# Assessment of driving performance of drivers with brain pathologies in urban roads, using a driving simulator

Dimosthenis Pavlou[a,*], Eleonora Papadimitriou[a], Sophia Vardaki[a], Constantinos Antoniou[a], Panagiotis Papantoniou[a], George Yannis[a], John Golias[a], Ion Beratis[b], Alexandra Economou[b], Sokratis G. Papageorgiou[b]

[a]*National Technical University of Athens, Athens, Greece*
[b]*National and Kapodistrian University of Athens, Athens, Greece*

**Abstract**

Driving requires possessing sufficient cognitive, visual and motor skills and drivers must have adequate motor strength, speed and coordination. Perhaps more importantly, cognitive skills including concentration, attention, adequate visual perceptual skills, insight and memory need to be present. The normal ageing process leads to declines in these motor and cognitive skills, and when combined with a cerebral disease, it may significantly impair the person's driving performance. The objective of this paper is the analysis of driving behaviour of drivers with cognitive impairment due to various brain pathologies, in urban areas, using a driving simulator. An experiment with three assessments for healthy and impaired drivers is carried out: a medical/neurological assessment, a neuropsychological assessment and a driving simulator experiment, in which participants drive in urban area in low and high traffic volumes, and thus, the driving performance of the two driver groups can be analysed. More specifically, the brain pathologies examined include early Alzheimer's disease (AD), early Parkinson's disease (PD), and Mild Cognitive Impairment (MCI) and the vehicle control measures examined are both longitudinal and lateral (speed, lateral position, space headway, reaction time at unexpected incidents, accident probability). So far, 97 participants (out of which 35 impaired) have completed the experiment and the results suggest that there are significant differences in the driving performance of healthy drivers and drivers with cognitive impairments. Impaired drivers appear to drive at slower speeds, tend to drive to the right border of the road, have higher mean headways, react slower at unexpected incidents than the healthy ones and are more likely to get involved in an accident. More specifically, AD and PD drivers seem to have increased accident probability in high traffic urban environment and cannot adjust their driving behaviour in different driving conditions.

*Keywords:* cerebral diseases, driving performance, driving simulator, unexpected incidents.

[*]Tel.: +30 210 7721380; fax: +30 210 7721454.
*E-mail address*: dpavlou@central.ntua.gr

## 1. Background and objectives

### *1.1. Introduction*

Driving requires possessing sufficient cognitive, visual and motor skills and drivers must have adequate motor strength, speed and coordination. Every driver must have adequate motor strength, speed and coordination and perhaps more importantly, higher cognitive skills: concentration, attention, adequate visual and perceptual skills, insight, judgement and memory.

Higher cortical functions required for driving include strategic and risk taking behavioural skills, including 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 (Waller, 1980; Freund et al., 2005).

As a result, the ability to drive can be affected by various motor, visual, cognitive and perceptual deficits which are either age-related or caused by neurologic disorders. More specifically, diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to neurological diseases as Alzheimer’s disease, Parkinson’s disease, or Cerebrovascular disease (stroke), effect of pharmaceutical substances used for the treatment of various neurological and/or psychiatric disturbances) may significantly impair the person's driving ability.

These conditions have obvious impacts on driving performance, but 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. Taking into account that the percentage of the elderly in society is increasing (Baldock et al., 2007), while at the same time the level of motorization also increases (Yannis et al., 2011), the need to investigate the impact of these conditions on driving behaviour becomes quite critical.

### *1.2. Cerebral diseases and driving performance*

Drivers suffering from a brain pathology may have difficulties in their usual activities, including driving ability. However, scientists cannot agree to what extend mild cognitive impairment is affecting driving behaviour and driving safety. The greater the dementia severity, the greater the likelihood of poor driving ability (Hunt et al. 1993). While it might be assumed that individuals with dementia would stop driving after onset of symptoms, it is estimated that around one-third of drivers with dementia continue to drive (Silverstein 2008). Most drivers are early in the disease process when cognitive deficits are generally mild (Adler and Kuskowski 2003) and changes to driving performance are minimal. Nonetheless, drivers with dementia are one of the groups considered at greatest risk for unsafe driving performance (Langford et al. 2007). Road accidents, while infrequent, are also of concern for drivers with dementia, whose crash risk is two to five times that of unimpaired older drivers (Charlton et al. 2003).

