Exploring the Association between Working Memory and Parkinson's Disease in a Driving Simulator

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Abstract

A driving simulator was used to explore whether varying levels of operational and tactical driving task demand would differentially affect healthy drivers versus drivers with Parkinson’s disease (PD) in their message recall. Study participants aged between 50 and 70 years included a group of drivers diagnosed with Parkinson’s disease and a control group of drivers with no pathological conditions. Drivers of the control group were more likely to perform better than PD drivers in a sign recall task, but this trend was not statistically significant; also, disregarding group membership, subjects’ performance differed according to varying levels of task demand. Although the conclusions drawn from this study are tentative, the evidence presented here is encouraging with regard to the use of a driving simulator to identify performance differences related to medical conditions. With an understanding of its limitations, such driving simulation in combination with functional assessment batteries measuring physical, visual and cognitive abilities could comprise one component of a multi-tiered system to evaluate medical fitness-to-drive.

Keywords: driving simulator; Parkinson’s disease, working memory, sign recall, fitness-to-drive

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Exploration de l'association entre la mémoire de travail et la maladie de Parkinson dans un simulateur de conduite

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Résumé

Un simulateur de conduite a été utilisé pour déterminer si les niveaux variables de tâches de conduite opérationnelle et tactique affectent différemment les conducteurs sains par rapport aux conducteurs de maladie de Parkinson (PD) dans leur rappel de messages. Les participants de l'étude étaient âgés de 50 a 70 ans incluent un groupe de conducteurs atteints de la maladie de Parkinson et un groupe de contrôle de conducteurs sans conditions pathologiques. Les conducteurs du group contrôle étaient plus susceptibles de mieux réussir que les conducteurs PD dans une tâche de rappel de signe, mais cette tendance n'était pas statistiquement significative; aussi, sans tenir compte l'appartenance à un groupe, la performance des sujets différait en fonction de différents niveaux de travail demandé. Bien que les conclusions tirées de cette étude soient provisoires, la preuve présentée ici est encourageant en ce qui concerne l'utilisation d'un simulateur de la conduite pour identifier les différences de performance liées à des troubles médicaux. Par la compréhension de ses limites, tels essais de la simulation de conduite en combinaison avec des séries d'évaluation fonctionnelle de mesure des capacités physiques, visuelles et cognitives pourrait comprendre une composante d'un système à plusieurs niveaux pour évaluer l'aptitude médicale à la conduite.

Mots-clés: Simulateur de conduite; Maladie de Parkinson, Mémoire de travail, Signe de rappel, Aptitude à la conduite

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1. Introduction

The ability to drive can be affected by various motor, visual, cognitive and perceptual deficits either related to normal ageing or caused by neurological disorders such as stroke, Parkinson's disease, Alzheimer's disease, multiple sclerosis and traumatic brain injury, which are more prevalent among older persons (Akinwuntan, 2012). Age and medical diagnosis are insufficiently reliable predictors of driver safety and crash incidence; furthermore, in determining fitness to drive, it is the diminished visual, perceptual-cognitive and physical abilities themselves that are of principal concern, and not the chronological age or the underlying medical conditions (a particular diagnosis) that may have produced a functional loss (Staplin, 2012; Staplin et al. 2003; Uc and Rizzo, 2011). In a review of older driver assessment methods, Ball and Ackerman (2011) noted that "assessment provides a basis for identifying options for licensing recommendations and determining the possibility of remediation". While the gold standard of driving assessment is considered to be on-road evaluation, its effectiveness and efficiency is under investigation (Ball and Ackerman, 2011; Mullen et al., 2008). Driving simulators are considered a promising tool for reliable and safe evaluation of driving performance in America and Europe, especially in people with a loss of functional ability(ies) needed to drive safely due to physical or neurological conditions (Singh et al., 2011; Hakamies and Peters, 2000).

