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Design of a Large Driving Simulator Experiment on Performance of Drivers with Cerebral Diseases

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ABSTRACT

This paper presents the design of a large driving simulator experiment aiming to assess the effect of cerebral diseases on driver performance. The experiment was designed by an interdisciplinary team, including neurologists, neuropsychologists and transportation engineers. The pathologies considered include Alzheimer's disease, Parkinson's disease, cerebrovascular disease and Mild Congitive Impairment. The sample consists of both healthy and impaired drivers, with oversampling of the >55 years age group, in which these conditions are more prevalent. A total sample of 300 drivers will be examined within a 2 years period. The experiment consists of three types of assessment: (i) clinical medical and neurological assessment, (ii) neuropsychological assessment by means of appropriate tools, and (iii) driving simulation experiment. The driving simulator experiment in particular consists of three parts. The first and second part, in rural and urban area respectively, includes scenarios where driver performance is measured in 'typical' and 'distracted' driving conditions, at moderate or high traffic, in a within-subject design. The third part, concerns a test of basic driver skills at operational level, for specific tasks. Driver performance is examined in terms of both traffic (e.g. speed, lateral position etc.) and safety (e.g. reaction time) parameters. Preliminary results from the pilot-testing phase (25 drivers, out of which 18 impaired) already suggest detectable differences in specific performance measures between healthy and impaired drivers. Parkinson's disease patients in particular show the most impaired driving performance. The results of this research extend existing knowledge on impaired driving mechanisms and driving performance due to cerebral diseases, as well as on the methods for designing and conducting related simulator experiments (e.g. for other pathologies, fatigue, alcohol, etc.).

Keywords*: distraction, cerebral diseases, driving performance, simulator experiment.*

BACKGROUND AND OBJECTIVES

Literature Review

Road accidents constitute a major social problem in modern societies, accounting for more than 1.3 million fatalities per year worldwide (WHO, 2009), 30.000 in Europe and 1.300 in Greece (ERSO, 2008). Despite the fact that road traffic casualties presented a constantly decreasing trend during the last years, the number of fatalities in road accidents in several countries and in Greece in particular is still unacceptable and illustrates the need for even greater efforts with respect to better driving performance and increased road safety (OECD, 2008).

A number of cerebral diseases may affect driving performance in the general population and particularly in the elderly. Older drivers generally exhibit a higher risk of involvement in a road accident (Baldock et al., 2007; OECD, 2008). More specifically, diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to cerebral diseases such as Alzheimer's disease (even in the early stages), Parkinson's disease, cerebrovascular disorders (strokes or even silent-infarcts), effect of pharmaceutical substances used for the treatment of various disturbances), may significantly impair the person's driving performance, especially when unexpected incidents occur (Wood et al., 2005; Cordell et al., 2008; Cubo et al., 2009; Frittelli et al., 2009).

Regarding Alzheimer's disease, although research findings suggest that individuals with this disease may still be fit to drive in the early stages (Ott et al., 2008), they may show visual inspection and target identification disorders during driving (Uc et al., 2005). Moreover, the associated impairment in executive functions appears to have a significant effect on driving performance (Tomioka al., 2009), especially at unexpected incidents. Studies regarding Parkinson disease are less conclusive in terms of the impact of its clinical parameters on driving abilities (Cordell et al., 2008; Cubo et al., 2009). Although these conditions have obvious impacts on driving performance, in the very early stages, they may be imperceptible in one's daily routine yet still impact one's driving ability.

Mild Cognitive Impairment (MCI), which is considered to be the predementia stage of various dementing diseases of the brain (e.g. Alzheimer's, Cerebrovascular, Parkinson's disease), is a common disorder that may be observed in about 16% of individuals over 64 years old in the general population (Ravaglia et al., 2008), a percentage that increases further if individuals with mild dementia are also included. Recent studies suggest that MCI is associated with impaired driving performance to some extent (Frittelli et al., 2009), as it is characterized by attentional and functional deficits, which are expected to affect the driver's ability to handle unexpected incidents. Moreover, self-reported road accident involvement was correlated with future diagnosis of dementia (Lafont et al., 2008).

