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# Compensatory driving behaviour of older drivers with Parkinson's disease. Is it sufficient to counterbalance their driving difficulties?

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**Abstract**

Drivers with Parkinson's disease (PD) may have difficulties in their driving competence and these deficits may lead to reduced driver performance and increased accident probability. The objective of the present paper is the analysis of traffic and safety behaviour of drivers with PD and the identification of possible compensatory strategies that these drivers follow, by applying a large driving simulator experiment. A thorough neurological and neuropsychological assessment was carried out and then a driving simulator experiment was applied. 54 elderly drivers of similar demographics went through the whole experimental procedure: 34 healthy controls and 20 PD patients. The following driving performance measures were examined: mean speed, time headway, lateral position, steering angle variability, reaction time, and accident probability, by Generalized Linear Models. Summarizing patients with PD are aware of their driving difficulties and they try to develop - not in a successful way - a compensatory driving behaviour and follow a more conservative driving pattern.

*Keywords:* Older drivers; Parkinson's disease; compensatory driving behaviour; driving difficulties;

## 1. Introduction

Parkinson's Disease (PD) is a slowly progressive, degenerative disease of the basal ganglia, with motor dysfunction as a cardinal feature (Fritsch et al., 2012; Gazewood et al., 2013). In addition to motor dysfunction, PD is related to 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 et al., 1982; Starkstein et al., 1990). Other factors that can also affect the functionality of individuals with PD are related to dosage regulation ("wearing-off syndrome", "on-off phenomenon", "peak dose dyskinesias"), and possible side effects of dopaminergic treatment, such as excessive daytime sleepiness (Knie et al.., 2011). An area of functioning that is commonly influenced in a negative way by the multimodal clinical picture of PD, is the driving fitness of individuals belonging to the specific clinical group. The concept of driving fitness refers to the presence of sufficient physical and mental skills for driving in a safe and consistent manner by reacting appropriately to the demands of a driving environment (Assessing Fitness to Drive, 2016).

Findings from on-road driving evaluations show increased driving difficulties in drivers with PD that compromise their driving fitness as compared to drivers without an underlying neurological condition (Classen et al., 2009; Classen et al., 2011; Grace et al., 2005; Uc et al., 2007; Uc et al., 2009; Wood et al., 2005). For example, in the study of Classen et al., (2009), 42% of the drivers with PD failed the on-road driving test as compared to the 21% of age-matched controls who also did not pass the driving evaluation. Similarly, in another study that utilized an on-road driving assessment, more than half of drivers with PD (56%) failed the evaluation (Classen et al., 2011). According to a recent review that summarizes the findings of previous relevant studies (Devos et al., 2015), the percentage of drivers with PD that did not pass an on-road driving assessment ranged between 30%-56%. In addition, the following indicative driving errors or difficulties were identified: (a) lateral positioning, (b) signal use, (c) control of the pedals or of the steering wheel, (d) speed adaptation, (e) identification of signs or landmarks, (f) driving behavior at intersections and (g) making right and especially left turns or changing lanes (Devos et al., 2015). Along the same vein, driving simulator experiments indicate an elevated risk for impaired driving performance in individuals with PD (Stolwyk et al., 2005; Stolwyk et al., 2006; Ranchet et al., 2011). Also, epidemiologic studies provide some evidence about the presence of an increased crash risk in drivers with PD (Dubinsky et al., 1991; Meindorfner et al., 2005). Indicatively, findings from Germany indicate that 15% of patients with PD holding an active driving license were engaged in car accidents during a period that covered the past five years (Meindorfner et al., 2005).

## 2. Objectives

The objective of the present paper is the analysis of traffic and safety behaviour of drivers with PD and the identification of possible compensatory strategies that these drivers follow, on the basis of a driving simulator experiment, in which healthy and PD active drivers drove in different driving scenarios, following a thorough neurological and neuropsychological assessment. The key driving performance measures that will be examined are: mean speed, time headway, lateral position, steering angle variability, reaction time, and accident probability. The basic research questions are whether PD patients try to develop a compensatory driving behaviour, whether they follow a more conservative driving pattern in order to counterbalance their driving difficulties and whether this strategy is successful or not.

