DRIVING PERFORMANCE PROFILES OF DRIVERS WITH PARKINSON'S DISEASE

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Abstract

The objective of this research is the driving performance profiles analysis of drivers with Parkinson's disease (PD), on the basis of a driving simulator experiment, in which healthy and PD participants drive in different driving scenarios, following a thorough neurological and neuropsychological assessment. The driving scenarios include driving in rural area in low and high traffic volumes and driving in motorway. The driving performance of PD is compared to that of healthy controls by means of a generalized linear model (GLM) which was developed in order to estimate the effect of the examined disease in driving behaviour.

In this specific research, a sample of 62 participants is statistically analysed (21 PD and 41 control drivers). Various driving performance measures are examined, including speed, lateral position, steering angle, headway, reaction time at unexpected events, accident probability, some in terms of their mean values and some in both their mean values and their variability. Moreover, another factor indicating driving behaviour is examined: manoeuvres through work-zone segments in motorway.

The results suggest that Parkinson's disease do affect driving behaviour in several ways. More specifically, PD drivers drive at significantly lower speeds and with larger headway compared to healthy drivers. Moreover, they appear to have worse reaction times, are more likely to have accident inside a work-zone segment, have difficulties in positioning the vehicle in the lane and have difficulties in dealing with demanding tasks.

Keywords: driving performance, Parkinson's disease, driving simulator

Background

Parkinson's Disease

Parkinson's disease (PD) is a slowly progressive, degenerative disease of the basal ganglia with motor dysfunction as a main feature, that manifests as symptoms, such as slowness of movement (bradykinesia), rigidity, resting tremor, flexed posture, shuffling gait and postural instability (Fritsch et al., 2012; Gazewood, Richards, & Clebak, 2013). The main pathological finding in PD is the death of cells that secrete dopamine in the pars compacta region of the substantia nigra (Fritsch et al., 2012; Gazewood, Richards, & Clebak, 2013). In addition to motor dysfunction, PD may cause cognitive (memory, visuo-spatial and executive dysfunction), emotional (e.g. depression, apathy) and behavioral-neuropsychiatric symptoms (e.g. agitation, hallucinations, delusions) (Dubois & Pillon, 1997; Kupersmith, Shakin, Siegel, & Lieberman, 1982; Starkstein, Preziosi, Bolduc, & Robinson, 1990). The multimodal clinical picture of PD appears to influence in a negative fashion the performance of various activities of everyday life, including driving, as indicated by research that shows that PD patients have an increased risk to be engaged in car accidents (Uc & Rizzo, 2008; Uitti, 2009).

Degraded driving performance because of PD

Several studies in international literature have investigated the driving capacity of PD patients and have attempted to detect significant predictors, in many cases successfully, of driving competence or incompetence in the specific clinical group. Because driving is a multi-domain task that engages various aspects of cognition and motor functioning, studies investigating fitness to drive in PD patients have used a large variety of measures for predicting driving capacity.

Generally, the use of multiple measures that assess various domains should be the choice of preference in research projects that investigate the driving capacity of PD patients, because it permits the extraction of the unique effect of each predictor as well as the estimation of its relative importance. Other issues that should be considered is the matching of the control group and the group of PD patients for age, gender and driving experience, as well as the sample size to be large enough for performing the statistical analysis with sufficient power. Also, the disease stage of the PD patients should be defined together with the enclosure of sufficient information about the medication regime and medication status during the driving process and the neurological/neuropsychological assessment. Inclusion criteria for the selection of patients with PD should include the presence of a valid driver's license, regular and not occasional car driving, a score equal to or less than 1 on the CDR (Morris, 1993), and a score between 1 and 3 in the scale of Hoehn & Yahr. On the other hand, exclusion criteria that should be considered are alcohol or illicit substance use, and the presence of significant neuropsychiatric symptoms related to PD (i.e. agitation, delusions, and hallucinations).

