Driving behaviour of drivers with Mild Cognitive Impairment and Alzheimer's Disease: A driving simulator study

Dimosthenis Pavlou[a1], Eleonora Papadimitriou[a], Constantinos Antoniou[a], Panagiotis Papantoniou[a], George Yannis[a], John Golias[a], Sokratis G. Papageorgiou[b]

[a] National Technical University of Athens, Department of Transportation Planning and Engineering, Athens, Greece
[b] National and Kapodistrian University of Athens, Medical School, Department of Neurology, Athens, Greece

Abstract

The objective of this research is the analysis of the driving performance of drivers with Alzheimer's disease (AD) and Mild Cognitive Impairment (MCI), on the basis of a driving simulator experiment, in which healthy "control" drivers and impaired drivers drive in different driving scenarios, following a thorough neurological and neuropsychological assessment of all participants. The driving scenarios include driving in rural and urban areas in low and high traffic volumes. The driving performance of drivers impaired by the examined pathologies (AD and MCI) is compared to that of healthy controls by means of Repeated Measures General Linear Modeling techniques. In this paper a sample of 75 participants is analyzed. Various driving performance measures are examined, including speed, lateral position, steering angle, headway, reaction time at unexpected events etc., some in terms of their mean values and some in both their mean values and their variability. The results suggest that the two examined cerebral diseases do affect driving performance, and there are common driving patterns for both cerebral diseases, as well as particular characteristics of specific pathologies. More specifically, drivers with these cerebral diseases drive at lower speeds and with larger headway compared to healthy drivers. Moreover, they appear to have difficulties in positioning the vehicle on the lane. Cerebral diseases also appear to significantly affect reaction times at incidents.

Key-words: driving performance; driving simulator; Mild Cognitive Impairment; Alzheimer's disease

[1] Corresponding author: Dimosthenis Pavlou
National Technical University of Athens, Department of Transportation Planning and Engineering
Address: 5 Heroon Polytechniou str. GR-15773 Athens
Tel: +302107721380, Fax: +302107721454
E-mail: dpavlou@central.ntua.gr

1. Background

The task of driving requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses (Waller, 1980; Freund et al., 2005). Various motor, visual, cognitive and perceptual deficits can affect the ability to drive. These deficits are either age-related or caused by neurologic disorders and lead to reduced driver fitness and increased crash risk. More specifically, diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to neurological diseases as Alzheimer’s disease) may significantly impair the person's driving ability (Wood et al., 2005; Cordell et al., 2008; Cubo et al., 2009; Frittelli et al., 2009). These conditions have obvious impacts on driving performance, but in mild cases and importantly in the early stages, they may be imperceptible in one’s daily routine yet still impact one’s driving ability. Furthermore, neuropsychological parameters associated with driving performance are reaction time, visual attention, speed of perception and processing, and general cognitive and executive functions. These parameters show considerable decline with age or at the presence of cognitive impairments and are associated with the probability of accident involvement (Lunsman et al., 2008).

Relatively little is known about the competence of drivers with Mild Cognitive Impairment (MCI). This constitutes a considerable gap, given that MCI is a pathological condition with high prevalence in the general population as ~15% of people >65 years old are affected. In addition, MCI eventually develops into dementia with a high annual rate (Winblad et al., 2004). The concept of MCI has been described as a cognitive state that lies between normal aging and dementia (Petersen et al., 1995). Persons with MCI exhibit cognitive decline beyond what is expected to be normal for age, but are otherwise functioning well and do not meet criteria for dementia. Research results are not conclusive on the extent to which MCI is affecting driving behaviour and safety. MCI drivers seem to have statistically significant driving behaviour deviation (maintaining speed, wheel stability, and lateral control) from the control driving population (Wadley et al., 2009). Another study tried to ascertain which cognitive features contribute to the safe driving behaviour of MCI drivers. Participants drove using a driving simulator and seemed to have considerable difficulties in maintaining lateral control on a road and in following the vehicle ahead (Kawano et al., 2012).