## 3. Methodological approach

### *3.1. Overview of the experiment*

This paper was carried out by an interdisciplinary research team which consists of engineers, neurologists and psychologists (Yannis et al. 2013). The experiment includes three types of assessment:

a) Neurological assessment which concerns the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of these cerebral diseases,
b) Neuropsychological assessment which concerns the administration of a series of neuropsychological tests and psychological-behavioural questionnaires to the participants. The tests that were 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.,

c) Driving at the simulator assessment; after clustering our sample scheme in two categories by the neuropsychological and the neurological teams (Control group, PD group) all participants moved on to the third type of assessment.

Diagnosis of PD was made by a specialized neurologist team in the field of movement disorders according to the following established criteria (UK Parkinson's Disease Society Brain Bank, Hughes et al., 1992).

The NTUA driving simulator is a FOERST motion base quarter-cab. 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. The simulator is validated against a real world environment, with satisfactory relative validity as regards gender, age groups and area type i.e. urban or rural (Yannis et al., 2015).

The design of the driving scenarios included driving in different road conditions, such as in a rural and urban area. The driving simulator experiment started with a familiarization drive on the basis of several quantitative and qualitative criteria (handling the simulator, keeping the lateral position of the vehicle, keeping stable speed and appropriate for the road environment, braking and immobilization of the vehicle), until the participant fully familiarized with the simulation environment. Afterwards, all participants drove at two sessions: a rural route that was 2.1 km long, single carriageway, lane width was 3m, with zero gradient and mild horizontal curves and an urban route that was 1.7km long, at its bigger part dual carriageway, separated by guardrails and the lane width was 3.5m. Hand shift gears were used by all subjects.

During each trial, two unexpected incidents were scheduled to occur at fixed points along the route: sudden appearance of an animal (deer or donkey) on the roadway, and sudden appearance of an adult pedestrian, or of a child chasing a ball on the roadway (Figure 1), or of a car suddenly getting out of a parking position and getting in the road in the urban area. The hazard didn't appear at the same location between the trials, in order to minimize learning effects. Finally, patients were to carry out the simulator experiment while under their usual medication, so that their driving performance corresponds to their everyday condition, as treated by their neurologist.

Figure 1. Screenshot from the simulated environment (incident in urban road)

The study was approved by the Ethics Committee of the "Attikon" University General Hospital. Informed consent was obtained from all individuals studied; it was clearly explained to them that participation was voluntary and that they had the right to withdraw any time they wished to. Participants were informed on the nature of the study, the duration of their engagement and the type of information that they would be asked to give during the data collection process. Also, participants were ensured of the anonymity and confidentiality of the procedure.

## 4. Sample and data

In order to fulfil this papers' objectives, 54 individuals were recruited in order to participate in the driving simulator experiment. More specifically, the sample consists of: 34 healthy "controls" (65.4 years of age on average) and 20 PD patients (63.3 years of age on average). Participants with PD and controls were similar in terms of age, education and overall driving experience. In line with our methodology, no history of accidents was reported for any member of the two groups during the period of the last two years. In addition, all participants should fulfil the following criteria regarding their driving profile: (a) a valid driving license, (b) driving for more than 3 years, (c) driving more than 2500km during the last year, (d) driving at least once a week during the last year, (e) driving at least 10km/week during the last year, (f) no history of major accidents, (g) absence of any important kinetic or eye disorder, (h) absence of dizziness or nausea while driving, (i) absence of alcohol or any other drug addiction, and (j) no history of a major depressive episode.

## 5. Results

Linear regression is used to model a linear relationship between a continuous dependent variable and one or more independent variables. Furthermore, the generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for inclusion of dependent 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. It also allows the magnitude of the variance of each measurement to be a function of its predicted value. The driving performance measures examined 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)
- Lateral position (vehicle distance from the central road axis in meters)
- Steering angle variability (the standard deviation of steering angle)
- 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)
- Accident Probability (the proportion of total crashes occurred to total incidents)

### *5.1. Average Speed*

The relationship between speed and accidents is widely recognized in the road safety community and as such, speed is a commonly used dependent variable in transportation human factors research, especially when neurological diseases affecting cognitive functionality is examined. In Table 1 the parameter estimates of two generalized linear models (GLM), on the dependent variable of the mean speed in: a) rural area, and b) urban area is presented.