Studies have demonstrated that the use of driving simulators as part of an assessment battery may be a promising method for assessment of older drivers and also that performance on the simulator is associated with performance in on-road testing (Ball and Ackerman, 2011). Driving simulators have enabled a better understanding of driving errors and their relationships with the type and degree of a driver's functional impairments, allowing researchers to distinguish between controls and people with neurodegenerative disorders including Parkinson disease and Alzheimer's disease (Uc and Rizzo, 2011). Considering Parkinson's disease (PD), in particular, it is impairments in cognition and visual perception rather than motor symptoms that are the main determinants of performance and safety of drivers with PD. Based on the findings of a recent review of studies on driving performance (on-road tests and simulators), Crizzle et al. (2012) propose a framework of risk factors to help clinicians determine when drivers with PD are at risk. These authors found that cognitive deficits may be present in the early stages of PD; also, simulated driving performance in drivers with PD tend to be worse in low contrast conditions, which may possibly be predicted by deficits of contrast sensitivity. In a validation study (Devos et al. 2013; Devos et al. 2007) of a screening battery to predict decisions (pass-fail) about driving fitness in PD drivers, the inclusion of driving simulation increased the accuracy of the clinical model; this suggests an association between driving simulation measures and actual on-road performance in PD.

Driving simulators vary in their characteristics, i.e. motion base vs. fixed base, interactivity, resolution and field of view, as well as in their validity against actual road driving (Uc and Rizzo, 2008). The simulator used in the research by Devos et al. (2007) was a stationary full-sized Ford Fiesta 1.8 car with automatic gear transmission powered by the STISIM Drive System, Model 300, Version 1.03.05. Different simulators pose different technological limitations for researchers, making the exact replication of reality impossible. For example, poor quality of sensory information may result in fewer perceptual cues available to drivers, who rely on them to make tactical judgments (Rizzo 2011; Staplin 2010; Vardaki,Yannis et al. 2013).

There are a number of cognitive functions essential for safe driving performance that may be studied effectively using these platforms, notwithstanding the aforementioned limitations. Working memory is a cognitive ability of key importance to driving; it allows a driver to remember—and apply when needed—navigational directions and rules for traffic operations, even as s/he is processing and responding to the real-time demands of steering, anticipating and avoiding conflicts, and performing other moment-to-moment vehicle control tasks (Staplin, 2012; Staplin et al., 2003). Executive functions including decision-making, impulse control, judgment, task switching and planning strongly interact with working memory, and with attention, which operates on the contents of working memory (Rizzo, 2011). Anecdotally, the loss of short-term memory is one of the most common complaints of older people. The ability to recall directions and information from signs and other traffic control devices is an important element in avoiding the confusion that can lead to accidents. Not only does it make sense that those drivers with working memory problems are more likely to become lost and/or confused, and to respond inappropriately to unusual or unexpected traffic situations, research has shown that (age-related) impairments in working memory are a significant predictor of at-fault crashes (Ball et al., 2006;Staplin et al., 2003).

In a driving simulator study (Lee et al. 2003), one of the cognitive abilities associated with crash occurrence in a sample of older drivers was working memory. Performance in driving tasks involving working memory was measured with a recall task. According to the results of a logistic regression analysis, after adjusting for age, each added point on the working memory scale (recall) was associated with a 45% decrease in risk (Lee et al., 2003). Lee et al. (2007), exploring the validity of using the interactive PC-based STISIM driving simulator, observed that participants with PD tended to drive more slowly in response to road hazards and were unable to control speed and movement of the steering wheel; to apply the brakes smoothly; to address two tasks simultaneously; and to make quick decisions and judgments. These problems may be related to decrements in motor skills, visuo-spatial processing, working memory and the executive function of planning. The authors concluded from the findings of the study that driving simulators can provide valuable information on PD drivers' ability.

In a pilot study using a fixed-base driving simulator, Vardaki, et al. (2014) found that medically at-risk subjects (with MCI and PD) performed worse in a sign recall task than controls; and that a longer versus shorter delay before message recall had no significant effect on either group. There was a main effect, such that increasing the level of driving task demand between message presentation and recall (while holding delay roughly equal) had an inverse impact on recall performance across both groups of study participants. The present investigation builds upon the tentative conclusions from this pilot study, using an improved experimental methodology to examine how varying levels of operational and tactical driving task demands might differentially affect message recall for older drivers with PD versus a group of matched, healthy controls.