Neuropsychological parameters pertain to cerebral disease, as well. Because they are the neurocognitive measures of cerebral diseases, they are directly linked to driving performance, in health and disease. These parameters are measured on the basis of reaction time, visual attention, speed of perception and processing, and general cognitive and executive functions. The tasks with the highest sensitivity to driving performance involve speed of visual processing, especially as measured by the Useful Field of View test, attention (e.g. selective attention, divided attention, etc.) and executive functions (Bieliauskas, 2005, de Raedt & Ponjaert-Kristoffersen, 2000, Mathias & Lucas, 2009, Weaver et al., 2009). These tasks show considerable decline with age and are associated with the probability of accident involvement (Clay et al., 2005, Lunsman et al., 2008).

In conclusion, various parameters may be related to the driving performance of individuals with cerebral diseases, including demographic, medical, neurological and neuropsychological parameters. However, these inter-related parameters which are rather common in the general population, especially in older adults, and may have an important effect on driving performance, especially at unexpected incidents, have not been investigated sufficiently and with a comprehensive methodology. 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 for investigation and comparative assessment of the impact of these conditions on driving performance becomes a high priority.

Objectives

This paper presents the design of a large driving simulator experiment aiming to assess the driving performance of drivers with cerebral diseases. The basic cerebral diseases to be considered concern Alzheimer's disease, Parkinson's disease, Cerebrovascular disease (strokes or small-vessel disease). These pathologies are studied both in their Mild Cognitive Impairment (pre-dementia) stages, but also in their mild dementia stages. The driver performance is examined in terms of both traffic and safety parameters. For this purpose, an experiment including three types of assessment takes place, on the basis a specially developed methodology.

The main hypotheses that have been made at the design phase of the study are:

- Cerebral diseases affect driving performance and especially at unexpected incidents.
- Cerebral diseases interact with the other medical, neuropsychological, demographic characteristics of the drivers and road - traffic parameters, and lead to downgrade of driving performance.

EXPERIMENT DESIGN

Introduction

This study is carried out within the framework of two research projects: the DriverBrain and the DISTRACT research project.

- The DriverBrain research project, entitled "Analysis of the performance of drivers with cerebral diseases", concerns drivers with Alzheimer's disease, Parkinson's disease, Cerebrovascular disease - both in their MCI (pre-dementia) stages, but also in their mild dementia stages. These drivers are compared to those from the general population.
- The DISTRACT research project, entitled "Analysis of causes and impacts of driver distraction", concerns endogenous and exogenous causes of driver inattention and distraction and their impacts on driver bevahiour and safety.

For the purposes of these two research projects, a common driving simulator experiment was designed by an interdisciplinary research team consisting of:

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

Sample characteristics

In order to include a sample that is broadly representative of the general population of drivers but also includes a relatively larger sample of the age groups of interest, oversampling of older drivers and drivers with pathologies was chosen. The sample of participants thus comprises two distinct groups:

- One 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 (Table 1).

Table 1 Overview of the sampling scheme

Age	*Impaired*	*Healthy*	*Total*
> 55	125	75	200
< 55	50	50	100
Total	175	125	300

Overview of the Experiment

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

- Medical / neurological assessment: The first assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation.
- Neuropsychological assessment: The second assessment concerns the administration of a neuropsychological and psychological evaluation of the participants, with the use of appropriate tools.
- 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.

Additionally, the participants will be asked to fill in a questionnaire concerning their driving experience, self-reported behaviour and perceptions (Vardaki et al., 2011), their distracted driving habits (e.g. compensation strategies), and emotions (e.g. anger while driving), and their accident history. Family members completed questionnaires about their impressions of their family members with impairment.

Key Research Parameters

Because it is unlikely that all potential determinants (medical, neuropsychological, road type and traffic parameters etc.) will be of equal importance to the study, and because it is important to keep the experiment to a manageable size, a selection of the critical parameters is necessary. As a result of an exhaustive literature review, and of pilot-testing different options, the following key parameters were selected:

- Medical and neurological parameters: According to the literature, the most important parameters of impaired driving are related to brain pathology due to Alzheimer's disease, Cerebrovascular disease and Parkinson's disease. An affected individual can be mildly demented or present only a Mild Cognitive Impairment (MCI) according to the severity of brain pathology due to the aforementioned diseases.
- Neuropsychological parameters: attentional parameters, visuo-spatial perceptive deficits, executive parameters (e.g. impairments in decision making, set shifting strategies, psychomotor speed).
- Road type and traffic parameters: impaired driving performance is most important in urban areas, where the road and traffic environment is more complex. Moreover, the effect of traffic volume is considered an important parameter, which has received notably less attention in driving simulator experiments.
- Driver behaviour and safety parameters: Driver speed and vehicle lateral position are the most representative driver behaviour parameters, and reaction time and accident probability in case of unexpected incidents are the most representative safety parameters.