Based on the findings of the previous studies it appears that various measures could be helpful in detecting individuals with PD that have impaired driving skills. However, neurological and neuropsychological testing should be viewed as one

part of the screening process that could help the evaluation of the driving capacity of patients with PD and should not be used alone, because this could lead to imprecise and dangerous consequences. Future studies that take into account the above recommendations can further our knowledge about the driving capacity of patients with PD under classical driving conditions as well as under driving conditions with distraction.

Objectives

The objective of this research is to present and analyse the driving performance profiles of drivers with Parkinson's disease (PD), on the basis of a driving simulator experiment, in which healthy and PD participants drive in different driving scenarios, following a thorough neurological and neuropsychological assessment. The driving scenarios include driving in rural area in low and high traffic volumes and driving in motorway. 21 PD and 41 control drivers (all over 55 years of age) have completed the experiment. The driving performance of PD is compared to that of healthy controls by means of a generalized linear model (GLM) which was developed in order to estimate the effect of the examined disease in driving performance.

Experiment Design

This study is carried out within the framework of the **Distract research project**. They are carried out by an interdisciplinary research team of engineers, neurologists and psychologists (Yannis et al. 2013, Pavlou et al. 2014). According to the objectives of the analysis, the experiment includes three types of assessment:

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 assessment
After clustering our sample scheme in two categories by the neuropsychological and the neurological teams (Control group and PD group) all participants continue with the third type of assessment. The third type of assessment concerns the programming of a set of driving tasks into the driving simulator for different driving scenarios.

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. The NTUA driving simulator is a motion base quarter-cab manufactured by the FOERST Company (Figure 1). The simulator consists of 3 LCD wide screens 40'' (full HD: 1920x1080pixels), driving position and support motion base. The dimensions at a full development are 230x180cm, while the base width is 78cm and the total field of view is 170 degrees. It's worth mentioning that the simulator is validated against a real world environment (Nikas 2014).

Rural Session

The design of the driving scenarios includes driving in rural area with different traffic conditions (high and low traffic volume). More specifically, the driving simulator experiment begins with one practice drive (usually 15-20 minutes), until the participant fully familiarizes with the simulation environment. Afterwards, the participant drives the rural session (approximately 20 minutes, 2.1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves). The traffic conditions examined include:

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

During each rural trial, 2 unexpected incidents are scheduled to occur at fixed points along the route. More specifically, incidents in rural area concern the sudden appearance of an animal (deer or donkey) on the roadway (Figure 2).

Regarding the time that the hazard appears, it depends on the speed and the time to collision in order to have identical conditions for the participant to react, either they drive fast or slowly. Thus, there is no possibility for the incident to appear closely or more suddenly to a participant than to another. The experiment is counterbalanced concerning the number and the order of the trials.

Finally, PD participants carry out the driving simulator experiment while under their usual medication, so that their driving performance corresponds to their everyday condition, as treated by their neurologist.

Figures 1, 2 - Driving simulator, unexpected incident (donkey)

Motorway session
After the rural session (and after a reasonable break) all participants (control and PD group) were asked to drive in the motorway (Vardaki et al., 2015). All participants drove 2 trials (100 seconds each). 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*."

Driving scenarios involved driving along straight sections and gentle curves on a limited access, divided roadway (Figure 3 - approximate). Scenarios avoided sharp curves or frequent stops (Trick et al. 2011) to reduce the likelihood of simulator adaptation syndrome.