2. Research methods

2.1 Participants

This driving simulation study was conducted at the Department of Transportation Planning and Engineering of the School of Civil Engineering at the National Technical University of Athens (NTUA) in Athens, Greece, using a FOERST Driving Simulator FPF. The driving simulator consists of 3 LCD screens, each 40'' wide, with driver's seat and controls, and support base. Display resolution for the LCD screens was full HD (1920x1080pixels). Later figures illustrate the simulator configuration used during data collection.

This study was part of a larger driving simulator experiment described in Yannis et al. (2013), from which current participants were drawn. All participants in this research held a valid driving license, and had to meet certain criteria: they must have driven for more than 3 years; they must have driven more than 2500km during the last year; they must have driven at least once a week during the last year; they must have driven at least 10km/week during the last year; they must have a Clinical Dementia Rating (CDR) score <2; they must not have a significant psychiatric history of psychosis; they must not have any significant kinetic disorder that prevents them from basic driving movements; they must not suffer dizziness or nausea while driving, either as a driver or as a passenger; they must not be pregnant; they must not be alcoholic or have any other drug addiction; they must not have any significant eye disorder that prevents them from driving safely; and they must not have any disease of the central nervous system.

Table 1. Comparison of patients with PD and of a Control group without neurological history on various demographics with the use of the Wilcoxon Rank Sum Test

	PD group	Control group	P-values
Age, y, mean±SD(median)	62.2±8.4(66)	57.6±5.1(58)	0.247
Gender, n, M/F	10, 10/0	10, 7/3	0.280
Driving experience, y, mean±SD (median)	37.3±6.8 (37)	33.9±4.3 (35)	0.218
Days/week, median (range)	4(2-7)	5 (2-7)	0.143
Kilometers driven/week, median (range)	3 (1-3)	3(2-5)	0.035[a]
Accidents (2 years)-reported,median (range)	0 (0-0)	0 (0-.0)	1.000
Accidents (total)-reported,median (range)	1 (0-4)	2 (1-8)	0.029[a]
Education, y, median (range)	13.7±3.1(14)	14.1±3.5(16)	0.684
CDR[b]	0.06±0.17(0-0.5)	0	1.000
Parkinsonism(n=10)			
UPDRS[c]	12.9±9.2(3-29)		

H&Y[d]	1.90±0.57(1-3)
Dopa equivalent dosage (mg/day)	575±313(150-1150)

[a]Statistically significant between-group difference at the 0.05 level
[b]Clinical Dementia Rating
[c]Unified Parkinson's disease Rating Scale – motor scores
[d]Hoehn&Yahr stage

Two groups of drivers participated in the present study, a group of drivers diagnosed with Parkinson's disease (PD) and a group of controls. The PD group included 10 subjects with a mean age of 62.2 years (s.d.=8.4), all males. The control group consisted of 10 subjects, 7 men and 3 women, who were medically evaluated and found to have no pathological condition, with a mean age of 57.6 years (s.d.=5.1). In Table 1, the between-group comparisons in age, driving experience, driving exposure (number of days driven per week and kilometers per week), in the number of years of education, the total accidents and accidents in the past two years, and the CDR score are presented. The difference in age between the two groups was not statistically significant at the 0.05 level (p=0.247); the groups were not statistically different in terms of gender, driving experience, frequency of driving (number of days they drive per week), years of education and (reported) number of recent accidents (within the last two years) (Table 1 Statistical differences were found in the number of kilometers driven per week (p=0.035) and in the (reported) number of their total accidents (p=0.029) (Table 1). The drivers with PD had mild to moderate disease severity, as indicated by their Unified Parkinson's Disease Rating (UPDRS) score and the Hoehn&Yahr (H&Y) stage (Table 1). All subjects completed a series of neuropsychological tests at the ATTIKON University General Hospital, before their participation in the driving simulation experiment. In Table 2 the between-group comparisons in performance measures in neuropsychological tests are presented.

