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First findings from a simulator study on driving behaviour of drivers with cerebral diseases

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Abstract

Driving performance may be affected by a number of cerebral diseases, in the general population and particularly in the elderly, who exhibit a higher risk of involvement in a road accident. The objective of this research is the investigation of the driving performance - assessed on driving simulator - of drivers with cerebral diseases, especially at unexpected incidents. The basic cerebral diseases considered concern Mild Cognitive Impairment (MCI), Alzheimer’s Disease (AD), and Parkinson’s disease (PD). The driver performance is examined in terms of both traffic and safety parameters. A large experiment is carried out by an interdisciplinary team, in which participants (patients and control population) take part in driving simulator experiment, neurological and neuropsychological tests. The driving performance measures examined include speed, lateral position, reaction time at incidents etc. Preliminary results (39 drivers) confirm that cerebral diseases downgrade the driving performance and particularly the higher impact of PD in relation to MCI/AD and control drivers.

Keywords: cerebral diseases, older drivers, driving performance, accident probability

Résumé

Les performances de conduite peuvent être affectées par un certain nombre de maladies cérébrales, fréquentes de la population générale et plus particulièrement chez les personnes âgées, qui présentent un risque plus élevé d'être impliquées dans un accident de la voie publique (AVP). L'objectif de cette recherche est l'étude de la performance des conducteurs - évalué en simulateur de conduite - souffrant de maladies cérébrales à des incidents inattendus. Les maladies cérébrales fréquentes examinées sont le défict cognitif léger (Mild Cognitive Impairment-MCI), la maladie d'Alzheimer (AD), et la maladie de Parkinson (PD). La performance du pilote est examinée en termes de paramètres de trafic et de sécurité. Une étude expérimentale est réalisé par une équipe interdisciplinaire, dans laquelle les conducteurs (patients et sujets contrôles) participent à la conduite du simulateur et sont examinés par des neurologues et des neuropsychologues. Les mesures de la performance de conduite examinés comprennent: la position latérale, la vitesse et le temps de réaction à des incidents. Les résultats préliminaires (39 conducteurs) confirment que les maladies cérébrales dégradent la performance de conduite. Leur impact semble et particulièrement plus élevé chez des patients souffrant de la PD vis à vis les conducteurs MCI/AD et de contrôle.

Mots-clé: maladies cérébrales, les conducteurs âgés, les performances de conduite, la probabilité d'accident

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1. Background and objectives

1.1. Introduction

Driving behaviour is a crucial parameter of traffic safety as driving is a quite complex task that requires possessing sufficient cognitive, visual and motor skills. 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).

Consequently, 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

In this research, three cerebral diseases are studied regarding their effects on driving performance: Mild Cognitive Impairment (MCI), Alzheimer's Disease (AD) and Parkinson's Disease (PD). An extensive literature review presented below suggests that these conditions are indeed associated with impaired driving performance, although the magnitude of their effects needs further investigation.

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). Klimkeit et al., (2009) showed that most individuals with PD decide to cease driving based on their own judgment, or advice from family and/or clinician rather than as a result of a formal driving assessment. This is somewhat concerning given that clinicians including neurologists, may overestimate driving skills of PD patients, and a substantial proportion of drivers tend to overestimate their driving abilities. 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. Objectives

The objective of this paper is to analyse the driving performance of drivers with cerebral diseases by means of a driving simulator. More specifically, 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. This study addresses research questions that have not been adequately explored: a) attempts to compare different pathologies, b) examines the interaction of cerebral diseases with road and traffic parameters. So far, 39 participants have been through all phases of the experiment and various driving performance measures have been examined, e.g. speed, lateral position, 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 two research projects: the DriverBrain (http://www.nrso.ntua.gr/driverbrain) and the Distract (http://www.nrso.ntua.gr/distract) research projects, 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 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 (5-10 minutes), until the participant fully familiarizes with the simulation environment. Afterwards, the participant drives the two sessions (~20 minutes each). Each session corresponds to a different road environment: 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:

- QL: 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.
- QH: 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.