Furthermore, driving skills predictably worsen (Adler et al. 1999) and will ultimately require individuals with dementia to stop driving (Adler et al. 2005). Driving decisions need to be made not on diagnosis but on an assessment of the dementia’s progress and the disease’s effects on functional abilities (Duchek et al. 2003, Eby et al. 2009a, Eby and Molnar 2010). A typical approach to assessing driving skills in individuals with dementia uses a driving simulator. Learning to use a simulator, however, can be difficult for drivers with dementia even when given time to adapt to the setting (Cox et al. 1998). Ott et al. (2003) employed a computerized executive functioning mazes test, and found a relationship between errors and driving ability ratings. Owsley et al. (1991) developed a computerized paradigm, “useful field of view” (UFOV) that captures both speed of visual attention and ability to focus visual attention despite distractions. In two prospective studies, UFOV was found to predict crashes over a three year time period (Ball et al. 1993, Owsley et al. 1991) in a sample of older adults.

Moreover, in patients with mild dementia, visual selective attention has been related to on-road driving performance. In fact, visual search abilities were predictive of driving abilities above and beyond dementia severity (Duchek et al. 1998).

Other cognitive measures, including memory scores, did not further predict driving performance. In a recent meta-analysis of the relationship between performance on neuropsychological tests and on-road driving ability in patients with dementia and elderly controls, measures of visuospatial abilities were more strongly associated with driving than were other cognitive domains (Reger et al. 2004).

### *1.2.1. Mild Cognitive Impairment*

While health related problems in the elderly and cognitive changes of aging can have a negative impact on driving ability, (Morgan, 1995), 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, 2004). The concept of MCI has been described as a cognitive state that lies between normal aging and dementia (Petersen, 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, lateral control) from the control driving population (Wadley et al. 2009). Kawano et al. (2011) 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.

### *1.2.2. Alzheimer's Disease*

Alzheimer's disease (AD) is the most frequent form of dementia worldwide. About 10% of the people who are over 65 years old suffer from some kind of dementia (Evans et al., 1989) and about 90% of those people have Alzheimer's disease (Lim et al., 1999; Lobo et al., 2000). 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). Dawson et al. (2009) showed that AD drivers (especially the elderly) made many more safety errors (the most common errors were lane violations). Duchek et al. (2003) provide longitudinal evidence for a decline in driving performance over time, primarily in early-stage dementia of the Alzheimer type. 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; Uc et al., 2005 Dobbs et al., 1997; Cotrell et al., 1999; O'Neill et al., 1996).

### *1.2.3. Parkinson's Disease*

Parkinson's disease (PD) is a degenerative disorder of the central nervous system. The main factors affecting the driving ability and behaviour of PD patients are: age, severity and duration of the disease, mobility problems (control of the wheel, reaction time), cognitive impairment (visuospatial skills, executive functions), dementia, excessive daytime sleepiness, and sudden onset of sleep. The most significant cognitive fields affecting the driving ability and behaviour of PD patients are: visual perception and memory, visuospatial perception, structure from motion, attention, and visual processing speed.

Finally, the main factors determining the safe driving of PD patients are: cognitive abilities, motor function, ability to stay on alert, and self-perception of safe driving ability (Duke Movement Disorders Center 2011). Meindorfner et al. (2005) sent a questionnaire about sudden onset of sleep (SOS) and driving behaviour to 12.000 PD patients. Subsequently, of 6,620 complete data sets, 361 patients were interviewed by phone. A total of 82% of those 6,620 patients held a driving license, and 60% of them still participated in traffic. Of the patients holding a driving license, 15% had been involved in and 11% had caused at least one accident during the past 5 years. The risk of causing accidents was significantly increased for patients who felt moderately impaired by PD.

## *1.3. Driving in urban areas*

Some 11,000 people are killed each year in road traffic crashes in EU urban areas. 37% of these are pedestrians. In addition, many more people are seriously injured, sustaining life changing injuries. Road safety statistics show that progress in reducing road fatalities has been below average in urban areas. In urban areas, the restricted space must be used intelligently and effectively to enable increased mobility without compromising safety. In 2012, around 28,000 people were reported to have died in road traffic crashes in the Union. About 40% of these fatalities occurred on urban roads. Between 2000 and 2009, the number of road fatalities inside urban areas decreased by 32%. The number of road fatalities on other roads decreased by 38% for the same period. Therefore, urban road deaths now make up a larger share of the total road safety problem compared to ten years ago.