Statistical differences between groups were found in Frontal Assessment Battery (FAB) assessing executive functioning, Hopkins Verbal Learning Test-Immediate Recall Total Score (HVLT-Total) assessing the immediate recall of verbal material, Spatial Addition Test assessing working memory, Symbol Digit Modalities Test (SDMT) assessing information processing speed, Useful Field of View Subtest 3 (UFV3) assessing selective attention. The overall pattern of performance indicates that the group of patients with PD as compared to the control group is facing difficulties on neuropsychological tests engaging episodic memory operations as well as executive, attentional and working memory resources.

Table 2. Comparison of patients with Parkinson's disease and of the Control group on a broad array of neuropsychological tests with the use of Wilcoxon Rank Sum Test

	PD group	Control group	P-values
MMSE 4	28.4±1.88	29.40±.84	.163
Frontal assessment battery(FAB)[a]	12.89±3.30	17.00±.30	<.001
ImmediateRecall_HopkinsTotal[a]	19.22±2.82	23.60±4.90	.037
HopkinsDelayedRecall	5.56±2.56	6.90±3.14	.549
LNS[b]	8.00±3.87	10.10±1.56	.211
Spatial Addition Test[a]	7.22±3.07	14.40±4.12	.001
SDMT[c,a]	31.33±10.20	47.20±9.08	.001
TMT-A[d a]	54.78±34.23	38.60±10.47	.191
TMT-B[e]	164.67±99.67	95.70±32.14	.141
UFV1[f]	354375±169646	263700±164370	.209
UFV2[g]	1946250±1653138	643700±529057	.099
UFV3[h a]	3167125±1249620	3073700±4927899	.023
Driving Scenes Test	40.50±12.58	45.70±6.13	.154

[a]Statistically significant between-group difference at the 0.05 level
[b]Letter Number Sequencing
[c]Symbol Digit Modalities Test
[d]Trail Making Test Part A
[e]Trail Making Test Part B
[f]Useful Field of View Subtest 1
[g]Useful Field of View Subtest 2
[h]Useful Field of View Subtest 3

2.2. Procedure

The drivers with PD were tested during periods of optimal symptom control. Experimenters were blind to the results of the neuropsychological tests. All subjects gained a degree of familiarity with the simulator through participation in a prior experiment that lasted approximately 45 minutes. Subjects were afforded a rest period of at least 15 minutes between their experience in the prior experiment and their participation in the present study. This prior experience allowed participants to practice all their driving skills (distance judgment, pedal and steering control) and also served as a screen for susceptibility to simulator adaptation syndrome (SAS) for the study sample. None were so affected.
The study aim noted above was addressed in an experiment completed in a single laboratory session. The experiment included three conditions, TC1 and TC2 and TC3 and used repeated measures for the PD and C subjects during simulator drives of approximately two minutes' duration. The experiment measured the effect of different levels of intervening driving task demand (i.e., between message presentation and recall) on the recall of the sign information by the PD and C subjects, while the amount of time between the presentation and recall of the safety message was roughly equivalent across conditions. In order to have precise control over the time the message was displayed to the subjects, before each of the three drives in the simulator a safety message on a sign was presented for a fixed interval (~8 sec) that is constant across study participants (Campbell et al., 2012).

Before each of the three drives in the simulator, subjects were instructed to respond to traffic control information and always maintain safe gaps with other vehicles just as they would when actually driving. They were also instructed to maintain a constant speed at the posted speed limit unless they encountered the road section where barriers were present. Specifically, they were told to try to "*maintain a constant speed at the maximum posted speed limit for the roadway throughout the entire drive, unless you encounter road conditions where you must reduce speed to avoid hazards. In this situation, drive at what you feel is the maximum safe speed for conditions*." They were also told by the experimenter, "*At some point during this drive you will see a sign with a safety message displayed in white letters on a blue background. I will ask you to recall it at the end of the drive*." An example is shown in Figure 1.

Fig. 1. Example message sign indicating border crossing 6 km ahead where drivers should stop for inspection.