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 (i.e. 2 trials in rural area - low and high traffic volume - and 2 trials in urban area).

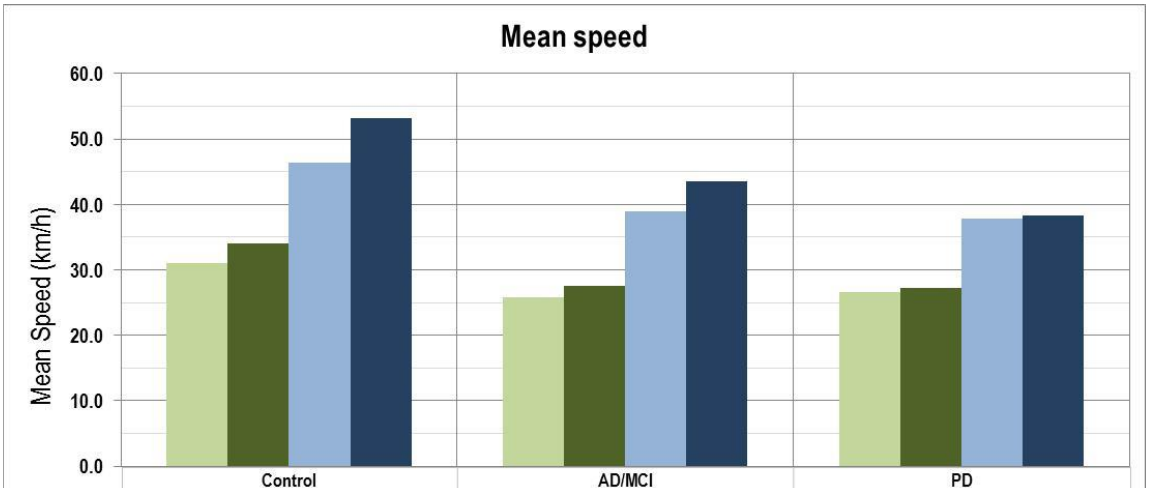
3. First findings

So far 39 participants have been through all phases and assessments of the experiment. In this research three groups are compared: AD/MCI, PD, and Control group, in rural and urban driving session, without any kind of external distraction, in low and high traffic volume. AD and MCI conditions are grouped together, due to the known similarities between the two pathologies, in order to have an acceptable sample size for this group. Out of the 39 participants, 17 are controls, and 22 are impaired: 15 AD or MCI patients and 7 PD patients. Concerning the driving at the simulator, on typical driving conditions (rural and urban driving sessions), impaired drivers completed on average 4 trials (out of the 6 trials of each session), while control drivers completed on average 5 trials respectively. 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. Moreover, it takes approximately 1 minute more for the impaired drivers to complete one trial than the control group. The key variables examined 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.
- headway - refers to the time distance between the front of the simulator vehicle and the front of 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 right border of the road.

3.1. Mean speed

In Fig. 1, the mean speed of drivers along the trial (in rural and 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 24% higher speed overall than impaired drivers. Mean speed is lower in urban areas, as expected, especially in high traffic volume. Moreover, drivers with AD or MCI drove at slightly higher speed than drivers with PD. It is also worth noticing that the mean speed reduction in urban area is similar for all drivers. In urban areas, especially at high traffic volume, impaired drivers' mean speed is noticeably low (over 50% lower than the speed limit).



	Control	AD/MCI	PD
Urban QH	31.09	25.77	26.59
Urban QL	34.10	27.56	27.30
Rural QH	46.35	38.87	37.84
Rural QL	53.15	43.45	38.34

Fig. 1. Mean speed (km/h)

3.2. Headway

In Fig. 2, the headway of drivers is presented per trial. It is observed that impaired drivers keep much larger headways from the vehicle ahead compared to the control group. This is obviously happening because of their lower speed and their conservative driving. The PD drivers' headways in rural area with low traffic volume are noticeably high, however this needs further investigation through a larger sample.