The present research aims to capture the interaction of cerebral diseases, other related parameters (i.e. demographic, medical, neuropsychological) as well as road and traffic conditions, with respect to driving performance. The combined effect of these key parameters on driving performance and road safety (speed, position on the road lane, reaction time and accident probability[1]) will be examined according to the conceptual framework of Figure 1.

The above design of the experiment is highly original, because it integrates different sources of impaired driving in the same study. The first two assessments will result in an estimation

[1] Accident probability refers to the probability of a driver to cause an accident at an unexpected incident

of the impact of medical, neurological and neuropsychological parameters on driving performance, while the simulator experiment will add the impact of road and traffic parameters on driving performance. The two first assessments are independent (predictor) variables at the subject level, which, in addition to the distraction (independent variables at the task level), road type and traffic characteristics, and individual characteristics, will predict the outcome variables (driving parameters) recorded during the simulator experiment.

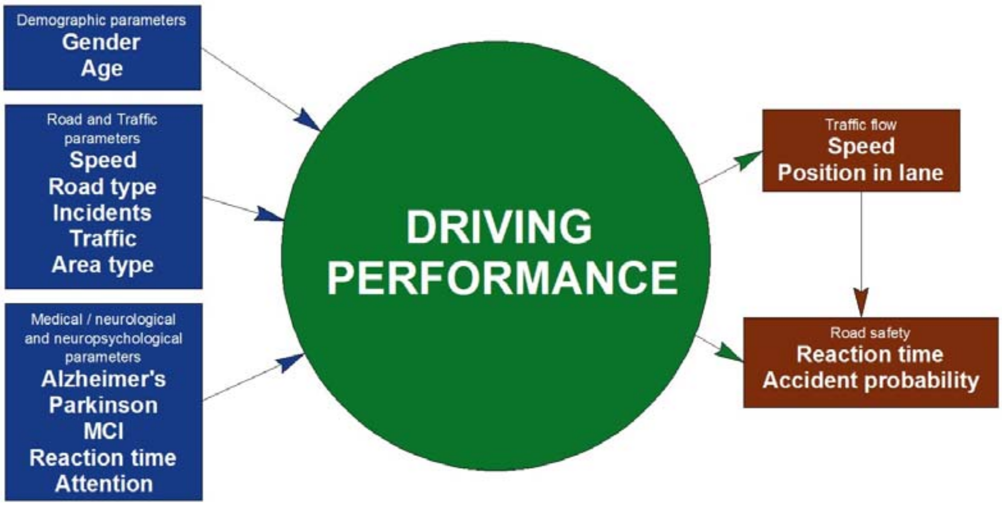

Figure 1 Conceptual framework of the research

The driving simulator equipment and software allows for the recording of all driver behaviour and safety parameters considered in this research, as well as the scheduling of unexpected incidents during the drive, and use of such simulator equipment is considered to be an appropriate and useful technique for the analysis of impaired driving performance.

PHASES OF THE EXPERIMENT

Medical / Neurological Assessment

The first assessment concerns the administration of a full medical, clinical and neurological evaluation including a thorough medical and neurological examination and taking of a detailed background history of all the participants, in order to identify the existence of disorders (e.g. Alzheimer's, Parkinson's, Cerebrovascular disease and the related MCI stages) as well as other related parameters of potential impact on driving (e.g. use of medication affecting the Central Nervous System).

This assessment includes two phases: Phase 1A - pre-simulator with up to 14 exams and Phase 1B - post simulator with up to 2 exams.