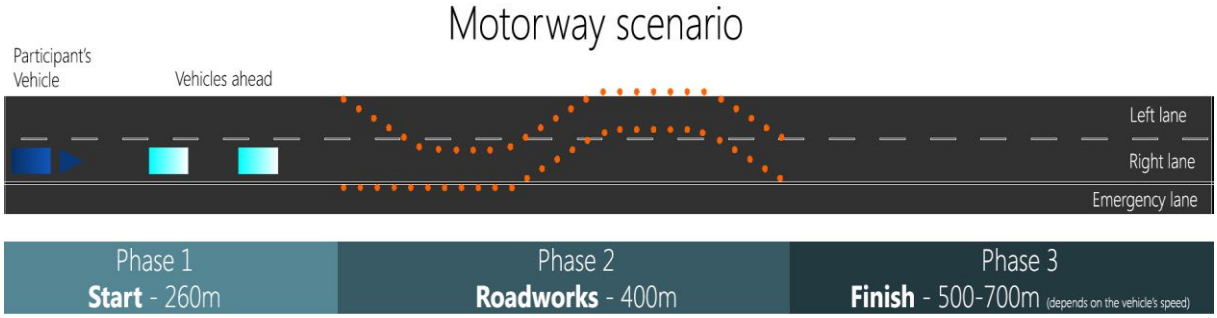

Figure 3 - Motorway session

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. After the initial period of low-demand driving, the level of demand was increased by imposing different types of operational and tactical driving tasks on subjects. The subject is negotiating the road work section, as the lane width tapers to its narrowest dimension. All drivers made a double lane change that involved driving through a road work section containing large blocks (barriers) (Figure 4) on each side of the road, causing the road to progressively narrow (1:20 taper ratio; lane width 3m).

Figure 4 - Motorway session: work-zone segment

Data and analysis methods
The aim of this research is to analyze and compare the driving performance of PD and healthy drivers in rural and motorway road environment. For that purpose, the driving trials in rural area in low and high traffic volumes and the motorway trials with the driving segment with roadworks were analyzed.

The analysis method selected is the generalized linear model (GLM) for the rural session. In statistics, the generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for response variables that have error distribution models other than a normal distribution. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value.

On the other hand the motorway session was analyzed in terms of descriptive statistics, because the aim was to have just additional information about the driving profile of the participant. In future researches further statistical analyses will be presented, concerning motorway session data.

At the present time more than 122 participants (PD group and Control group) have participated in the driving simulator experiment in approximately 2 years' time. However, about 25 participants had simulator sickness issues (a usual phenomenon in driving simulators) and didn't complete the driving trials of the experiment. For that reason they are eliminated from the study. Moreover there are 35 participants of younger age (<55 years old) who are eliminated too for age representativity reasons. The analysis is thus based on the existing related sample of the (ongoing) simulator experiment of healthy and impaired participants of over than 55 years of age who completed all of the examined four trials were selected, which consists of **62 participants** (36 males).
More specifically, the sample of the present study consists of:

- **41 healthy "controls"** (64.1 years old on average ±8.1) and
- **21 PD patients** (65.3 years old on average ±6.9)

The driving performance measures examined in rural session include both longitudinal control measures and lateral control measures. More specifically:

- **Mean speed** (mean speed of the driver along the route, excluding the small sections in which incidents occurred)
- **Time Headway** (time distance between the front of the simulator vehicle and the front of the vehicle ahead)
- **Reaction time** at unexpected incidents (time between the first appearance of the event on the road and the moment the driver starts to brake in milliseconds)
- **Lateral position** (vehicle distance from the central road axis in meters)
- **Lateral position variability** (the standard deviation of lateral position)
- **Mean wheel steering angle** (in degrees)
- **Steering angle variability** (the standard deviation of steering angle)

Moreover the driving performance measures examined in the motorway session include:

- **Mean speed** (mean speed of the driver along the route)
- **Accident probability** inside the roadworks segment

Results

The GLM models extracted for all examined measures are presents and discussed in this paragraph. It is worth mentioning that in all models the reference variable is the value of the control group in high traffic volume, and thus all other categories are compared with this one.

In table 1, starting with the longitudinal control measures, mean speed of drivers along the trial (in rural road area, in high (Q_H) and low (Q_L) traffic volume) is analyzed per driving group. The GLM model indicated statistically significant differences between the two groups. It seems that PD drivers drive at significant slower speeds (20% lower speed overall). The traffic volume seems to have the same effect on all participants.

Table 1 - GLM: Mean Speed (km/h)

Parameter Estimates	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	**42,776**	1,0525	40,713	44,839	1651,677	1	0,000
PD Q_L	**-6,362**	2,0489	-10,378	-2,346	9,641	1	**,002**
PD Q_H	**-8,723**	2,0489	-12,738	-4,707	18,123	1	**,000**
Controls Q_L	**2,609**	1,5186	-,367	5,586	2,953	1	,086
Controls Q_H	**0**[a]						
(Scale)	58,716[b]	7,0179	46,453	74,215			

Dependent Variable: Speed
Model: (Intercept), ID

a. Set to zero because this parameter is redundant. b. Maximum likelihood estimate.