Urban areas constitute a more complex driving environment than rural areas, due to increased traffic, presence of bicyclists and pedestrians, more traffic signs and more frequent junctions, requiring several tasks to be performed simultaneously and can be thus considered a more cognitively demanding driving environment. Thus, it’s a lot more difficult for the impaired drivers to address with this demanding cognitive task.

### *1.4. Objectives*

The objective of this paper is to analyse the driving performance in urban roads of drivers with cerebral diseases by means of a driving simulator. The cerebral diseases examined are AD, PD and MCI. An extended literature review has been made before the design and the executions of a large scale driving simulator experiment. So far, 97 participants have been through all phases of the experiment and various driving performance measures have been examined, e.g. speed, lateral position, space headways, reaction time at unexpected incidents and accident probability in specific unexpected event. The driving performance of impaired drivers is compared to that of healthy control drivers.

## 2. Driving simulator experiment

### *2.1. Overview of the experiment*

This study is carried out within the framework of the **Distract** (http://www.nrso.ntua.gr/distract) research project, carried out by an interdisciplinary research team of engineers, neurologists and psychologists. 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, Alzheimer’s disease, Parkinson’s disease, Cerebrovascular disease (stroke)as well as other related parameters of potential impact on driving (e.g. use of medication affecting the Central Nervous System).

- **Neuropsychological assessment**:
  The second assessment concerns the administration of a series of neuropsychological tests and psychological-behavioural questionnaires to the participants. The tests carried out cover a large spectrum of Cognitive Functions: visuospatial and verbal episodic and working memory, general selective and divided attention, reaction time, processing speed, psychomotor speed etc.

- **Driving at the simulator**:
  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.

### *2.2. Sampling scheme*

The sample of participants comprises two distinct groups:
- One “impaired” group of participants with a cerebral pathological condition (neurological disease), explicitly selected by the neurology / neuropsychology research teams.
- One “control” group of participants with no known pathological condition.

A sample of at least 175 participants with a pathological condition is to be examined in approximately 2 years time. Individuals older than 55 years will be included with priority in the study, due to the increased likelihood of exhibiting such pathological conditions. A similar control group of another 125 participants with no known pathological condition, of the same age groups should then be sufficient. Therefore, the sample of participants will total at least 300 individuals.

*2.3. Driving at the simulator*

The third type of assessment concerns the programming of a set of driving tasks into the driving simulator for different driving scenarios. The design of these scenarios is a central component of the experiment and includes driving in different road and traffic conditions, such as in a rural, urban area (in this research only the urban driving environment is examined) with high and low traffic volume. More specifically, this assessment includes an urban driving session with up to six trials and a rural driving session with up to six trials. These trials aim to assess driving performance under typical conditions, with or without external distraction sources. The driving simulator experiment takes place at the Department of Transportation Planning and Engineering of the National Technical University of Athens, where the Foerst Driving Simulator FPF is located. It is a quarter-cab simulator with a motion base.

The driving simulator experiment begins with a practice drive (15-20 minutes), until the participant fully familiarizes with the simulation environment. Afterwards, the participant drives the two sessions (~25 minutes each). Each session corresponds to a different road environment: divided urban arterial and undivided two-lane rural road. Within each road / area type, two traffic scenarios and three distraction conditions are examined in a full factorial within-subject design. The experiment is fully counterbalanced concerning the number and the order of the trials per participant.

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 $\sigma^2$=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 $\sigma^2$=3 sec, corresponding to an average traffic volume of Q=600 vehicles/hour.

Moreover, during each trial two unexpected incidents are scheduled to occur at fixed points along the drive (but not at the exact same point in all trials, in order to minimise learning effects). 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 a car suddenly entering the road from a parking position. The distraction conditions are: no distraction, cell-phone conversation and conversation with passenger. In this research, only the undistracted driving conditions are examined.

**3. Results**

So far 97 participants have been through all phases and assessments of the experiment. In this research four groups are compared: **AD, MCI, PD, and Control group, in urban driving session, without any kind of external distraction, in low and high traffic volume**. Out of the 97 participants, 62 are controls, and 35 are impaired: 11 AD patients, 18 MCI patients and 6 PD patients (fig. 1). The age distribution of the sample examined in this research is: Control group 42.7 y.o., AD group 76.0 y.o., MCI group 69.2 y.o. and PD goup 58.7 y.o. (fig. 2). The lower number of complete trials in the impaired drivers' group is due to the fact that the majority of the impaired group was getting tired earlier, as well as to slightly increased drop out due to simulator sickness.