Moreover, Alzheimer’s disease (AD) is the most frequent form of dementia worldwide (Evans et al., 1989). In the early stages of the disease, a variety of symptoms can be observed with gradually progressive memory impairment being the most prominent symptom. Additional deficits may be present, including, visuospatial deficits, impaired attention, executive dysfunction and judgment, verbal fluency and confrontation naming (Zec, 1993). Another research showed that AD drivers (especially the elderly) made many more safety errors (the most common errors were lane violations) (Dawson et al., 2009). Longitudinal evidence was provided for a decline in driving performance over time, primarily in early-stage dementia of the Alzheimer type (Duchek et al., 2003). Mild AD significantly impaired simulated driving fitness, while MCI limitedly affected driving performance (Frittelli et al., 2009). What is more, an accurate judgment of someone’s own ability to drive and the resultant compensatory behaviour are prerequisites of safe driving, an ability that is often impaired in dementia (Johansson & Lundberg, 1997).

Given that the percentage of the elderly in society is increasing (Baldock et al., 2007), and that the level of motorization also increases (Yannis et al., 2011), the investigation of the impact of these conditions on driver performance becomes quite critical. It is also highlighted that relatively few studies exist analyzing the effect of a specific pathology on driving performance, and even fewer studies comparing different pathologies.

2. Objectives

The objective of this research is to analyze the driving performance of drivers with Alzheimer's disease (AD) and Mild Cognitive Impairment (MCI), by means of a driving simulator experiment. Various driving performance measures are examined in both rural and urban environment, e.g. mean speed, lateral position, steering angle, headway, reaction time at unexpected events etc. The driving performance of drivers impaired by the above pathologies is compared to that of healthy controls by means of Repeated Measures General Linear Modeling techniques. The research questions that are examined in this paper are: how MCI and AD affect various measures of driving performance and how these diseases interact with road and traffic parameters.
The paper starts a presentation of a large driving simulator experiment, in which the driving performance of the impaired and healthy drivers was examined in different driving scenarios, following a thorough neurological and neuropsychological assessment of all participants. The existing sample size and characteristics are presented next, followed by a short description of the analysis methods, dependent and independent variables. The results are presented and discussed, and some concluding remarks are provided.

3. Driving Simulator Experiment

3.1. Overview

This research is based on a methodological framework for the combined assessment of traffic, behavioural, medical, neurological and neuropsychological parameters on driving performance. In this framework, the aspects of driver behaviour and safety research addressed are inherently interdisciplinary, and an experiment was designed by an interdisciplinary research team including:

- Transportation Engineers - Department of Transportation Planning and Engineering, of the National Technical University of Athens (NTUA)
- Neurologists - 2nd Department of Neurology, University of Athens Medical School, at ATTIKON University General Hospital, Haidari, Athens
- Neuropsychologists - Department of Psychology, University of Athens, the 2nd Department of Neurology of ATTIKON University General Hospital, Haidari, Athens and the Aristotle University of Thessaloniki.

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

- Medical / neurological assessment:
  The first assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of these disorders (e.g. MCI, AD, PD, 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:
  The third assessment concerns the driving behaviour by means of programming of a set of driving tasks into a driving simulator for different driving scenarios.

The first and second assessments are carried out at the ATTIKON University General Hospital, and their description is beyond the scope of this paper; for details the reader is referred to Papadimitriou et al., 2014. The third assessment, (driving simulator experiment) takes place in the NTUA Road Safety Observatory and is presented in detail in the following section.

3.2. Driving at the simulator

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).

The design of the driving scenarios includes driving in different road and traffic conditions, such as in a rural, urban area with high and low traffic volume, with or without external distraction. More specifically, the driving simulator experiment begins with one practice drive (usually 10-15 minutes), until the participant fully familiarizes with the simulation environment. Afterwards, the participant drives two sessions (approximately 20 minutes each). Each session corresponds to a different road environment: a rural route that is 2.1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves and an urban route that is 1.7km long, at its bigger part dual carriageway, separated by guardrails and the lane width is 3.5m. Two traffic controlled junctions, one stop-controlled junction and one roundabout are placed along the route.