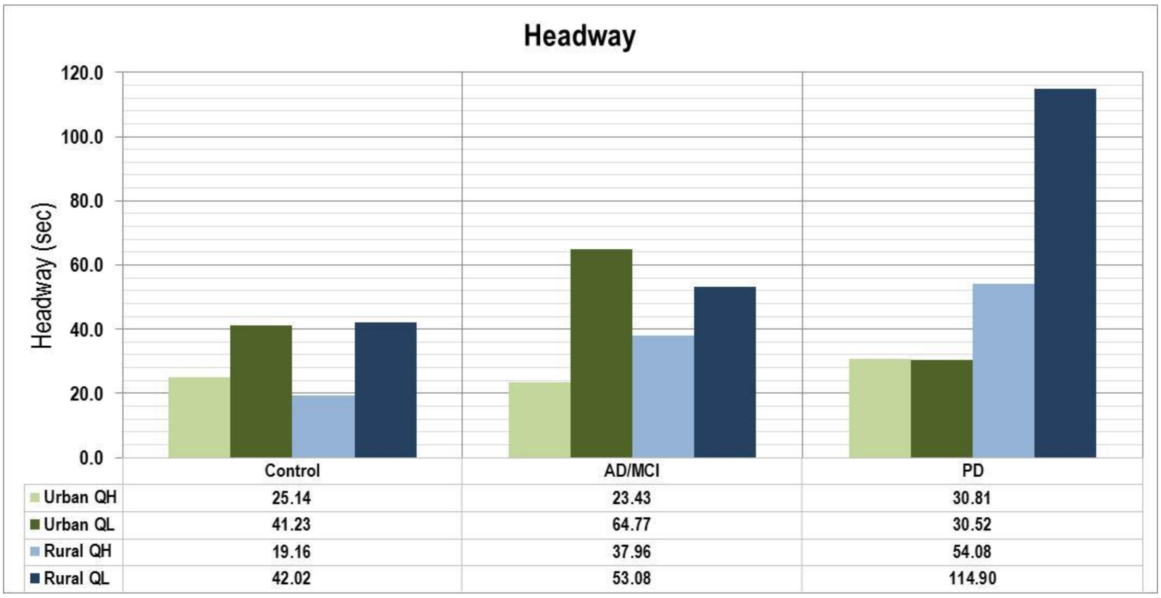


Fig. 2. Headway (sec)

3.3. Standard deviation of lateral position

In Fig. 3, the variability of lateral position of drivers is presented per trial. It is observed that in rural area there are no differences in lateral position, because the participants drive on a single narrow lane (lane width equals to 3 meters) and there are no opportunities for overtaking. On the other hand, in urban area, 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. Traffic volume does not appear to significantly affect the lateral control of drivers.