In table 2, the time headway of drivers along the trial (in rural road area, in high (Q_H) and low (Q_L) traffic volume) is analyzed per driving group. The GLM model (as expected by the speed results) indicated statistically significant differences between all groups. PD drivers keep very large headways. The higher traffic volume seems to affect more the PD group.

Table 2 - GLM: Time headway (seconds)

Parameter Estimates	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	**28,583**	3,8588	21,020	36,147	54,867	1	,000
PD Q_L	**72,009**	7,5118	57,286	86,732	91,893	1	**,000**
PD Q_H	**26,723**	7,5118	12,000	41,446	12,655	1	**,000**
Controls Q_L	**20,754**	5,5675	9,842	31,666	13,896	1	**,000**
Controls Q_H	**0**[a]						
(Scale)	789,204[b]	94,3279	624,383	997,533			

Dependent Variable: Time Headway
Model: (Intercept), ID

a. Set to zero because this parameter is redundant. b. Maximum likelihood estimate.

In table 3, the reaction time of drivers along the trial (in rural road area, in high (Q_H) and low (Q_L) traffic volume) is analyzed per driving group. The GLM model indicated statistically significant differences between the two groups. PD drivers have statistically worse reaction times in all traffic environments (30% worse reaction times overall). Moreover, it seems that the higher is the traffic volume the worse is the reaction time for PD participants. Finally, no significant differences appeared between control group in low traffic volume and control group in high traffic volume. Traffic volume does not affect reaction time of the control group.

Table 3 - GLM: Reaction time (milliseconds)

Parameter Estimates	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	**1719,896**	76,1698	1570,606	1869,186	509,845	1	0,000
PD Q_L	**349,576**	151,2780	53,076	646,076	5,340	1	**,021**
PD Q_H	**641,465**	151,2780	344,965	937,964	17,980	1	**,000**
Controls Q_L	**-130,447**	109,8968	-345,841	84,947	1,409	1	,235
Controls Q_H	**0**[a]						
(Scale)	307497,655[b]	37018,3676	242867,378	389326,919			

Dependent Variable: Reaction Time
Model: (Intercept), ID

a. Set to zero because this parameter is redundant. b. Maximum likelihood estimate.

In table 4, moving on with the lateral control measures, lateral position of drivers along the trial (in rural road area, in high (Q_H) and low (Q_L) traffic volume) is analyzed per driving group. The GLM model indicated statistically significant differences. PD drivers tend to drive "to the left" compared with the control ones at high traffic volume. High traffic volume leads to more conservative driving for all examined groups so this result seems obvious.

Table 4 - GLM: Lateral Position (m)

Parameter Estimates	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	**1,600**	,0183	1,564	1,636	7637,803	1	0,000
PD Q_L	**-,156**	,0356	-,226	-,086	19,242	1	**,000**
PD Q_H	**-,061**	,0356	-,131	,009	2,905	1	,088
Controls Q_L	**-,113**	,0264	-,165	-,061	18,335	1	**,000**
Controls Q_H	**0**[a]						
(Scale)	,018[b]	,0021	,014	,022			

Dependent Variable: Lateral Position
Model: (Intercept), ID

a. Set to zero because this parameter is redundant. b. Maximum likelihood estimate.

In table 5, the variability of the lateral position of drivers along the trial (in rural road area, in high (Q_H) and low (Q_L) traffic volume) is analyzed per driving group. This lateral control measure is considered to be more important because it refers to the variability of positioning the vehicle in the lane. The GLM model indicated that PD participants in low traffic volume have significantly larger variability in lateral position than the control group. It seems that PD drivers have difficulty in positioning the vehicle inside the lane especially in low traffic volume. Finally, in low traffic volume, even control group have larger variability in lateral position compared with the high traffic volume.