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

- Low traffic conditions - ambient vehicles' arrivals are drawn from a Gamma distribution with mean m=12sec, and variance σ^2=6 sec, corresponding to an average traffic volume Q=300 vehicles/hour.
- High traffic conditions - ambient vehicles' arrivals are drawn from a Gamma distribution with mean m=6sec, and variance σ^2=3 sec, corresponding to an average traffic volume of Q=600 vehicles/hour.

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

Consequently, in total, each session (urban or rural) includes six trials 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. 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.

4. Analysis Methods and Data

The aim of this research is to analyze and compare the driving performance of MCI, AD and healthy drivers in rural and urban road environment. For that purpose, four trials of the simulator experiment are selected: the undistracted driving trials in rural area and the undistracted driving trials in urban area in both low and high traffic volumes.

The analysis method selected is the Repeated Measures General Linear Model (GLM). The repeated measures GLM is the equivalent of the one-way ANOVA, but for related, not independent groups. A repeated measures GLM may be based on a within-subjects or a mixed design (Caird et al., 2011).

At the present time more than 140 participants have participated in the driving simulator experiment in approximately 15 months time. However, about 30 participants had simulator sickness issues (a usual phenomenon in driving simulators) and didn't complete the driving trials of the experiment. For that reason they are eliminated from the study. Moreover there are 35 participants of younger age (<55 years old) who are eliminated too for age representativity reasons. The analysis is thus based on the existing related sample of the (ongoing) simulator experiment of healthy and impaired participants of over than 55 years of age who completed all of the examined four trials were selected, which consists of 75 participants (49 males). More specifically, the sample of the present study consists of:

- 38 healthy "controls" (66.4 years old on average),
- 14 AD patients (74.6 years old on average) and
- 23 MCI patients (68.3 years old on average).

It is noted that the gender distribution of healthy and impaired drivers is currently not fully similar, i.e. the proportion of females is lower in the impaired drivers group (no female AD participant), which is in any case representative of the general population. On the other hand, the age distributions of impaired and healthy drivers are comparable to a satisfactory degree, taking into account that it is expected that impaired drivers are on average older than healthy ones.

The variables examined in the present research include a between-subject variable, namely the presence of a disease (AD or MCI). They also include one within-subject variables, namely the traffic scenario (low or high traffic volume). It is noted that area type (rural, urban) is not examined as a within-subject variable, because all participants drove first in rural area and then in urban area; this was done for practical reasons but obviously results in order effects, and consequently the two area types are examined separately and not comparatively. The driving performance measures examined include both longitudinal control measures and lateral control measures. More specifically:

- Longitudinal control measures:
  - Mean speed (mean speed of the driver along the route, excluding the small sections in which incidents occurred, and excluding junction areas)
  - Headway (time distance between the front of the simulator vehicle and the front of the vehicle ahead)
  - Reaction time at unexpected incidents (time between the first appearance of the event on the road and the moment the driver starts to brake in milliseconds)
- Lateral control measures:
  - Lateral position (vehicle distance from the central road axis in meters),

- Lateral position variability (the standard deviation of lateral position),
- Mean wheel steering angle (in degrees)
- Steering angle variability (the standard deviation of steering angle).

5. Results

A Repeated Measures General Linear Model was developed for each one of the driving performance measures considered. The analysis of variance for the within subject variables (Table 1) indicated that traffic volume has a significant effect on mean speed, mean headway and lateral position in both road environments, and lateral position variability and steering angle variability only on rural road. Regarding the between-subject variable, the presence of a disease was found to significantly affect mean speed and reaction time in both road environments. The presence of a cerebral disease seems to affect mean headway, lateral position variability and steering angle variability only in rural roads and lateral position only in urban road environment.