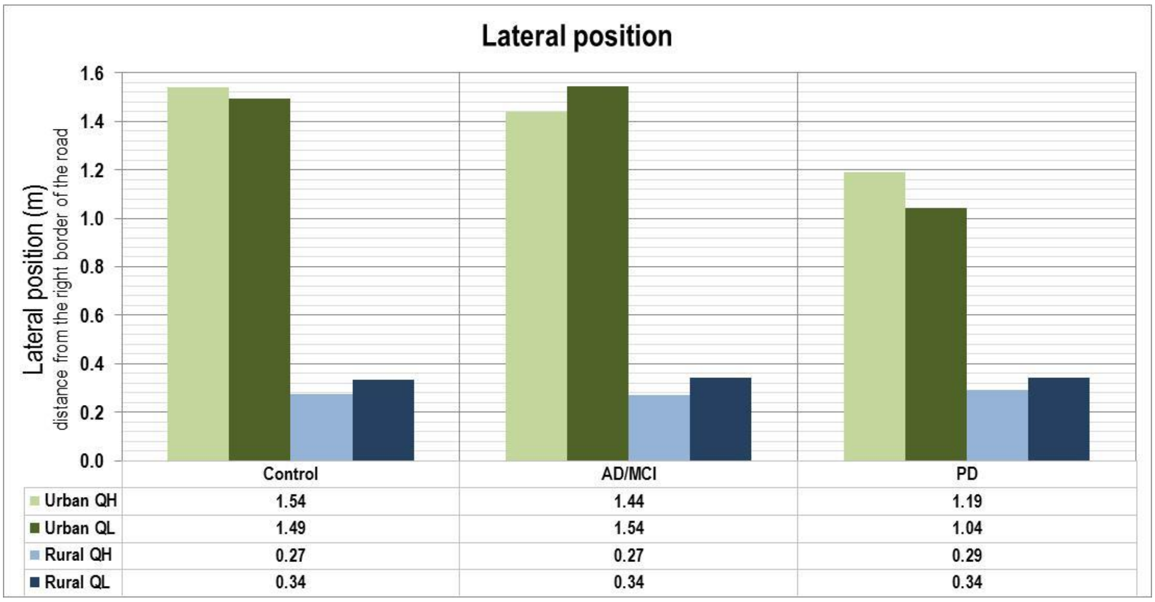


Fig. 3. StDev of lateral position (m)

3.4. Reaction time

In Fig. 4, the reaction time of drivers is presented per driving condition. It appears that AD or MCI drivers in urban area have improved reaction times, a finding that needs further investigation. In lower traffic volume reaction times are faster; it is possible that the more complex traffic environment makes incidents less detectable. It is observed that impaired drivers have higher reaction times in all driving conditions (by 18% overall) than the control group. These worse reaction times of impaired drivers are likely to be confirmed by their neurological and neuropsychological assessment.

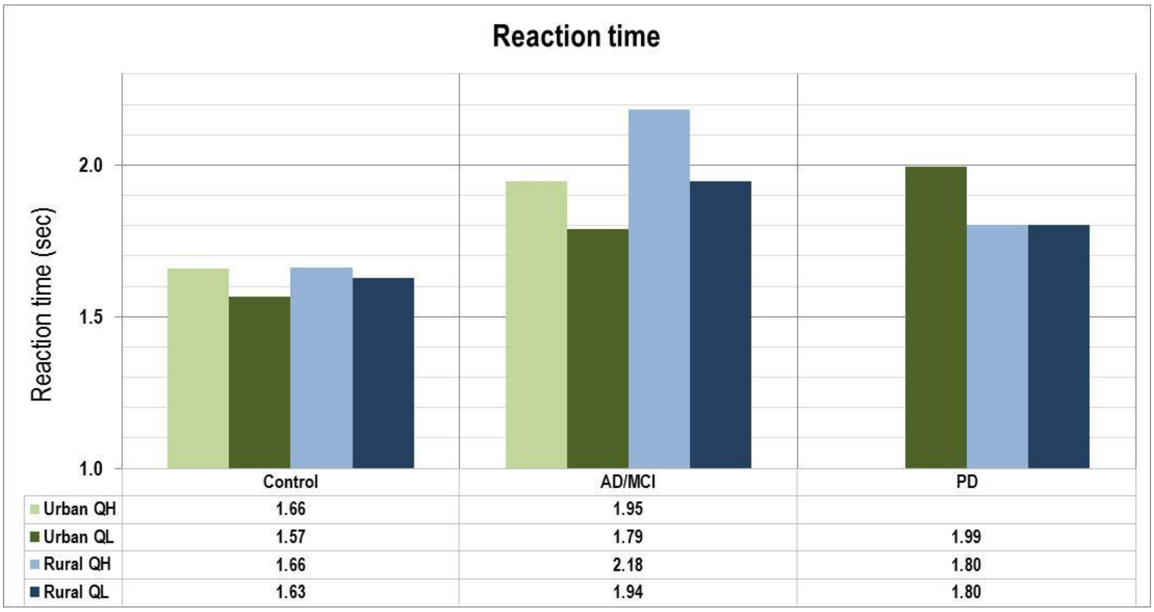


Fig. 4. Reaction time (sec)