Alternate messages were constructed for use in each test condition, each with three units of information, indicating the *type of situation ahead*, *distance* and a *driver action* that is required (Campbell et al., 2012) using standard wording (HMTI, 2010). The information units conveyed in the example in Figure 1 indicate a *Border crossing* (one unit, indicating the situation/problem ahead*)*, *6 km* (one unit, indicating the distance to the situation ahead), where the driver must *stop for inspection* (one unit, indicating what the driver is required to do). The other messages presented were: *Road construction*, *3km*, *deviation* (TC1); *Tunnel*, *5 km*, *reduce speed* (TC2) and *Ice on the road*, *4 km*, *use chains* (TC3).

All driving scenarios involved driving along straight sections and gentle curves on a limited access, divided roadway. Scenarios avoided sharp curves or frequent stops (Trick et al. 2011) to reduce the likelihood of simulator adaptation syndrome. Across all test conditions, the driving scenario began with a period of low-demand driving, requiring minimal steering input and with the only other traffic being two vehicles ahead with the lead vehicle in a safe distance ahead of the driver. These low-demand driving conditions persisted throughout TC1. In test conditions TC2 and TC3, however, after the initial period of low-demand driving, the level of demand was varied by imposing different types of operational and tactical driving tasks on subjects. In TC2, the subject is negotiating the road work section, as the lane width tapers to its narrowest dimension. In TC3 the demand on working memory is different from the other test conditions, due to the addition of a concurrent driving task. The presentation order of conditions was randomized.

The test conditions are described below:

- <u>TC1-Demand Level 1.</u>In TC1, the driver experienced only a low level of demand for intervening, operational-level driving tasks.
- <u>TC2-Demand Level 2</u>. In TC2, drivers made a double lane change that involved driving through a road work section containing large blocks (barriers) on each side of the road, causing the road to progressively narrow (1:20 taper ratio; lane width 3m). The demand in this scenario was higher than TC1
- <u>TC3-Demand Level 3</u>. In TC3, drivers met the same steering requirements as in TC2, and after the forced lane changes along the road works section were completed, they were also required to execute a lane change in response to a discriminative stimulus (activation of the brake lights on the lead vehicle). The demand in this scenario was higher than TC2

The research design required subjects to remember and apply rules for car following and lane changes throughout the drives. In the high demand condition (TC3), the demand on working memory is different from the other test conditions. It may be noted that the discriminative stimulus in TC3 is a lane change of the car ahead *after it activates the brake lights*; lane changes of lead vehicles without brake light activation were also present in the other test conditions. Figure 2 shows a subject in the simulator during a drive under test condition TC2; the blocks/barriers of the road work section are just visible in the distance. In TC1 the driver experienced only the open road condition that is visible immediately ahead of the driver in Figure 2a. In Figure 2b, the subject is negotiating the road work section, as the lane width tapers to its narrowest dimension.

Immediately after the end of each drive, subjects were asked to recall the safety message presented on the corresponding sign. The experimenter then assigned a score 0-3, indicating that none, 1, 2 or all 3 information units were recalled. With the exception of the distance unit, the accuracy of recall was assessed on the basis of the meaning of the message information, rather than the exact wording.

Fig. 2. Test condition TC2 (a:left) with a road works section visible in the distance; (b:right) as barriers narrow the road to a single lane.

3. Results

For the present analysis, data were analysed from participants that had performed the cognitive task in TC3 according to the instructions, executing a lane change in response to the discriminative stimulus. As a manipulation check, to confirm that the demand of the driving task varied across test conditions as revealed through drivers' speed reductions to negotiate the road works section, a two-way mixed ANOVA (using SPSS) tested for main effects of medical status (PD), a between-subjects variable, and the level of demand for intervening driving tasks, a within-subjects variable, on drivers' speed; and also for a possible two-way interaction between these variables.