Table 1 to be inserted here

5.1. Effect of cerebral diseases in rural roads

The results of the GLMs fitted to the data for the various longitudinal and lateral control measures of the rural driving session, in terms of parameter estimates and their statistical significance, are presented in Tables 2 and 3. Table 2 refers to the longitudinal control measures in rural area, whereas table 3 refers to lateral control measures in rural area.

Cerebral diseases appear to have a significant effect on driver mean speed in rural driving environment. AD and MCI patients drive at significantly lower mean speed compared to healthy drivers, both at low and high traffic volumes. AD drivers' speed is significantly lower than the MCI drivers' speed, in both driving environments.

Moreover, cerebral diseases appear to have a significant effect on mean headway in rural roads but only for AD patients: they have significantly longer mean headway compared to healthy drivers at both traffic environments. This is happening for MCI drivers too, but the confidence level was only 85%. AD drivers have much longer mean headway compared with the MCI drivers. These results are intuitive, given that lower speeds naturally result in larger headways, with a given distribution of ambient traffic on the road network. It is also noted that headways at low traffic volumes are longer for all driver groups, which is also intuitive.

Significant differences in the driving behavior of healthy and impaired drivers were also identified as regards the drivers' reaction time at unexpected incidents in rural roads (sudden appearance of a deer or a donkey). In both traffic environments impaired drivers have about 0.5 sec longer reaction times than the healthy ones. This difference was found to be statistically significant at 90% confidence level for both impaired groups and both traffic volumes, except for MCI drivers in high traffic volume who have longer reaction times than the control group statistically significant at 95% confidence level.

Table 2 to be inserted here

Regarding lateral position in rural area, it is worth mentioning that the width of the driving lane is 3m (i.e. very narrow), so the drivers don't have so much flexibility in positioning their vehicle on the lane. Thus, there are no significant differences in lateral position for the drivers. Positive values indicate driving more closely to the right border of the road.

On the other hand, the lateral position variability seems to have differences for MCI drivers in both traffic volumes. Lateral position variability is lower than that of healthy controls, and this may be a result of the lower speed and their more conservative driving.
Finally, no statistically significant differences are observed in mean steering angle in rural area, between control group and impaired drivers - a positive mean steering angle means more counter-clockwise steering movements, which is in accordance with a lateral position closer to the central road axis. On the other hand, there is statistically significant variability in steering angle; all examined impaired drivers in high traffic volume environment have lower steering angle variability.

Table 3 to be inserted here

5.2. Effect of cerebral diseases on urban roads
The results of the GLMs fitted to the data for the various longitudinal and lateral control measures of the urban driving session, in terms of parameter estimates and their statistical significance, are presented in Tables 4 and 5. Table 4 refers to the longitudinal control measures in urban area, whereas table 5 refers to lateral control measures in urban area.
In urban road environment similar statistical results with the rural area type were observed, regarding the longitudinal control measures. Mean speed is significantly lower for impaired drivers in urban driving environment. AD and MCI drivers seem to drive at the same speed in both at low and high traffic volumes.
However, cerebral diseases appear not to have a significant effect on mean headway in urban roads. Only MCI patients seem to have significantly longer mean headway compared to healthy drivers only at high traffic environment.
Finally, regarding the reaction times, they appear to be improved for the impaired drivers compared to the rural road. They are more closely to the reaction times of the control group and have significant differences at 90% confidence level only in low traffic volume. This is possibly also due to the learning effect resulting from the fact that the urban area trials took place after the rural area trials for all participants

Table 4 to be inserted here

Regarding lateral position in urban area, MCI patients appear to drive at longer distance from the central road axis compared to healthy drivers, both at high and at low traffic volumes (statistically significant at 90% confidence level). AD drivers in high traffic volume have significant differences in lateral position too. This is observed only in urban road environment and it' is worth mentioning, that the width of the driving lane is 3,5m, there are 2 lanes in the bigger part of the route, so there are opportunities for overtaking and there are choices in positioning the vehicle on the road. It seems that in urban areas the high traffic volume makes the conditions more complex for the impaired drivers and leads them to drive more closely to the right border of the road. Especially for AD drivers there is significant increase in the variability of the lateral position in high traffic volume (in contrast with all other cases).
Statistically significant differences are not observed for mean steering angle, or for the variability in the steering angle between control group and impaired drivers.