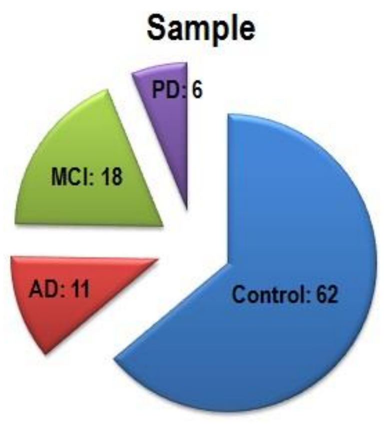



Fig. 1. Sample

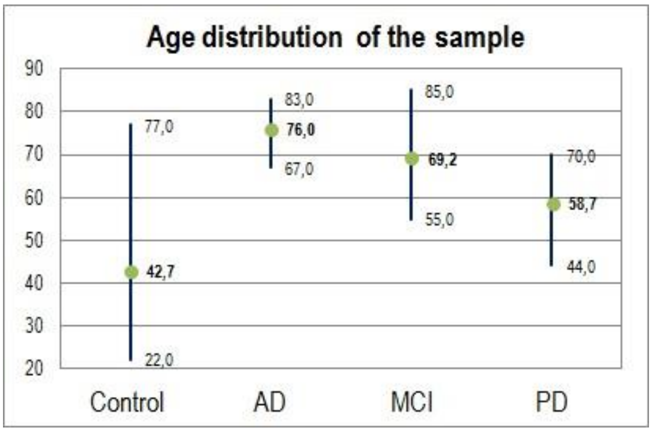



Fig.2. Age distribution

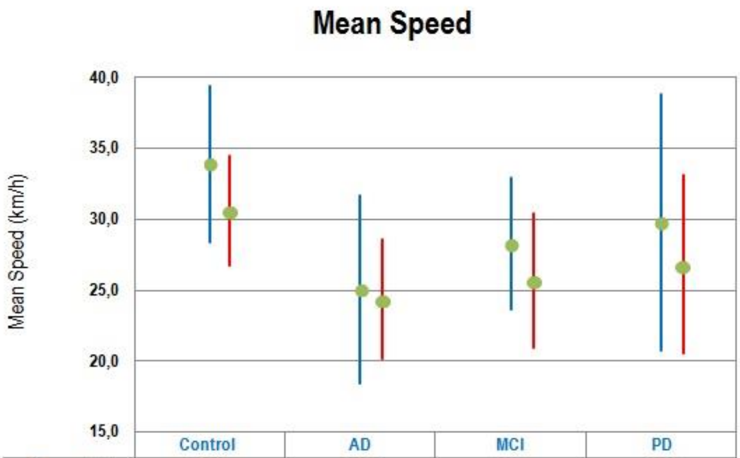
The key driving performance measures examined in this research correspond to longitudinal and lateral driving control measures and are presented below:

- **mean speed** - refers to the mean speed of the driver along the route, excluding the small sections in which incidents occurred, and excluding junction areas.
- **space headway** - refers to the space between the simulator vehicle and the vehicle ahead
- **reaction time** - refers to the time between the first appearance of the event - “obstacle” on the road and the moment the driver starts to brake.
- **accident probability in specific incident** - refers to the proportion of unexpected incidents resulting in accidents.
- **lateral position** - refers to the distance between the simulator vehicle and the middle of the road.

All these key measures analysed by descriptive statistics and the results are presented below. It is worth mentioning that average values are compared and average values plus and minus standard deviation are shown on diagrams.

*3.1. Mean speed*

In Fig. 3, the mean speed of drivers along the trial (in urban road area, in high and low traffic volume, no external distraction) is presented per driving condition. It is observed that control drivers drove the trial road section at approximately 18% higher speed than impaired drivers in low traffic volume and 16% higher speed in high traffic volume. Mean speed is lower in high traffic volume conditions, as expected. Moreover, drivers with AD at slightly lower speed than all other impaired drivers. It is also worth noticing that at high traffic volume, impaired drivers’ mean speed is noticeably low (over 50% lower than the speed limit[†]). Finally, the variability of all mean values is large, especially for PD drivers.