Table 3 provides descriptive statistics for the two levels of each independent variable. From the table we can see that on average in Level 1 of intervening task the mean speed was higher than mean speed in Levels 2 and 3; in addition, the mean speed of the PD group was lower than the mean speed of the control group across all levels of task demand. ANOVA indicates that the effect of group membership on speed is significant ($F(1, 18)=9.07$, $p=0.008$), and also that differences in speed associated with the level of intervening task demand were reliable, ($F(1.32, 36)=57.22$, $p<0.001$). In other words, disregarding group membership, subjects reduced speed across driving test conditions suggesting that the level of demand was indeed varied by imposing different types of operational and tactical driving tasks on subjects. Bonferroni corrected post hoc test showed that mean speed at level 1 was significantly different than both levels 2 and level 3 (both $p<0.001$). Speeds at level 3 were not significantly different than speeds at level 2 (both $p>0.05$).

Table 3. Descriptive Statistics of Speed

	Group	Mean	Std. Deviation	N
Speed, Demand Level1	Control	68.10	11.27	10
	PD	51.80	14.31	10
	Total	59.95	15.07	20
Speed, Demand Level2[a]	Control	39.09	10.87	10
	PD	30.54	8.72	10
	Total	34.81	10.55	20
Speed, Demand Level3[a]	Control	39.31	8.82	10
	PD	30.97	9.56	10
	Total	35.14	9.92	20

[a]Average speed along the road works section

The interaction graph (Figure 3) illustrates these differences as well as the nature of the interaction between group membership (medical status) and intervening task demand which is not statistically significant ($F(1.32, 36)=1.42$, $p>0.05$).The "whiskers" (bars) denote one standard error around the mean of speeds for each group with varying levels of task demand.

A General Estimating Equation (GEE) model (ordered multinomial logistic regression) was specified to examine the relationship between participant group and performance in the sign recall task, adjusting for potential intercorrelations among sign recall task for each participant at the three test conditions. The ordinal logistic GEE showed that controls were more likely to perform better than PD drivers in the sign recall task; this trend however was not statistically significant (B(SE)=.53(.68), OR=1.70, CI=0.45, 6.41, $p>0.05$) (Table 4). This analysis revealed that, disregarding group membership, subjects performed better in the recall of safety information in TC1 versus TC3 (B(SE)=.72(.48), OR=2.05, CI=0.79, 5.29, $p>0.05$) (Table 4), although this difference was not significant. Performance in the sign recall task was more likely to be higher in TC2 (lower level of driving task demand) than TC3 (higher level of driving task demand) and this difference was statistically significant (B(SE)=.89(.42), OR=2.44, CI=1.07, 5.60, $p<0.05$). While age was not included in the final model specification, it was considered during the model building process, but not retained as it was not significant in any reasonable significance level.

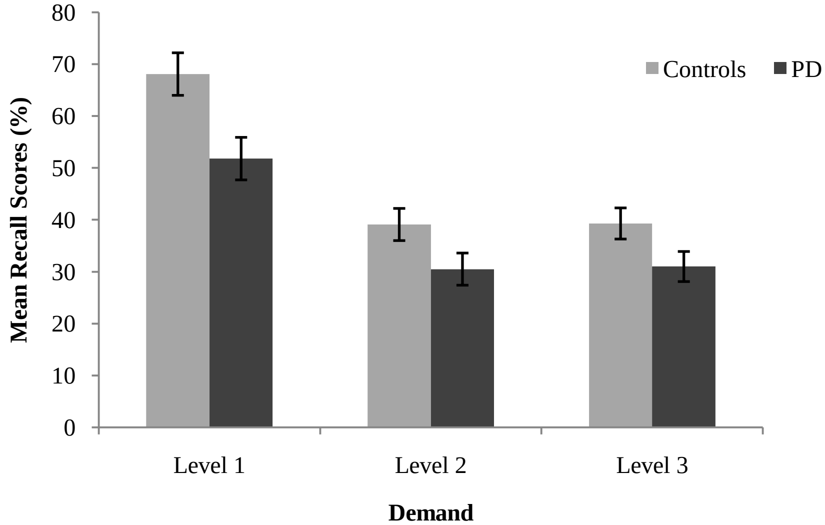

Fig. 3. Mean speed for each group with varying levels of task demand with error bars denoting one standard error around the mean