Table 5 to be inserted here

6. Conclusions and Discussion

This paper analyzed the driving performance of drivers with cerebral diseases, with focus on the comparative assessment of AD and MCI pathologies. Relatively few studies exist analyzing the effect of a specific pathology on driving performance, and even fewer studies comparing different pathologies. The majority of these studies indicate serious deterioration in driving performance of drivers with a cerebral disease compared to healthy drivers.

The research questions examined in this paper are: how the examined pathologies affect various measures of driving performance and how they interact with road and traffic parameters. For this purpose, four trials were selected from a large driving simulator experiment including twelve trials in total, namely those concerning undistracted driving in rural and urban areas with low or high traffic volume. These four trials were based on a mixed (within-and between-subject) counterbalanced design. Both longitudinal and lateral control measures are examined, e.g. speed, lateral position, steering angle, headway, reaction time at unexpected events etc. by means of Repeated Measures General Linear Modeling techniques. This research in progress is one of the few which attempt to compare different pathologies in terms of their effect on driving performance.

Summarizing the results, AD and MCI drivers were found to drive at significantly lower speeds compared to the healthy control group drivers, both at low and at high traffic volume. AD drivers in rural environment have even lower mean speed compared to the MCI drivers, but in urban roads their speed is approximately the same. As would be expected, this reduced speed results under given ambient traffic conditions in increased headways, both at low and at high traffic volumes in rural roads, however in urban environment there are statistically significant differences in mean headways only for MCI drivers in high traffic volume.

Analyzing the reaction times of the impaired drivers at unexpected incidents, it is observed that MCI and AD drivers have significantly longer reaction times in rural road in both traffic volumes compared with the control group. In urban area, they have longer reaction times, but only in low traffic volume this difference is significant. Compared with each other, MCI drivers seem to have slightly better reaction times than the AD group in most cases. These longer reaction times of impaired drivers are likely to be confirmed by their neurological and neuropsychological assessments (at the present time the medical and neuropsychological database is under preparation in order to be finalized and used in future statistical analyses, and thus it is not available).

Analyzing the lateral control measures it is observed that in rural area there are more statistically significant differences between the driving groups except for lateral position because of the very narrow lane in rural area. More specifically, MCI patients drive more closely to the right border of the road in urban area and in both traffic volumes, whereas AD drivers only in high traffic volume in urban area. Regarding the variability of this measure, a significantly higher variability is highlighted for AD divers in high traffic volume in urban area. It seems that the more complex is the driving environment the more the AD drivers have difficulty in maintaining the position of the vehicle on the lane. Finally, in rural area both impaired groups have low steering variability in high traffic volume that is a result of their low speed and conservative driving.

The effect of the sample representativity is something that needs to be highlighted; the age and gender distributions of the impaired and control populations seem balanced at the present time, however sample representativity should be improved in the next steps of the ongoing experiment. The larger proportion of female drivers in the control group is representative, as the proportion of female AD or MCI patients is low in the general population. On the other hand, the average age of the examined groups should be totally balanced, in order to eliminate the possibility that the differences of the diving behaviour between the examined groups are a result of age distribution.

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.

7. Acknowledgement

This research 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, and the Action: ARISTEIA (Action’s Beneficiary: General Secretariat for Research and Technology), co-financed by the European Union (European Social Fund - ESF) and Greek national funds.

More information available at: DRIVERBRAIN: http://www.nrso.ntua.gr/driverbrain and DISTRACT: http://www.nrso.ntua.gr/distract.

8. References

Baldock, M. R. J., Mathias, J., McLean, J., & Berndt, A. Visual attention as a predictor of on-road driving performance of older adults. *Australian Journal of Psychology*, 59, 2007, pp. 159-168.