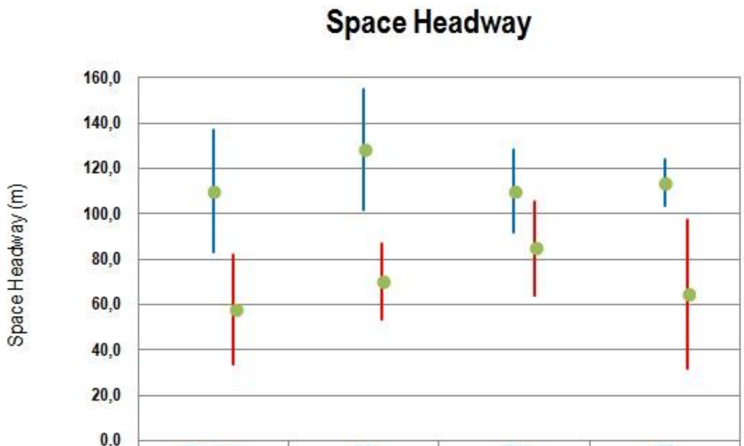

| | Control | AD | MCI | PD |
|---|---|---|---|---|
| QL aver+stdev | 39,42 | 31,71 | 32,92 | 38,79 |
| QL aver-stdev | 28,37 | 18,42 | 23,64 | 20,75 |
| QL aver | 33,89 | 25,06 | 28,28 | 29,77 |
| QH aver+stdev | 34,50 | 28,63 | 30,46 | 33,14 |
| QH aver-stdev | 26,78 | 20,26 | 20,99 | 20,59 |
| QH aver | 30,64 | 24,44 | 25,72 | 26,87 |

Fig. 3. Mean Speed (km/h)

*3.2. Space Headway*

In Fig. 4, the space headway of drivers is presented for the examined conditions. It is observed that impaired drivers keep larger headways from the vehicle ahead compared to the control group (7% in low traffic volume and 27% in high traffic volume). This is obviously happening because of their lower speed and their conservative driving. AD and PD drivers seem to having trouble dealing with the high traffic volume and their space headways are significally reduced. Of course in high traffic volume lower space headways are obvious results. It’s worth noticing the large variability of mean space headways for PD drivers in high traffic volume compared with their variability in low traffic volume.

[†] 60km/h

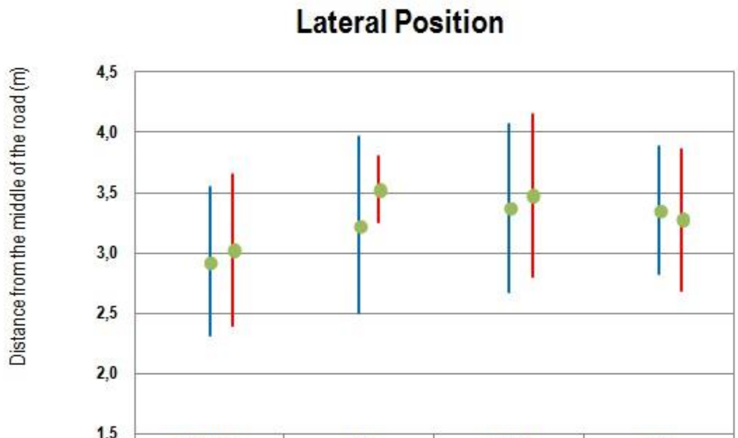



| | Control | AD | MCI | PD |
|---|---|---|---|---|
| QL aver+stdev | 137,33 | 154,86 | 128,58 | 124,15 |
| QL aver-stdev | 83,06 | 101,93 | 92,15 | 103,35 |
| ● QL aver | 110,20 | 128,40 | 110,36 | 113,75 |
| QH aver+stdev | 81,80 | 86,95 | 105,53 | 97,23 |
| QH aver-stdev | 33,76 | 53,40 | 64,18 | 31,77 |
| ● QH aver | 57,78 | 70,18 | 84,85 | 64,50 |

Fig. 4. Space Headway (m)

*3.3. Lateral position*

In Fig. 5, the lateral position of drivers is presented per trial. Impaired drivers drive approximately 40cm to the right compared to the control group. Especially AD drivers seem to driver to the right when dealing with high traffic volume. Control drivers show somewhat increased variability in lateral position, because there are parts of the road with two lanes per direction, and these drivers take initiatives for lane changing or overtaking, whereas the impaired group drives more conservatively. It is observed that traffic volume doesn't affect the lateral position in all driving groups (maybe at high traffic volume all drivers drive slightly nearly the right border of the road).