More specifically the exams are:

- Present & past history, pharmacological treatment, life habits (alcohol consumption, smoking, etc)
- Detailed neurological examination (neurological symptoms and signs: markers for a disease)
- Psychiatric assessment for depression, anxiety, behavioral disturbances
- Ophthalmological evaluation: visual acuity, visual fields, fundoscopy

- Motor ability-tests in Fitness to Drive: Specific clinical tests examining motor control, balance, visual fields etc. related to driving skills

Neuropsychological Assessment

The second assessment concerns the administration of a neuropsychological and psychological evaluation of the participants, with the use of appropriate tools. This assessment has two phases: Phase 2A - pre-simulator with up to 13 tests and Phase 2B - post simulator with up to 6 tests.
More specifically the tests carried out cover a large spectrum of Cognitive Functions: visuo-spatial and verbal episodic and working memory, general selective and divided attention, reaction time, processing speed, psychomotor speed etc. More specifically, the following neuropsychological tests will be administered to all participants:

- Cognitive screening tests:
  - General Cognitive State tests: Mini Mental State Examination, MoCA (Montreal Cognitive Assessment)
  - Other Cognitive screening tests: Clock Drawing Test, Semantic and Phonemic Fluency, Frontal Assessment Battery, Apraxia Examination
- Specific Cognitive Tests
  - Short-term & Working Memory: Letter-Number Sequencing (Wechsler Memory Scale -IV), Spatial Span (Wechsler Memory Scale-III)
  - Attention: Symbol Digit Modalities Test - Written & Oral, Neuropsychological Assessment Battery (NAB) – Driving Scenes Test, Useful Field of View (UFOV), Psychomotor Vigilance Test
  - Learning & Memory: Hopkins Verbal Learning Test, Brief Visuospatial Memory Test-Revised (BVMT)
  - Visual Perception: Judgment of Line Orientation-short form, Embedded Figure Test
  - Executive Functions: Wechsler Memory Scale-IV (WMS-IV) – Spatial Addition, Comprehensive Trail Making Test

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. This assessment has three sessions: (1) Urban Driving Session with up to six trials and (2) Rural Driving Session with up to six trials, which aim to assess driving performance under typical conditions, with or without external distraction sources. In the third session (3), a motorway driving session, driver performance on vehicle control and working memory tasks is investigated.

<u>Rural and Urban driving sessions - Typical Driving Conditions, with or without External Distraction</u>

The driving simulator experiment takes place at the Laboratory of Traffic 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 (Figure 2).

Figure 2. FOERST Driving Simulator FPF

The driving simulator experiment begins with one practice drive (5-10 minutes), until the participant fully familiarizes with the simulation environment. Afterwards, the participant drives 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, as shown in Table 2.

More specifically, the distraction conditions are: no distraction, cell-phone conversation and conversation with passenger. The traffic scenarios are:

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

Therefore there are 2 driving sessions with up to 6 trials each[2] (Table 3), which are randomized between and within sessions.

Table 2 Within-subject design parameters of the driving simulator experiment

	Road Traffic Conditions			
	Urban Area		*Rural Area*	
Distraction Sources	Q_M	Q_H	Q_M	Q_H
No Distraction	√	√	√	√
Cell Phone	√	√	√	√
Conversation With Passenger	√	√	√	√

[2] If a participant claims that he or she does not use a cell phone while driving under any circumstances, the 2 trials that include cell-phone distraction are subtracted.

Table 3 Experiment Phases 1 & 2: Sessions and trials characteristics

Session	*Area Type*	*Trial*	*Traffic*	*Distractor*	*~ Length* **(Km)**	*~ Duration* **(Min)**
1	Urban	1	Moderate	None	1,7	3:30
		2	High	None	1,7	3:30
		3	Moderate	Cell Phone	1,7	3:30
		4	High	Cell Phone	1,7	3:30
		5	Moderate	Conversation	1,7	3:30
		6	High	Conversation	1,7	3:30
2	Rural	7	Moderate	None	2,1	3:30
		8	High	None	2,1	3:30
		9	Moderate	Cell Phone	2,1	3:30
		10	High	Cell Phone	2,1	3:30
		11	Moderate	Conversation	2,1	3:30
		12	High	Conversation	2,1	3:30
				Total	**22,8**	**42:00**

Moreover during each trial 2 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.

This experiment's design (repeated measures) allows the investigation of the effects of impairment due to cerebral diseases (between-subjects variable) and the road type, traffic and distraction conditions (within-subjects variable) on driver performance. It also allows for the investigation of the possible interactions between these variables on driver performance (Boyle, 2011; Dawson, 2011).