Caird, J.K., Horrey, W. Twelve practical and useful questions about driving simulation. In Fisher, D.L., Rizzo, M., Caird, J.K., & Lee, J.D. (Eds). (2011). *Handbook of Driving Simulation for Engineering, Medicine, and Psychology*. Boca Raton, FL:, 2011, CRC Press.

Cordell, R., H. C. Lee, et al. Driving assessment in Parkinson's disease - a novel predictor of performance?. *Mov Disord* 23(9), 2008, pp 1217-1222.

Cubo, E., P. Martinez Martin, et al. What contributes to driving ability in Parkinson's Disease. *Disabil Rehabil*, 2009.

Dawson, J.D., Anderson, S.W., Uc, E.Y., Dastrup, E., Rizzo, M., (2009). Predictors of driving safety in early Alzheimer disease. *Neurology*, 72, 521–527.

Duchek, J.M., Carr, D.B., Hunt, L., Roe, C.M., Xiong, C., Shah, K., Morris J.C. (2003). Longitudinal Driving Performance in Early-Stage Dementia of the Alzheimer Type. *Journal of the American Geriatrics Society*, 51, 1342–1347.

Evans, D.A., Funkenstein, H.H., Albert, M.S., Scherr, P.A., Cook, N.R., Chown, H.J., Hebert, L.E., Hennekens, C.H., Taylor, J.O. (1989). Prevalence of Alzheimer’s disease in a community population of older persons: higher than previously reported. *J. Am. Med. Assoc*. 262, 2551 – 2556.

Freund B, Gravenstein S, Ferris R, Burke BL, Shaheen E. Drawing clocks and driving cars: Use of Brief Tests of Cognition to Screen Driving Competency in Older Adults. *J Gen Intern Med.* 20 (3), 2005, pp. 240-244.

Frittelli, C., Borghetti, D., Iudice, G., Bonanni, E., Maestri, M., Tognoni, G., Pasquali, L., Iudice, A. (2009). Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test. *International Journal of Geriatric Psychiatry*, 24, 232–238.

Johansson, K., & Lundberg, C. (1997). The 1994 International Consensus Conference on Dementia and Driving: A brief report. *Alzheimer Disease and Associated Disorders*, 11, 62–69.

Kawano, N., Iwamoto, K., Ebe, K., Suzuki, Y., Hasegawa, J., Ukai, K., Umegaki, H., Iidaka, T., Ozaki, N. (2012). Effects of mild cognitive impairment on driving performance in older drivers. *Journal of the American Geriatrics Society*, 60(7), 1379-1381.

Lunsman, M., Edwards, J. D., Andel, R., Small, B. J., Ball, K. K., Roenker, D. L. What predicts changes in Useful Field of View test performance? *Psychology and Aging*, 23, 2008, pp. 917-927.

Nikas M., "Comparative analysis of young drivers' behaviour in normal and simulated conditions in interurban road", *Graduate diploma thesis, Department of Transportation Planning and Engineering, School of Civil Engineering, NTUA*, January 2014

Papadimitriou E., Pavlou D., Papantoniou P., Yannis G., Golias J., Papageorgiou S.G., "Results from a driving simulator study on performance of drivers with cerebral diseases in rural roads", *Proceedings of the 93rd Annual meeting of the Transportation Research Board*, Washington, January 2014

Petersen, R.C., Smith, G.E., Ivnik, R.J. Tangalos, E.G., Schaid, D.J., Thibodeau, S.N., Kokmen, E., Waring, S.C., Kurland, L.T. (1995). Apolipoprotein E status as a predictor of the development of Alzheimer's disease in memory impaired individuals. *Journal of the American Medical Association*, 16, 1274-1278.

Wadley, V.G., Okonkwo, O., Crowe, M., Vance, D.E., Elgin, J.M., Ball, K.K., Owsley, C. (2009). Mild cognitive impairment and everyday function: an investigation of driving performance. *Journal of Geriatric Psychiatry and Neurology*, 22(2), 87-94.

Waller, JA. Physician's role in highway safety. Functional impairment in driving. *N. Y. State J Med*, 80, 1980, pp. 1987-1991.