Table 4. Multinomial regression predicting recall scores

Parameter		B	Std. Error	Odds Ratio (OR)	95% CI for Odds Ratio Lower	Upper	Hypothesis Test Wald Chi-Square	df	Sig.
Threshold	Recallscores =0	-1.93	0.94	0.14	0.02	0.91	4.26	1.00	0.04
	Recallscores=1	-1.00	0.70	0.37	0.09	1.45	2.04	1.00	0.15
	Recallscores=2	0.31	0.57	1.36	0.44	4.18	0.29	1.00	0.59
Controls		0.53	0.68	1.70	0.45	6.41	0.61	1.00	0.43
PD		0							
TC1-Demand-Level1		0.72	0.48	2.05	0.79	5.29	2.19	1.00	0.14
TC2-Demand Level2		0.89	0.42	2.44	1.07	5.60	4.46	1.00	0.03
TC3-Demand Level3		0							

Dependent Variable: Recall scores, Model: (Threshold). status. Demand (Independence model)

4. Conclusions and discussion

The goals of this exploratory study were to determine whether varying levels of operational and tactical driving task demands would differentially affect highway sign message recall by healthy drivers versus drivers classified as medically at-risk due to a diagnosis of Parkinson’s disease (PD). An experiment was carried out using a fixed-base driving simulator, in a single laboratory session. Both groups of study participants were “young-old” drivers

(Knoblauch et al. 1997) of similar age (between 50 and 70 years). The two groups of participants were matched in terms of individual characteristics associated with driving competence such as age, driving experience and driving exposure. They were also matched in terms of (self-reported) number of accidents within the last two years. The application of neuropsychological tests focusing on various domains of cognition showed that the drivers with PD had difficulties on recalling verbal material as well as on performing executive, attentional and working memory operations.

Results showed that performance in the sign recall task was more likely to drop with increasing task demand; this difference was statistically significant, when the variation in task demand was associated with a cognitive task. The conclusions that can be drawn from this study are tentative, given various limitations. The sample size was small; and the results were not analyzed in relation to the order the test conditions were presented to the subjects. In addition, the results were not analysed in relation to individual characteristics such as driving experience, etc., nor functional status (i.e., visual acuity, contrast sensitivity, visual attention, perceptual-cognitive processes, and psychomotor ability). Finally, it must be acknowledged that, when using a simulator to assess driving skills in older adults, their performance is more likely (than younger drivers) to be affected by simulator sickness, even if they do not demonstrate overt symptoms (Brooks et al., 2010).

Notwithstanding these concerns, the evidence presented here is encouraging with regard to the potential use of a (fixed-base) driving simulator to identify performance differences that can reliably discriminate (older) individuals with medical conditions that often cause loss of function(s) needed to drive safely from healthy drivers in the same age cohort. With an understanding of its limitations, such driving simulation in combination with measures of physical, visual and cognitive abilities shown to be significant predictors of older driver crash risk could comprise one component of a multi-tiered system to evaluate medical fitness-to-drive.

5. References

Akinwuntan, A. E., Wachtel, J., & Rosen, P. N. (2011). Driving simulation for evaluation and rehabilitation of driving after stroke. *Journal of Stroke and Cerebrovascular Diseases*, 21(6), pp. 478-486.

Ball, K. K., D. L. Roenker, V. G. Wadley, J. D. Edwards, D. L. Roth, Jr. G. McGwin, R. Raleigh, J. J. Joyce, G. M. Cissell, & T. Dube (2006). Can High-Risk Older Drivers Be Identified Through Performance-Based Measures in a Department of Motor Vehicles Setting?.*Journal of the American Geriatric Society*,Vol. 54(1), pp. 77-84.

Brooks, J. O., R. R. Goodenough, M. C. Crisler, N. D. Klein, R. L. Alley, B. L. Koon, W. C. Logan, J. H. Ogle, R. A. Tyrrell, & R. F. Wills (2010). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention*,Vol. 42(3), , pp. 788-796.