Table 1. GLM-Parameter Estimates - dependent variable - Average Speed (km/h)

| | **Rural Area** | | | | | | | **Urban Area** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Confidence Interval | | Hypothesis Test | | | | | Confidence Interval | | Hypothesis Test | | |
| Parameter Estimates | **B** | Std. Error | Lower | Upper | Wald Chi-Square | df | **Sig.** | **B** | Std. Error | Lower | Upper | Wald Chi-Square | df | **Sig.** |
| (Intercept) | **44.04** | .4865 | 43.085 | 44.992 | 8194.986 | 1 | **0.000** | **29.770** | .3897 | 29.006 | 30.534 | 5835.150 | 1 | **0.000** |
| Parkinson's Disease | **-8.846** | .9503 | -10.708 | -6.983 | 86.638 | 1 | **0.000** | **-3.316** | .8133 | -4.910 | -1.722 | 16.620 | 1 | **.000** |
| Controls | 0[a] | | | | | | | 0[a] | | | | | | |
| (Scale) | 65.318[b] | 4.7765 | 56.596 | 75.384 | | | | 31.592[b] | 2.7190 | 26.688 | 37.397 | | | |

Dependent Variable: AverageSpeed

Model: (Intercept), Disease

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

In both rural and urban roads participants with PD drove at significantly lower mean speed than the controls (B=-8.8, p<.001 in rural area and B=-3.3, p<.001 in urban area). It seems that PD has a significant effect on mean speed, leading the PD participants slower down perhaps as a compensatory mechanism trying to counterbalance their driving difficulties.

### *5.2. Mean Headway*

One of the major contributors to accidents is the headway between two vehicles, when it is too short to allow the following driver to react appropriately to sudden braking by the leading vehicle. The headway between two vehicles can be expressed in terms of time and space. In Table 2 the parameter estimates of two generalized linear models (GLM), on the dependent variable of the mean headway in: a) rural area, and b) urban area is presented.

Table 2. GLM-Parameter Estimates - dependent variable - Mean Headway (m)

| | Rural Area | | | | | | | Urban Area | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Confidence Interval | | Hypothesis Test | | | | | Confidence Interval | | Hypothesis Test | | |
| Parameter | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. |
| (Intercept) | **326.03** | 11.0167 | 304.434 | 347.619 | 875.793 | 1 | **0.000** | **90.172** | 2.4620 | 85.347 | 94.998 | 1341.436 | 1 | **0.000** |
| Parkinson's Disease | **161.899** | 21.5216 | 119.718 | 204.081 | 56.590 | 1 | **0.000** | **7.399** | 1.1378 | 3.671 | 10.469 | 2.074 | 1 | **.049** |
| Controls | 0[a] | | | | | | | 0[a] | | | | | | |
| (Scale) | 33497.509[b] | 2449.58 | 29024.62 | 38659.70 | | | | 1260.786[b] | 108.51 | 1065.08 | 1492.45 | | | |

Dependent Variable: HWayAverage

Model: (Intercept), Disease

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

In both rural and urban roads participants with PD drove at significantly larger headways than the controls (B=-161.9, p<.001 in rural and B=7.4, p=.049 in urban area). The examined neurological disease affecting cognitive functions (PD) appear to have a significant effect on mean headway. These results are intuitive, given that lower speeds naturally result in larger headways, for a given distribution of ambient traffic on the road network.

*5.3. Lateral position*

Lateral position refers to the position of the vehicle on the road in the relation to the left border of the lane in which the vehicle is travelling and it is an indicator on how well the driver maintains the vehicle on the driving simulator environment. In Table 3 the parameter estimates of two generalized linear models (GLM), on the dependent variable of the lateral position in: a) rural area, and b) urban area is presented.

Table 3. GLM-Parameter Estimates - dependent variable - Lateral Position (m)

| | Rural Area | | | | | | | Urban Area | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Confidence Interval | | Hypothesis Test | | | | | Confidence Interval | | Hypothesis Test | | |
| Parameter | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. |
| (Intercept) | **1.54** | .0091 | 1.521 | 1.557 | 28594.391 | 1 | **0.000** | **3.177** | .0438 | 3.091 | 3.263 | 5253.687 | 1 | **0.000** |
| Parkinson's Disease | **-0.045** | .0178 | -0.080 | -0.010 | 6.494 | 1 | **0.011** | **0.107** | .0915 | -0.072 | 0.287 | 1.381 | 1 | **.240** |
| Controls | 0[a] | | | | | | | 0[a] | | | | | | |
| (Scale) | .023[b] | .0017 | .020 | .026 | | | | .400[b] | .0344 | .338 | .473 | | | |

Dependent Variable: LateralPositionAverage

Model: (Intercept), Disease

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Positive values indicate driving more closely to the right border of the road. In rural road participants with PD drove significantly closer to the right border of the road than the controls (B=-.045, p=.011). It seems that PD has a significant effect on lateral position but only in rural driving environment, leading the PD participants to more conservative and careful driving patterns perhaps as a compensatory mechanism trying to counterbalance their driving difficulties.