Winblad, B., Palmer, K., Kivipelto, M., Jelic, V., Fratiglioni, L., Wahlund, L.O., et al. (2004). Mild cognitive impairment – beyond controversies, towards a consensus: report of the International Working Group on Mild Cognitive Impairment. *Journal of Internal Medicine*, 256 (3),240–246.

Wood, J. M., C. Worringham, et al. Quantitative assessment of driving performance in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 76(2), 2005, pp.176-80.

Yannis G., Antoniou C., Papadimitriou E., Katsohis D., When may road fatalities start to decrease?, *Journal of Safety Research*,Vol. 42, Issue 1, 2011, pp. 17-25.

Zec, R.F. (1993). Neuropsychological functioning in Alzheimer's disease. In R. W. Parks, R. F. Zec, & R. S. Wilson (Eds.), *Neuropsychology of Alzheimer's disease and other dementias* (pp. 3–80). New York: Oxford University Press.

TABLE 1 Tests of within and between subjects in rural and urban road environment

	Rural Road				Urban Road			
	Tests of **Within-**Subjects Contrasts (Source **Traffic**)		Tests of **Between-**Subjects Effects (Source **Disease**)		Tests of **Within-**Subjects Contrasts (Source **Traffic**)		Tests of **Between-**Subjects Effects (Source **Disease**)	
	F	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**
Mean speed (km/h)	17,292	,000**	24,634	,000**	20,327	,000**	6,000	,004**
Mean headway (sec)	69,665	,000**	14,218	,000**	9,569	,003**	,294	,746
Reaction time (millisec)	1,785	,186	2,828	,066*	,466	,498	2,656	,078 *
Lateral position (m)	106,116	,000**	,375	,689	5,690	,021**	2,552	,085 *
Lateral position variability (st.dev of lateral position)	29,125	,000**	4,840	,011**	,430	,515	1,374	,262
Steering angle (degrees)	1,368	,246	,358	,701	,051	,823	,381	,685
Steering angle variability (st.dev of steering angle)	9,586	,003**	3,435	,038**	,037	,849	,313	,732

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

TABLE 2 Parameter estimates of the repeated measures GLM - Longitudinal control measures for rural driving environment

Parameter Estimates		**Low Traffic Volume**					**High Traffic Volume**				
Dependent Variable		**B**	**Std. Error**	**t**	**Sig.**		**B**	**Std. Error**	**t**	**Sig.**	
Mean speed (km/h)	Intercept	47,907	1,207	39,699	,000	**	45,296	,993	45,595	,000	**
	MCI	-6,112	1,965	-3,110	,003	**	-6,235	1,618	-3,854	,000	**
	AD	-13,982	2,326	-6,012	,000	**	-13,383	1,915	-6,990	,000	**
	Control	0					0				
Mean headway (sec)	Intercept	46,634	4,759	9,799	,000	**	22,382	4,730	4,732	,000	**
	MCI	12,361	7,750	1,595	,115		12,035	7,703	1,562	,123	
	AD	40,432	9,172	4,408	,000	**	51,314	9,116	5,629	,000	**
	Control	0					0				
Reaction time (millisec)	Intercept	923,048	153,950	5,996	,000	**	996,250	159,113	6,261	,000	**
	MCI	481,918	250,715	1,922	,059	*	532,628	259,123	2,056	,043	**
	AD	580,278	296,700	1,956	,054	*	446,428	266,688	1,674	,097	*
	Control	0					0				

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

TABLE 3 Parameter estimates of the repeated measures GLM - Lateral control measures for rural driving environment