3.5. Accident probability

In Table 1, the accident probability at unexpected incident per area type is calculated as the sum of accidents divided by the total number of incidents that took place; further distinction per traffic volume would not be meaningful due to the small sample of accidents. It is observed that control drivers in urban area have lower accident probability than the impaired drivers. In rural area control drivers and AD/MCI drivers seem to have the same probability of getting involved in an accident at the event. PD drivers seem to have very low accident probability in rural area, but one has to take into account their much lower mean speed than the control group. PD drivers appear to have strikingly higher accident probability in urban areas, possibly due to the complexity of the road and traffic setting. However, this needs further analysis and certainly a larger sample.

Table 1. Accident probability at unexpected incident

	Rural Area	*Urban Area*
Control	17%	12%
AD/MCI	17%	16%
PD	8%	25%

4. Conclusions and discussion

The experiment is currently at an early stage (39 participants have been through all phases and assessments, so far - 22 of whom impaired) and first 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. It seems that the first findings confirm the indications that drivers with neuropsychological impairment are more likely to be unsafe drivers in all disease groups - a finding that is consistent with that of Grace and al., (2005), who compared PD and AD patients with healthy controls. Some differences between different pathologies have already emerged from this first sample of drivers, revealing a slightly increased impairment by Parkinson's disease compared to mild Alzheimer's and MCI pathologies. This is probably due to the well-known procedural learning deficits encountered in patients with Parkinson's disease. However, this impairment may also be related to a deficient adaptation to the driving simulation conditions.

Summarizing the above preliminary results, impaired drivers were found to drive at significantly lower speeds compared to the control group drivers, both at low and at high traffic volume, both in rural and urban area. As would be expected, this reduced speed under given ambient traffic conditions results in increased headways, both at low and at high traffic volumes and both road area types. Moreover, PD patients drive at even lower speeds and with larger time headways compared to AD or MCI patients, especially in rural area with low traffic volume. This is probably happening because of their more conservative driving (and possibly their increased awareness of their downgraded driving performance).

Regarding the unexpected incidents, both reaction time and 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. Control drivers appear to drive more carefully in urban area and accident probability is lower compared to the impaired drivers. In rural area control drivers and AD/MCI drivers seem to have the same probability of getting involved in an accident at the event. PD drivers seem to have very low accident probability.

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 should be kept in mind, however, that this may be partly attributed to the road geometric design of the simulated drive: it may not be surprising that no lateral control variability was found in an undivided two-lane rural road with narrow lanes.

It is possible that the relatively small sample size does not allow for all potential effects of cerebral diseases on driving performance to be identified. The representativity of the sample also needs improvement. 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.

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References

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.

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.

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.

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, B.L., 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.

Grace, J., Amick, M.M., D'abreu, A., Festa, E.K., Heidel, W.C., Ott, B.R., "Neuropsychological deficits associated with driving performance in Parkinson's and Alzheimer's disease," *Journal of the International Neuropsychological Society*, vol. 11, no. 6, pp. 766–775, 2005.

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.

Klimkeit, E.I., Bradshaw, J.L., Charlton, J., Stolwyk, R., & Georgiou-Karistianis, N. (2009). Driving Ability in Parkinson's Disease: Current status of research. *Neuroscience and Biobehavioral Reviews*, 33, 223-231.

Lim, A., Tsuang, D., Kukull, W., Nochlin, D., Leverenz, J., McCormick, W., Bowen, J., Teri, L., Thompson, J., Peskind, E.R., Raskind, M., Larson, E.B. (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, L.J., Fratiglioni, L., Andersen, K., Di Carlo, A., Breteler, M.M., Copeland, J.R., Dartigues, J.F., 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.

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.

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, 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, 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, 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.

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.