### *5.4. Variability of steering angle*

Steering angle variability is a critical lateral control measure that refers to the smoothness of the use of the wheel by the driver and it is an indicator on how smooth and gentle the driver maintains the vehicle on the driving simulator environment. In Table 4 the parameter estimates of two generalized linear models (GLM), on the dependent variable of the steering angle variability in: a) rural area, and b) urban area is presented.

Table 4. GLM-Parameter Estimates - dependent variable - Variability of steering angle (degrees)

| | Rural Area | | | | | | | Urban Area | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Confidence Interval | | Hypothesis Test | | | | | Confidence Interval | | Hypothesis Test | | |
| Parameter | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. |
| (Intercept) | **17.55** | .1144 | 17.328 | 17.777 | 23531.024 | 1 | **0.000** | **22.402** | .3536 | 21.709 | 23.095 | 4014.771 | 1 | **0.000** |
| Parkinson's Disease | **-1.389** | .2235 | -1.827 | -0.950 | 38.588 | 1 | **0.000** | **-0.133** | .7378 | -1.579 | 1.313 | 0.032 | 1 | **.857** |
| Controls | 0[a] | | | | | | | 0[a] | | | | | | |
| (Scale) | 3.614[b] | .2643 | 3.131 | 4.171 | | | | 26.000[b] | 2.2377 | 21.964 | 30.778 | | | |

Dependent Variable: StdWheelAverage

Model: (Intercept), Disease

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

In rural road participants with PD had significantly lower steering angle variability than the controls (B=-1.39, p<.001). It seems that PD has a significant effect on the variability of the wheel but only in rural driving environment, indicating that PD participants are more careful and as smooth as possible with the wheel perhaps as a compensatory mechanism trying to counterbalance their driving difficulties for which they are aware of.

### *5.5. Reaction Time*

The next regression analysis regards the reaction time of drivers at unexpected incidents. Since range of reaction time measures can be examined including number of missed events, number of incorrect responses, reaction time and reaction distance, in the present experiment reaction time is measured at specific unexpected incidents. In Table 5 the parameter estimates of two generalized linear models (GLM), on the dependent variable of the reaction time in: a) rural area, and b) urban area is presented.

Table 5. GLM-Parameter Estimates - dependent variable - Reaction Time (milliseconds)

| | Rural Area | | | | | | | Urban Area | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Confidence Interval | | Hypothesis Test | | | | | Confidence Interval | | Hypothesis Test | | |
| Parameter | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. |
| (Intercept) | **1656.60** | 42.7497 | 1572.810 | 1740.386 | 1501.651 | 1 | **0.000** | **1396.348** | 35.0490 | 1327.653 | 1465.043 | 1587.216 | 1 | **0.000** |
| Parkinson's Disease | **691.828** | 84.3668 | 526.472 | 857.184 | 67.244 | 1 | **0.000** | **375.452** | 74.1245 | 230.170 | 520.733 | 25.656 | 1 | **.000** |
| Controls | 0[a] | | | | | | | 0[a] | | | | | | |
| (Scale) | 502571.766[b] | 36949.80 | 435127.47 | 580469.85 | | | | 234630.630[b] | 21155.90 | 196623.06 | 279985.13 | | | |

Dependent Variable: ReactionTime

Model: (Intercept), Disease

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Significant differences in the driving behaviour of healthy drivers and PD patients were also identified regarding the drivers' reaction time at unexpected incidents. In both rural and urban roads participants with PD had significantly worse reaction times than the controls at >99% confidence level. PD group had approximately 0.7 sec larger reaction times than control ones in rural area and 0.38 sec in urban area.

*5.6. Accident Probability*

The next regression analysis regards the accident probability in unexpected incident. The accident probability constitutes the most significant road safety measure. In Table 6 the parameter estimates of two generalized linear models (GLM), on the dependent variable of the accident probability in: a) rural area, and b) urban area is presented.