Motorway Driving Session - Driver Performance on Vehicle Control and Working Memory Tasks

The third phase of the experiment includes three test conditions where subject performance is measured in control tasks and working memory tasks with manipulation of task demand. Each test condition takes two minutes approximately to complete. Drivers are exposed to gradually increasing demands allowing the identification of relevant performance change. As it was concluded from the pilot study (six participants with cognitive impairment and six from the control group) each drive took longer than expected because older drivers liked to talk before and after the session and were slower than expected; the final design was developed taking into consideration these observations.

It should be stressed that a resting period of 15 minutes is provided for subjects concluding the first phase of the experiment before they begin the second phase, as well as brief rest breaks between the drives.

The memory task involves cued recall, at the end of each drive of three items of safety information from a sign: type of situation ahead, relevant distance, and a driver action that is required. The information units are the same across all test conditions. The sign information is presented to the subjects for a fixed interval which is constant across subjects, before they

begin the drive. At the end of the drive the subject is requested to recall this information to the experimenter.
The level of demand for control tasks that intervene between the presentation of the road sign information and the time of recall increases across the test conditions. All scenarios involve driving along straight sections and gentle curves while they end in a common manner. In particular:

- In the first (low demand) scenario, vehicle control tasks include driving within the lane, following other (same direction) vehicles maintaining a safe distance, maintaining a constant speed (at the posted speed limit).
- In the second scenario (moderate demand), the level of demand for control tasks is manipulated, with drivers forced to make a double lane change driving along a road works section.
- The third scenario (high demand) provides a higher level of demand since the double lane change task is followed by a cognitive task involving a decision that provides additional interference with working memory.

The instructions to the subjects are given before each drive. The order of exposure to the three drives is randomized for both (healthy and impaired) samples in an effort to minimize the order effect on the experiment.
The experiment's design (repeated measures) allows the investigation of the effects of cognitive status/impairment (between-subjects variable) and the level of demand for intervening driving tasks (within-subjects variable) on recall of the safety information. It also allows for the investigation of the possible two-way interaction between these variables on the recall of the safety information when holding constant the amount of time between the presentation and recall of safety information (Boyle, 2011; Dawson, 2011; Uc et al., 2011). Data from the three test conditions will also be used for the investigation of the effect of cognitive status and other individual characteristics (Vardaki et al., 2011; Ball et al., 2011) on measures of vehicle operation considering the different road sections separately.

PRELIMINARY RESULTS

The experiment is currently at its final pilot-testing phase. Twenty five drivers have completed all three types of assessment, out of which 18 impaired drivers and 7 healthy control drivers. Out of the 18 impaired drivers, 5 were diagnosed with Parkinson's disease (PD), while the remaining 13 drivers with MCI or early Alzheimer's disease (AD). Sample size may be quite small but only the preliminary results are presented in this paper. Next studies will include statistical tests to verify differences among driver groups and will be extensive covering all cases, even those without differences.
In particular, all participants completed the full medical / neurological and neuropsychological assessments. Concerning the simulator experiment, on typical driving conditions (rural and urban driving sessions), impaired drivers completed on average 2-4 trials (out of the 6 trials of each session), while healthy drivers completed on average 4-6 trials respectively. The lower number of complete trials in the impaired drivers' group is due to the fact that they all claimed never using their cell phone while driving, as well as to increased drop out due to simulator sickness.
Data reduction is currently in progress; however, as a preliminary step of data analysis, profiles of key driver performance measures along each trial were computed, namely speed and lateral position. Moreover, reaction times at incidents were computed. Indicative results are presented below, with emphasis on the comparison between healthy drivers and drivers with cerebral diseases. In this context, these results concern the rural road, moderate traffic volume trial with no external distraction. Moreover, mild AD and MCI conditions are

grouped together, because the sample of confirmed AD patients is currently very small (i.e. mild AD diagnosis is still pending for some individuals with MCI)

In Figure 3, the mean speed profiles of drivers along the rural road trial (moderate traffic volume, no external distraction) are presented per driver condition. It is observed that all drivers present very similar speed profiles in terms of general shape, which is intuitive given that the shape of the speed profile is largely dependent on the road geometry, the occurrence of incidents (i.e. speed drop is visible at around Km 0.85 and Km 1.35 of the profile) and the traffic conditions, which were the same for all drivers. Healthy drivers drove the trial road section at higher speeds than impaired drivers. Moreover, drivers with AD or MCI drove the trial road section at slightly lower speed, whereas drivers with PD drove the trial road section at significantly lower speed than healthy drivers. It is also observed that the mean speed reduction at unexpected incidents (Km 0.85 and Km 1.35 approximately) is less pronounced for PD drivers, because their initial (pre-incident) speed was lower.