Parameter Estimates		Low Traffic Volume				High Traffic Volume			
Dependent variable		**B**	**Std. Error**	**t**	**Sig.**	**B**	**Std. Error**	**t**	**Sig.**
Lateral position (m)	Intercept	1,491	,024	61,979	,000 **	1,605	,022	72,596	,000 **
	MCI	,029	,039	,746	,458	,030	,036	,830	,410
	AD	,010	,046	,224	,823	,014	,043	,328	,744
	Control	0				0			
Lateral position variability (st.dev of lateral position)	Intercept	,299	,009	31,520	,000 **	,266	,009	29,164	,000 **
	MCI	-,036	,015	-2,330	,023 **	-,027	,015	-1,821	,073 *
	AD	,024	,018	1,310	,194	,017	,018	,994	,324
	Control	0				0			
Steering angle (degrees)	Intercept	-1,793	,082	-21,993	,000 **	-1,949	,090	-21,680	,000 **
	MCI	-,102	,133	-,770	,444	,230	,146	1,571	,121
	AD	,045	,157	,284	,777	-,131	,173	-,757	,452
	Control	0				0			
Steering angle variability (st.dev of steering angle)	Intercept	17,747	,307	57,739	,000 **	17,646	,260	67,984	,000 **
	MCI	-,756	,501	-1,511	,135	-1,088	,423	-2,573	,012 **
	AD	-,505	,592	-,853	,397	-1,558	,500	-3,114	,003 **
	Control	0				0			

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

TABLE 4 Parameter estimates of the repeated measures GLM - Longitudinal control measures for urban driving environment

Parameter Estimates		Low Traffic Volume					High Traffic Volume				
Dependent variable			**Std. Error**	**t**	**Sig.**		**B**	**Std. Error**	**t**	**Sig.**	
Mean speed (km/h)	Intercept	33,677	,899	37,454	,000	**	30,372	,692	43,870	,000	**
	MCI	-4,854	1,733	-2,801	,007	**	-3,713	1,334	-2,783	,007	**
	AD	-4,357	2,435	-1,789	,079	*	-4,636	1,875	-2,473	,017	**
	Control	0					0				
Mean headway (sec)	Intercept	48,628	5,149	9,444	,000	**	23,784	2,309	10,302	,000	**
	MCI	7,538	9,944	,748	,461		11,989	4,449	2,695	,009	**
	AD	4,340	13,944	,311	,757		7,266	6,252	1,162	,250	
	Control	0					0				
Reaction time (millisec)	Intercept	1294,487	66,621	19,431	,000	**	1284,224	62,967	20,395	,000	**
	MCI	198,056	115,973	1,708	,092	*	139,062	121,353	1,146	,257	
	AD	296,187	165,711	1,787	,078	*	209,693	170,515	1,230	,224	
	Control	0					0				

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

TABLE 5 Parameter estimates of the repeated measures GLM – Lateral control measures for urban driving environment

Parameter Estimates		**Low Traffic Volume**					**High Traffic Volume**				
Dependent Variable		**B**	**Std. Error**	**t**	**Sig.**		**B**	**Std. Error**	**t**	**Sig.**	
Lateral position (m)	Intercept	2,961	,103	28,864	,000	**	3,064	,103	29,690	,000	**
	MCI	,305	,184	1,756	,099	*	,326	,185	1,762	,083	*
	AD	,171	,278	,616	,541		,514	,279	1,839	,071	*
	Control	0					0				
Lateral position variability (st.dev of lateral position)	Intercept	1,560	,098	15,839	,000	**	1,522	,099	15,351	,000	**
	MCI	,210	,190	1,107	,273		,195	,191	1,021	,312	
	AD	,171	,267	,640	,525		,482	,268	1,797	,078	*
	Control	0					0				
Steering angle (degrees)	Intercept	6,967	,203	34,374	,000	**	7,336	,294	24,963	,000	**
	MCI	,136	,391	,348	,729		-,379	,566	-,670	,506	
	AD	,546	,549	,996	,324		,196	,796	,246	,807	
	Control	0					0				
Steering angle variability (st.dev of steering angle)	Intercept	22,872	,753	30,365	,000	**	22,463	1,328	16,918	,000	**
	MCI	,368	1,452	,254	,801		1,646	2,559	,643	,523	
	AD	-,821	2,040	-,402	,689		,102	3,596	,028	,978	
	Control	0					0				

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