Table 5 - GLM: Lateral Position Variability

Parameter Estimates	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	**,255**	,0083	,239	,272	949,438	1	0,000
PD Q_L	**,046**	,0161	,014	,077	8,063	1	**,005**
PD Q_H	**,007**	,0161	-,025	,038	,179	1	,673
Controls Q_L	**,028**	,0120	,005	,051	5,477	1	**,019**
Controls Q_H	**0**[a]						
(Scale)	,004[b]	,0004	,003	,005			

Dependent Variable: Lateral Position Variability
Model: (Intercept), ID

a. Set to zero because this parameter is redundant. b. Maximum likelihood estimate.

In table 6, the steering angle of drivers along the trial (in rural road area, in high (Q_H) and low (Q_L) traffic volume) is analyzed per driving group. The GLM model indicated statistically significant differences between the two groups. PD participants in low traffic volume tend to turn the wheel "to the left" compared with the other groups. No other significant differences were detected.

Table 6 - GLM: Steering angle

Parameter Estimates	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	**-2,028**	,0908	-2,206	-1,850	498,582	1	0,000
PD Q_L	**,480**	,1768	,133	,826	7,356	1	**,007**
PD Q_H	**,183**	,1768	-,163	,530	1,074	1	,300
Controls Q_L	**,218**	,1310	-,039	,475	2,767	1	,096
Controls Q_H	**0**[a]						
(Scale)	,437[b]	,0523	,346	,553			

Dependent Variable: Steering Angle
Model: (Intercept), ID

a. Set to zero because this parameter is redundant. b. Maximum likelihood estimate.

In table 7, the steering angle variability of drivers along the trial (in rural road area, in high (Q_H) and low (Q_L) traffic volume) is analyzed per driving group. The GLM model indicated statistically significant differences between the two groups. PD participants have higher variability in wheeling angle compared with the control group in both traffic volumes.

Table 7 - GLM: Steering angle Variability

Parameter Estimates	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	**17,017**	,2504	16,527	17,508	4619,808	1	0,000
PD Q_L	**1,412**	,4874	,457	2,367	8,394	1	**,004**
PD Q_H	**,916**	,4874	,040	1,871	3,530	1	,060
Controls Q_L	**,395**	,3612	-,313	1,103	1,193	1	,275
Controls Q_H	**0**[a]				-1,871		
(Scale)	3,322[b]	,3971	2,628	4,199			

Dependent Variable: Steering Angle Variability
Model: (Intercept), ID

a. Set to zero because this parameter is redundant. b. Maximum likelihood estimate.

In Figure 4, the main results of the driving in the motorway are presented. It is easily detectable the lower speed for the PD group along the driving route (approximately 15% lower speed overall) and at the same time the accident probability inside the roadworks segment is 3 times higher. PD participants drive at 35 km/h inside the work-zone segment and have 25% accident probability. They seem to have difficulty in making the maneuver even with low speed.