| | Control | AD | MCI | PD |
|---|---|---|---|---|
| QL aver+stdev | 3,54 | 3,96 | 4,07 | 3,88 |
| QL aver-stdev | 2,31 | 2,51 | 2,68 | 2,83 |
| ● QL aver | 2,93 | 3,23 | 3,38 | 3,36 |
| QH aver+stdev | 3,66 | 3,80 | 4,15 | 3,87 |
| QH aver-stdev | 2,40 | 3,26 | 2,81 | 2,69 |
| ● QH aver | 3,03 | 3,53 | 3,48 | 3,28 |

Fig. 5. Lateral position (m)

*3.4. Reaction time*

In Fig. 6, the reaction time of drivers is presented per driving condition. Impaired drivers have worse reaction times than the control ones (0.25 sec worse overall). It appears that AD drivers have the worst reaction times.

These worse reaction times of impaired drivers are likely to be confirmed by their neurological and neuropsychological assessment. Finally, traffic volume does not appear to significantly affect the reaction time of drivers.

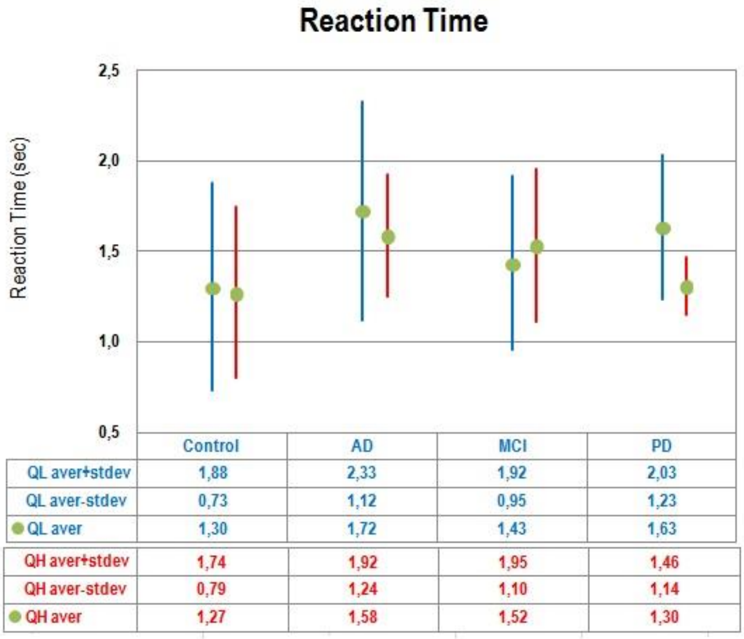



Fig. 6. Reaction time (sec)

*3.5. Accident probability*

In Fig. 7, the accident probability at unexpected incident per area type is presented. We detect that impaired drivers have higher accident probability than the control group (12% higher at low traffic, 18.1% at high traffic and 15% overall). It seems that high traffic volume has an effect on the accident probability at all drivers (except for MCI drivers); it seems more likely for all drivers to have an accident as the result of the incident in high traffic volume than in low (especially for AD drivers). PD and AD drivers seem to be affected from the more difficult driving environment (high traffic volume) and cannot adjust their driving behavior in these conditions, which led them in higher accident probability (more than 1 accident in 4 incidents for both groups in high traffic volume).

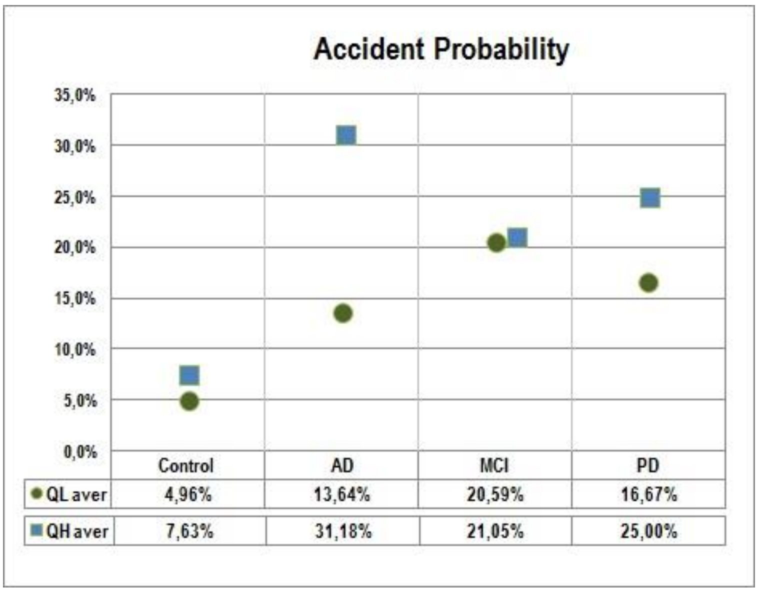



Fig. 7. Accident Probability

## 4. Conclusions and discussion

The experiment is currently approximately at its half way and results suggest that the specific methodology and design confirm the initial hypotheses and may reveal important differences between drivers with cerebral diseases and control drivers for several driver performance measures. In this specific research 97 participants have completed the 2 undistracted trials in urban driving environment in high and low traffic volume.