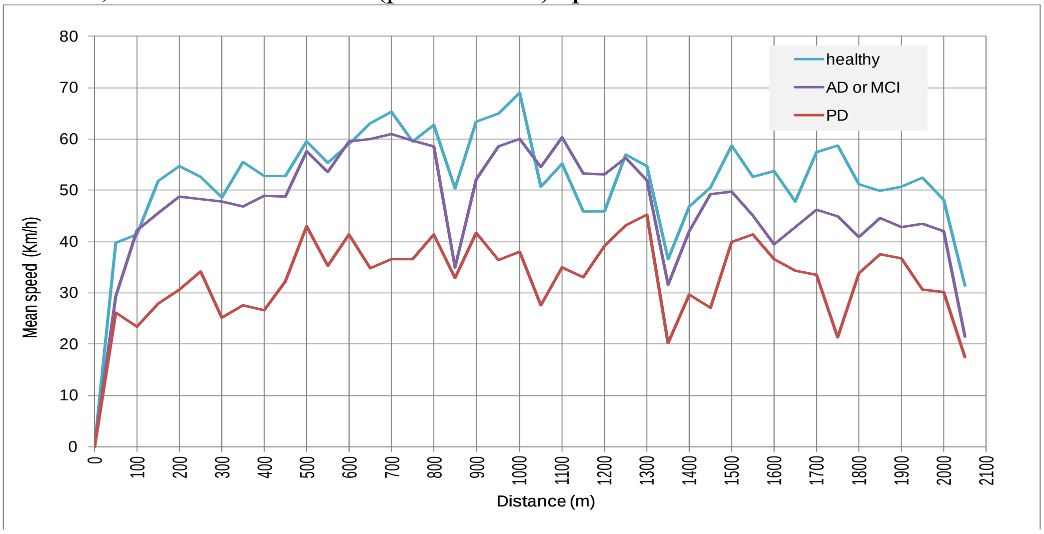

Figure 3 Mean speed profiles of healthy and impaired drivers (rural area, moderate traffic volume, no external distraction)

Figure 4 concerns the mean lateral position profiles per driver group along the rural road section trial (moderate traffic volume, no external distraction). Lateral position is defined as the vehicle’s distance from the right road border in metres. In this case, differences between drivers are less pronounced, yet detectable. Lateral position profiles between healthy drivers and AD or MCI impaired drivers exhibit more similarities in terms of overall shape of the profile and magnitude of the examined measure. PD impaired drivers present slightly increased differences compared to healthy drivers, especially in specific intervals of the profile.

These smaller differences in lateral position between healthy and impaired drivers may be attributed to the fact that, by definition, lateral position is a less sensitive measure of driving performance (due to the restrictions of the road section geometry). However, the small sample size does not allow for further interpretation of these differences.