Campbell, J. L., Lichty, M. G., Brown, J. L., Richard, C. M., Graving, J. S., Graham, J., Mitchell O' Laughlin, Darren Torbic &Douglas Harwood (2012). *NCHRP Report 600 (Second Edition): Human Factors Guidelines for Road Systems*. Transportation Research Board of the National Academies, Washington D.C,.

Crizzle, A.M, Classen, S., & Uc, E. Y.(2012). Parkinson disease and driving. An evidence-based review. *Neurology*,79:2067–2074.

Devos, H., Vandenberghe, W., Nieuwboer, A., Tant, M., Baten, G., & De Weerdt, W. (2007). Predictor of fitness to drive in people with Parkinson's disease, *Neurology*, 69, 1434-1441.

Devos, H., Vandenberghe, W., Nieuwboer, A., Tant, M., De Weerdt, W., Dawson, J.D., & Uc, E. Y. (2013). Validation of a Screening Battery to Predict Driving Fitness in People With Parkinson's Disease, *Movement Disorders*, Vol. 28, (5), pp 671-674.

Hakamies-Blomqvist, & L., Peters, B. (2000). Recent European research on older drivers. *Accident Analysis & Prevention*, 32, pp. 601-607.

Hellenic Ministry of Transport and Infrastructure (HMTI), *Freeway Signing Guidelines*., Athens 2010.

Mullen, N. W., Chattha, H. K., Weaver, B. & Bedard, M. (2008). Older driver performance on a simulator: associations between simulated tasks and cognition, *Advances in Transportation Studies*, 2008 Spec. Iss., pp. 31-42.

Rizzo M. Medical Disorders. *Handbook of Driving Simulation for Engineering, Medicine and Psychology*. CRC Press, 2011.

Singh, H., Barbour, B. M. & Cox, D. J. (2011). *DrivingRehabilitation as Delivered by Driving Simulation*. Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

Staplin, L., Lococo, & K., Byington, S. (1998). *Older driver highway design handbook*. Federal Highway Administration, Mc Lean ,VA, 1998.

Staplin, L., Lococo, K. H., Gish, K. W., & Decina, L.E. (2003). Model Driver Screening and Evaluation Program.Final Technical Report. Volume 2: Maryland Pilot Older Driver Study. Washington, D.C., National Highway and Traffic Safety Administration. http://www.nhtsa.dot.gov/people/injury/olddrive/modeldriver/

Staplin L..(2010). *Safe Driving Tactics: What Role for Low Cost Simulation?*. Proceedings of the 89th Annual Meeting of the Transportation Research Board (TRB), January, 2010, Washington, D.C., USA.

Staplin, L. (2012) Choosing Among Measures of Driver Cognitive Status that Predict Crash Risk. Maryland Older Driver Symposium.

Staplin, L., Lococo, K. H., Martell, C., & Stutts, J. (2012). Taxonomy of Older driver behaviors and Crash Risk. Final Report, DOT HS 811 468A, National Highway and Traffic Safety Administration.

Uc, E., & Rizzo, M..(2011). Driving in Alzheimer’s Disease, Parkinson’s Disease, and Stroke. *Handbook of Driving Simulation for Engineering, Medicine and Psychology*. CRC Press.

Vardaki, S., Yannis, G. & S. Papageorgiou (2013), A Review of Driving Performance Assessment in Simulators, accepted for presentation at the *Road Safety and Simulation RSS013 International Conference*, Rome.

Vardaki, S., Yannis, G. Pavlou, G.,Beratis, I., & Papageorgiou, S. (2014). Sign recall in a fixed-base simulator as a measure of fitness-to-drive, Proceedings of the 93nd Annual Meeting of the Transportation Research Board (TRB), January 12-16, 2014, Washington, D.C., USA.

Yannis G., Golias J., Antoniou C., Papadimitriou E., Vardaki S., Papantoniou P., Pavlou D., Papageorgiou S., Andronas N., Papatriantafyllou I., Liozidou A., Beratis I., Kontaxopoulou D., Fragiadaki S., & Economou A., (2013). Design of a large driving simulator experiment on performance of drivers with cerebral diseases. Proceedings of the *4th International Conference on Road Safety and Simulation*, Rome.