Firstly, it is worth mentioning that sample size needs some improvement regarding the age distribution of the control group in relation to the impaired group.

Summarizing the above results, impaired drivers were found to drive at lower speeds compared to the control group drivers, both at low and at high traffic volume. As would be expected, this reduced speed under given ambient traffic conditions results in increased headways, both at low and at high traffic volumes. Moreover, AD patients drive at even lower speeds and with larger space headways compared to PD and MCI patients. This is probably happening because of their more conservative driving (and possibly their increased awareness of their downgraded driving performance). Moreover, AD drivers seems to be indifferent of the traffic volume as we see that their speed in not significally reduced in high traffic volume and thus their headways are much smaller.

It is observed that traffic volume doesn't affect the lateral position in all driving groups (maybe at high traffic volume all drivers drive slightly nearly the right border of the road). Impaired drivers drive approximately 40cm to the right compared to the control group. AD drivers are affected the most by the traffic volume and compared with the low traffic volume, they drive to the right border of the road.

Regarding the unexpected incidents, both reaction time and especially accident probability seemed to have differences between the drivers with cerebral diseases and the control group. Impaired drivers were found to have worse reaction times at incidents compared to the control group, in all driving conditions. Traffic volume does not appear to significantly affect the reaction time of drivers. Impaired drivers have worse reaction times than the control ones (0.2 sec worse overall). It appears that AD drivers have the worst reaction times. These worse reaction times of impaired drivers are likely to be confirmed by their neurological and neuropsychological assessment.

Regarding accident probability in specific incident (sudden appearance of an adult pedestrian, or of a child chasing a ball on the roadway, or a car suddenly entering the road from a parking position), it seems that high traffic volume has an effect on the accident probability at all drivers (except for MCI drivers); it seems more likely for all drivers to have an accident resulting from the incident that is suddenly appears in front of them in high traffic volume than in low (especially for AD drivers). Moreover we detect that impaired drivers have higher accident probability than the control group (12% higher at low traffic, 18.1% at high traffic and 15% overall).

It's worth to highlight the increased accident probability for AD and PD drivers in high traffic urban environment (more than 25%). We saw before that they don't adjust their speed in high traffic volume, have much smaller headways and 30% of the times they crash the incident.

Overall, cerebral diseases appear to have considerable impact on longitudinal driving performance measures, but less identifiable impact on lateral driving performance measures (unlike other studies). It is possible that the relatively small sample size of PD and AD drivers does not allow for all potential effects of cerebral diseases on driving performance to be identified. However, the above results are quite promising and it is likely that once a larger and more representative sample is available, the analysis may be enhanced in several ways. The application of appropriate statistical techniques on a larger sample, and the combined analysis of specific medical, neurological and neuropsychological indicators with the driving simulator data may shed some light on the mechanisms of impaired driving due to cerebral diseases.

## Acknowledgements

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

## References


Adler , G., Kuskowski, M. 2003. Driving habits and cessation in older men with dementia. Alzheimer Disease and Associated Disorders, 17, 68 -71.

Adler, G. et al. 2005. The older driver with dementia: An updated literature review. Journal of Safety Research, 36, 399-407.

Adler, G., Rottunda, S., Kuskowski, M. 1999. The impact of dementia on driving: Perceptions and changing habits. The Clinical Gerontologist, 20, 23-34.

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.

Charlton, J. et al. 2003. Influence of chronic illness on crash involvement of motor vehicle occupants. (Report No. 213). Melbourne, Australia, Monash University Accident Research Centre.

Cotrell V., Wild K. (1999). Longitudinal study of self-imposed driving restrictions and deficits awareness in patients with Alzheimer disease. *Alzheimer Disease and Associated Disorders*, 13, 151-156.