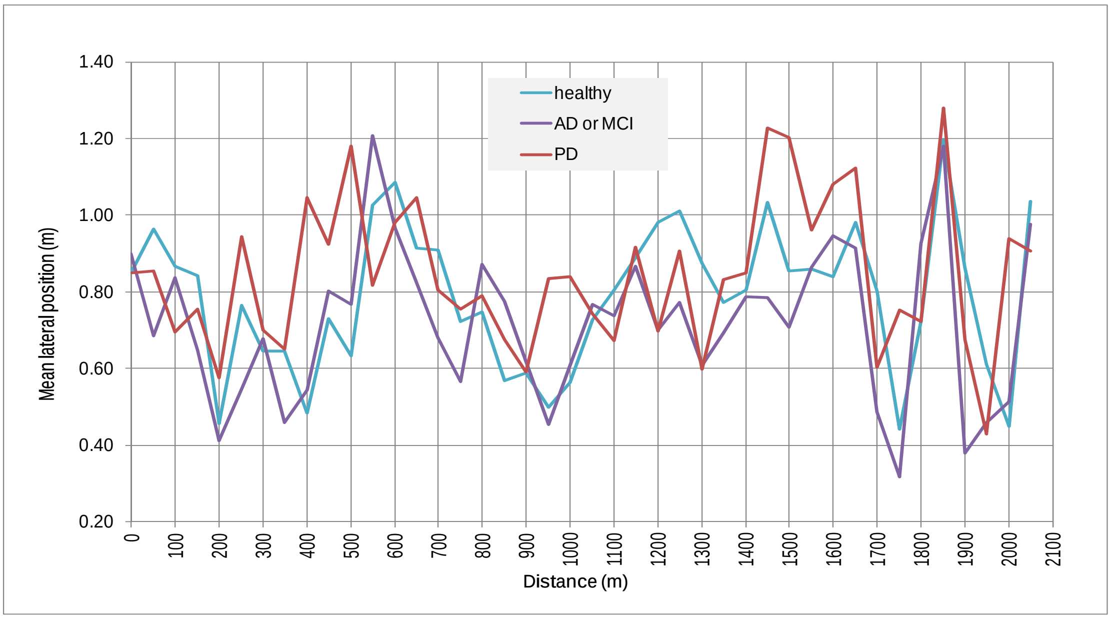

Figure 4 Mean lateral position profiles of healthy and impaired drivers (rural area, moderate traffic volume, no external distraction)

Finally, in Table 4 the mean reaction times[3] at unexpected incidents were computed for healthy drivers and drivers with cerebral diseases. Again, only low traffic volume and no external distraction trials were used, while AD and MCI impaired drivers were grouped together. It is observed that, in the rural road trial, impaired drivers present slightly higher reaction times than healthy drivers, while no difference is identified between the different pathologies. On the other hand, in the urban road trial, PD impaired drivers appear to have slightly higher reaction times at incidents, while there appears to be no difference between healthy and AD or MCI impaired drivers.

Table 4. Mean reaction times at incidents of healthy and impaired drivers per road type (moderate traffic volume, no external distraction)

Reaction time	***Rural area***	***Urban area***
Healthy drivers	1.54 sec	1.52 sec
Impaired drivers	1.79 sec	1.56 sec
AD or MCI	1.79 sec	1.51 sec
PD	1.78 sec	1.78 sec

It is noted that the above results concern preliminary findings from the first steps of data processing, they are based on a small sample of drivers, and therefore need to be considered with some caution.

[3] We consider reaction time as the time between the first move of the “obstacle” towards the road (animal, child, car) and the braking time.

DISCUSSION

In this study, the driving performance of drivers with cerebral diseases is explicitly considered for the first time in the international literature, by means of the integration of the different scientific disciplines involved in impaired driving research (traffic engineering, neurology and neuropsychology).
The analysis of the combined effect of cerebral diseases and other demographic, medical, neurological and neuropsychological parameters on the driving performance of individuals from the general population is both critical and challenging. The above questions have not been adequately examined in the literature, especially in simulation experiments, despite their high prevalence in the general population of drivers, especially the elderly.
The experiment is currently at its final pilot testing phase and first results suggest that the specific methodology and design seem to confirm the initial hypotheses and may reveal important differences between drivers with cerebral diseases and 'healthy' drivers for the examined driver performance measures. Some differences between different pathologies have already emerged from this first small sample of drivers, revealing an 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 condition. 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.
The single and combined effect of medical, neurological, neuropsychological, road type and traffic, external distraction and individual characteristics on driving performance will be investigated, resulting in a mixed (within- and between-subject) analysis design. Driving performance will be examined in terms of vehicle operation measures such as mean speed, speed variability, mean lateral position and lateral position variability, reaction time at incidents, as well as in terms of additional measures e.g. collisions, recall of safety information.
The results of this study can be eventually exploited in the development of recommendations and measures for addressing various aspects of impaired driving due to cerebral diseases, such as the effectiveness of measures for the improvement of the performance of older or impaired drivers, education and training for safe driving and dealing with unexpected incidents, special measures for specific high-risk groups and medical, neurological criteria for safe driving and monitoring of drivers at risk for presenting a condition that is associated with unsafe driving.
The methodological framework proposed in the present study can be extended to other related interdisciplinary research areas on road safety, such as driver drowsiness or fatigue, driving under the influence of alcohol or drugs, etc. and thus broaden the research perspective in the field.