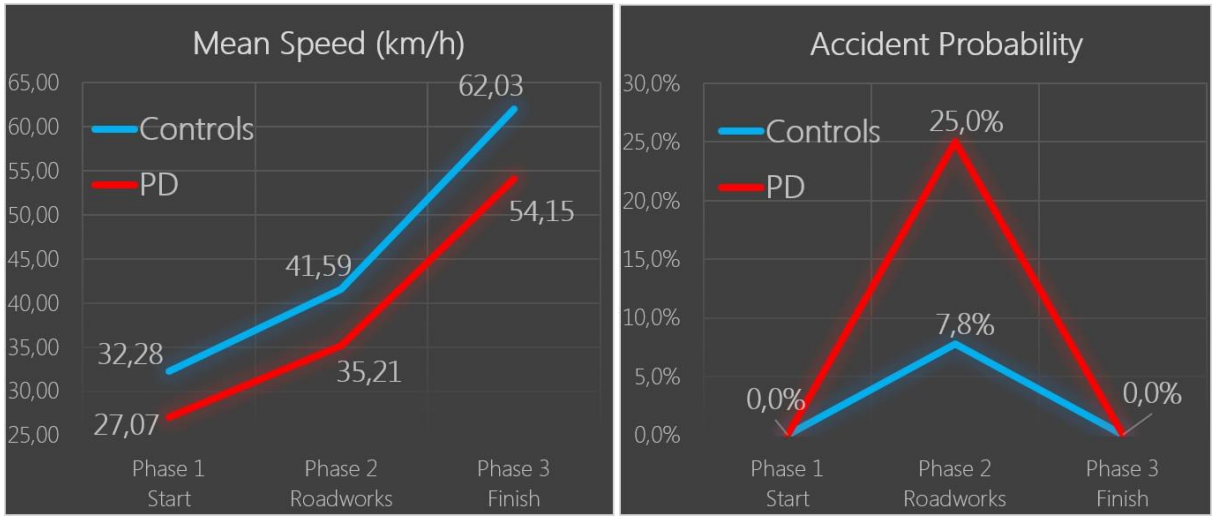

Figure 4 - Mean speed and accident probability in the motorway session

Conclusions - Discussion

The aim of this research is to analyse the driving performance of drivers with Parkinson's disease (PD), on the basis of a driving simulator experiment, in which healthy and PD participants drive in different driving scenarios (rural road and motorway), following a thorough neurological and neuropsychological assessment. 21 PD and 41 control drivers (all over 55 years of age) have participated in the experiment. The driving performance of PD is compared to that of healthy controls by means of a generalized linear model (GLM) which was developed in order to estimate the effect of the examined disease.

Both longitudinal and lateral control measures were analysed and examined: speed, lateral position, steering angle, headway, reaction time at unexpected events and accident probability inside work-zone segment, by means of generalized linear model (GLM) techniques.

Summarizing the results, PD drivers were found to drive at significantly lower speeds compared to the healthy control group drivers (20% lower speed overall), both at low and at high traffic volume. As would be expected, this reduced speed results under given ambient traffic conditions in increased headways, both at low and at high traffic volumes.

Moving on to the reaction times of the impaired drivers at unexpected incidents, it is observed that impaired drivers have significantly worse reaction times in rural road in both traffic volumes compared with the control group (30% worse reaction times overall). Moreover, it seems that the higher is the traffic volume the worse is the reaction time for PD participants. The more complex driving environment increase the difficulty level and leads the impaired drivers to worse reaction times. These worse reaction times of impaired drivers are confirmed by their neurological and neuropsychological assessments (at the present time the medical and neuropsychological database is under preparation in order to be finalized and used in future statistical analyses, and thus it is not available).

Analysing the lateral control measures it is observed that PD drivers have difficulties in positioning the vehicle inside the lane (significant differences in their variability of lateral position) and the lower is the traffic volume is, the higher is the variability of the lateral position. It is worth mentioning that in low traffic volume PD drivers tend to drive to the left double borderline. A possible explanation to this is that in high traffic volume they use the vehicle ahead as a "guide" of their route. In low traffic volume, though, there is no vehicle ahead (or it is too far) so they have difficulties in positioning the vehicle correctly inside the lane. These findings are confirmed by the wheeling angle variability results.

Finally, the results of the driving at the motorway indicate that even the PD drivers drive at slower speeds, the have 3 times higher accident probability inside a work-zone segment that demand a simple manoeuvre.

Overall, the deterioration of the driving performance of PD patients is confirmed and analysed with mathematical models by the present study. They drive at significantly slower speeds, have worse reaction times, have difficulties in positioning the vehicle in the lane, and have higher accident probability.

The effect of the sample representativity is something that needs to be highlighted; the age and gender distributions of the impaired and control populations seem balanced at the present time, however sample representativity should be improved in the next steps of the ongoing experiment. The results are to be considered within the limiting context of driving simulator studies - driving performance is known to be more accurately and reliably estimated by means of on-road studies. However, the relative effects of impaired vs healthy drivers are known to be quite identifiable in simulator studies.

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More information available at: http://www.nrso.ntua.gr/distract

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