Cox, D. J., Quillian, W. C., Thorndike, F. P., Kovatchev, B. P., Hanna, G. 1998. Evaluating driving performance of outpatients with Alzheimer disease. Journal of the American Board of Family Practice, 11, 264-271.

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

Dobbs A. R. (1997). Evaluating the driving competence of dementia patients. *Alzheimer Disease and Associated Disorders*, 11 (suppl. 1), 8-12.

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.

Duchek, J. M., Hunt, L., Ball, K., Buckles, V., Moris, J. C., 1998. Attention and Driving Performance in Alzheimer's Disease. Journal of Gerontology: PSYCHOLOGICAL SCIENCES, Vol. 53B, No. 2, pp.130-P141.

Eby, D.W., Molnar, L.J., Kartje, P.S. 2009. Maintaining Safe Mobility in an Aging Society. New York, NY: CRC Press.

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. (2005). Drawing clocks and driving cars: Use of Brief Tests of Cognition to Screen Driving Competency in Older Adults. *J Gen Intern Med.* 20 (3), 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.

Hunt, L., Morris, J.C., Edwards, D., Wilson, B.S., 1993. Driving performance in persons with mild senile dementia of the Alzheimer type. J Am Geriatr Soc., 41(7):747-52.

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.

Langford, J., Braitman, K., Charlton, J., Eberhard, J., O'Neill, D., Staplin, L., Stutts, J. 2007. Communiqué From the Panel, TRB Workshop 2007, Washington, DC

Lim A, Tsuang D, Kukull W, Nochlin D, Leverenz J, McCormick W, Bowen J, Teri L, Thompson J, Peskind ER, Raskind M, Larson EB. (1999). Clinico-neuropathological correlation of Alzheimer's disease in a community-based case series. *J Am Geriatr Soc*.47(5):564-9.

Lobo A, Launer LJ, Fratiglioni L, Andersen K, Di Carlo A, Breteler MM, Copeland JR, Dartigues JF, Jagger C, Martinez-Lage J, Soininen H, Hofman A. (2000) Prevalence of dementia and major subtypes in Europe: A collaborative study of population-based cohorts. Neurologic Diseases in the Elderly Research Group. *Neurology*. 54(11 Suppl 5):S4-9.

Meindorfner, C., Korner, Y., Moller, J. C., Stiasny-Kolster, K., et al. (2005). Driving in Parkinson's disease: mobility, accidents, and sudden onset of sleep at the wheel. *Movement Disorders* 20(7):832-42.

Morgan R, King D. (1995). The older driver-a review. *Postgraduate Medical Journal*, 71(839), 525-528.

O'Neill D. (1996). Dementia and driving: screening, assessment, and advice. *Lancet* 348, 1114.

Ott, B. R., Heindel, W.C., Whelihan, W.M., Caron, M.D., Piatt, A.L., DiCarlo, M.A. 2003. Maze test performance and reported driving ability in early dementia. Journal of Geriatric Psychiatry and Neurology. 16:151–155.

Owsley, C., Ball, K. K., Sloane, M., Roenker, D. L., Bruni, J. 1991. Visual/cognitive correlates of vehicle accidents in older drivers. Psychology and Aging, 6, 403–415.

Petersen RC, Smith GE, Ivnik RJ Tangalos EG, Schaid DJ, Thibodeau SN, Kokmen E, Waring SC, Kurland LT. (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.

Reger, M.A., Welsh, R.K., Watson, G.S., Cholerton, B., Baker, L.D., Craft, S. 2004. The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. Neuropsychology 18:85-93.

Silverstein, N. M. 2008. Alzheimer's disease and fitness to drive. In Eby, D., & Molnar, L.J. (Eds). 2008 North American License Policies Workshop Proceedings. AAA Foundation for Traffic Safety. (pp 71-85).

Uc E. Y., Rizzo M., Anderson S. W. et al. (2005). Driver landmark and traffic sign identification in early Alzheimer's disease. *Journal of Neurology, Neurosurgery and Psychiatry*, 76, 764–768.

Wadley VG, Okonkwo O, Crowe M, Vance DE, Elgin JM, Ball KK, 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, J. A. (1980). Physician's role in highway safety. Functional impairment in driving. *N. Y. State J Med*, 80, pp. 1987-1991.

Winblad B, Palmer K, Kivipelto M, Jelic V, Fratiglioni L, Wahlund LO, 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.

Yannis G., Antoniou C., Papadimitriou E., Katsohis D. (2011). When may road fatalities start to decrease? *Journal of Safety Research* 42 (1), 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.