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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.

Ball, K., Ackerman, M. (2011). The Older Driver Training and Assessment: Knowledge, Skills and Attitudes, In: Fisher, D., Rizzo, M., Caird, J., Lee J., Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

Bieliauskas, L. A. (2005). Neuropsychological assessment of geriatric driving competence. Brain Injury, 19, 221-226.

Boyle, L. (2011). Analytical Tools, In: Fisher, D., Rizzo, M., Caird, J., Lee J., Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

Clay, O., Wadley, V. G., Edwards, J. D., Roth, D. L., Roenker, D. L., & Ball, K. (2005). Cumulative meta-analysis of the relationship between useful field of view and driving performance in older adults: Current and future implications. Optometry and Vision Science, 82, 724-731.

Cordell, R., H. C. Lee, et al. (2008). Driving assessment in Parkinson's disease - a novel predictor of performance? Mov Disord 23(9): 1217-22.

Cubo, E., P. Martinez Martin, et al. (2009). "What contributes to driving ability in Parkinson's disease." Disabil Rehabil.

Dawson, J. (2011). Statistical Concepts, In: Fisher, D., Rizzo, M., Caird, J., Lee J., Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

de Raedt, R. & Ponjaert-Kristoffersen, I. (2000). The relationship between cognitive/neuropsychological factors and car driving performance in older adults. Journal of the American Geriatrics Society, 48, 1664-1668.

ERSO (2008). Annual Statistical Report 2008. Deliverable 1.20 of the “SafetyNet: Building the European Road Safety Observatory” Integrated Project. Available on-line at: http://erso.swov.nl/safetynet/fixed/WP1/2008/SafetyNet%20Annual%20Statistical%20Report%202008.pdf

Frittelli, C., D. Borghetti, et al. (2009). Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test. Int J Geriatr Psychiatry 24(3): 232-8.

Lafont, S., Laumon, B., Helmer, C., Dartigues, J. F., & Fabrigoule, C. (2008). Driving cessation and self-reported car crashes in older drivers: The impact of cognitive impairment and dementia in a population-based study. Journal of Geriatric Psychiatry and Neurology, 21, 171-182.

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

Mathias, J. L. & Lucas, L. K. (2009). Cognitive predictors of unsafe driving in older drivers: A meta-analysis. International Psychogeriatrics, 21, 637-653.

OECD (2008). Towards Zero: Ambitious Road Safety Targets and the Safe System Approach. OECD, Paris, October 2008.

Ott, B. R., W. C. Heindel, et al. (2008). A longitudinal study of drivers with Alzheimer disease. Neurology 70(14): 1171-8.

Ravaglia, G., Forti, P., Montesi, F., Lucicesare, A., Pisacane, N. Rietti, E. et al. (2008). Mild Cognitive Impairment: Epidemiological and dementia risk in an elderly Italian population. Journal of the American Geriatrics Society, 56, 51-58.

Tomioka, H., B. Yamagata, et al. (2009). Detection of hypofrontality in drivers with Alzheimer's disease by near-infrared spectroscopy. Neurosci Lett 451(3): 252-6.

Uc, E. Y., M. Rizzo, et al. (2005). Driver landmark and traffic sign identification in early Alzheimer's disease. J Neurol Neurosurg Psychiatry 76(6): 764-8.

Uc, E., Rizzo, M. (2011). Driving in Alzheimer’s Disease, Parkinson’s Disease and Stroke, In: Fisher, D., Rizzo, M., Caird, J., Lee J., Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

Vardaki, S., Karlaftis, M. G. (2011). An investigation of older driver road safety perceptions and driving performance on freeways, Advances in Transportation Studies, Special Issue 2011, pp.7-18.

Weaver, B., Bédard, M., McAuliffe, J., & Parkkari, M. (2009). Using the Attention Network Test to predict driving test scores. Accident Analysis and Prevention, 41, 76-83.

WHO (2009). Global status report on road safety 2009. WHO, Geneva. Available on-line at: http://whqlibdoc.who.int/publications/2009/9789241563840_eng.pdf

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

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.