vardaki S., Papantoniou P., Pavlou D., Papageorgiou S., Andronas N., Papatriantafyllou I., Liozidou A., Beratis I., Kontaxopoulou D., Fragkiadaki S., Economou A., "Design of a large driving simulator experiment on performance of drivers with cerebral diseases", Proceedings of the 4th International Conference on Road Safety and Simulation, Rome, October 2013

19 Pavlou D., Papadimitriou E., Yannis G., Papantoniou P., Papageorgiou S.G., "First findings from a simulator study on driving behaviour of drivers with cerebral diseases", Proceedings of the Transport Research Arena Conference, Paris, April 2014.

20 Yannis G., Papantoniou P., Nikas M., "Comparative analysis of young drivers behavior in normal and simulation conditions at a rural road", Proceedings of the 5th International Conference on Road Safety and Simulation, Universities of Central Florida and Tennessee, Orlando, Florida, October 2015