Table 6. GLM-Parameter Estimates - dependent variable - Accident Probability

| | Rural Area | | | | | | | Urban Area | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Confidence Interval | | Hypothesis Test | | | | | Confidence Interval | | Hypothesis Test | | |
| Parameter | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. | B | Std. Error | Lower | Upper | Wald Chi-Square | df | Sig. |
| (Intercept) | **0.15** | .0228 | 0.108 | 0.197 | 44.766 | 1 | **0.000** | **0.116** | .0259 | 0.065 | 0.167 | 20.026 | 1 | **0.000** |
| Parkinson's Disease | **0.089** | .0450 | 0.001 | 0.178 | 3.936 | 1 | **0.047** | **0.188** | .0542 | 0.081 | 0.294 | 11.990 | 1 | **.001** |
| Controls | 0[a] | | | | | | | 0[a] | | | | | | |
| (Scale) | .143[b] | .0105 | .124 | .165 | | | | .127[b] | .0115 | .107 | .152 | | | |

Dependent Variable: AccidentProbability

Model: (Intercept), Disease

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Significant differences in the driving behaviour of healthy drivers and PD patients were also identified regarding the drivers' accident probability at unexpected incidents. In both rural and urban roads participants with PD had significantly higher accident probability than the controls. They had approximately 9% higher accident probability in rural driving environment and approximately 19% higher accident probability in urban road.

## 6. Conclusions and discussion

The objective of this interdisciplinary study is the analysis of traffic and safety behaviour of drivers with PD and the identification of their possible compensatory strategies, on the basis of a driving simulator experiment, in which healthy and PD active drivers drove in rural and urban areas, following a thorough neurological and neuropsychological assessment. 54 elderly drivers (34 healthy controls and 20 PD patients) of similar demographics went through the whole experimental procedure. The following driving performance measures were examined: mean speed, time headway, lateral position, steering angle variability, reaction time, and accident probability. The basic research questions were whether PD patients try to develop a compensatory driving behaviour, whether they follow a more conservative driving pattern in order to counterbalance their driving difficulties and whether this strategy is successful or not. All these questions were answered by applying appropriate statistical techniques.

Several lines of previous research indicate that driving capacity in patients with PD is mainly compromised due to cognitive deficits that accompany this clinical condition. This is suggested by this study as well, as PD drivers had significant differences with the healthy control group of similar demographic characteristics. In particular, PD patients, as mathematically compared to their healthy control counterparts of similar demographics, drove at slower speeds, kept larger headways, drove more closely to the right border of the road, had lower variability on their steering angle, but on the other hand they had significantly worse reaction times and higher accident probability in an unexpected incident. It seems that PD drivers are aware of their driving difficulties, and they try

to compensate their "impaired" driving behavior by following a more conservative and careful driving pattern. Indeed, reduced mean speed, increased headways and the driving closer to the right road border may be considered beneficial for road safety. However, what is more significant for road safety is the reaction time and the accident risk when an unexpected incident occur. The results of this paper clearly suggest that this compensatory driving pattern that PD drivers follow is not adequate for safe driving. The neurological disease affecting cognitive functions which this study examines, namely PD has a detrimental impact on reaction time and accident probability, which are significantly worse compared to their healthy counterparts.

Road safety research often uses driving simulators, as they allow for the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. However, there is a number of recurrent threats to validity when conducting driving simulator experiments, such as failure to adequately screen participants, generalization issues, learning effects and drop out due to simulator sickness (Caird & Horrey, 2011). However, driving simulators are an increasingly popular tool for analyzing driving performance, and numerous studies have been conducted (Caird & Horrey, 2011; Papantoniou et al., 2015).

This paper revealed a number of open issues for further research, though. It would be an interesting future research challenge to periodically assess the driving behavior of patients with PD over time (i.e. driving simulator experiment combined to neurological and neuropsychological assessments, every year), in order to identify to which extent, the progression of this progressive and degenerative disease, deteriorates in a significant level several driving performance measures. Moreover, this methodology could be applied on-road and naturalistic experiments or field survey studies in order to estimate the effect of the risk factors investigated directly on the overall driving performance and safety behavior of patients with PD.

The results of this research could be appropriately exploited in the development of recommendations for addressing all aspects of impaired driving due to PD. It is suggested that every PD driver should be treated individually, through a modern interdisciplinary driving evaluation including medical, neurological and neuropsychological criteria for safe driving and of course assessment of driving performance through simulator tasks or on-road trials, as not every PD patient is unable to drive. Finally, enhanced understanding of the medical, behavioral and social issues related to impaired driving due to PD will lead to more appropriate driver training and licensing, criteria for driver license renewal for persons belonging to vulnerable groups, more appropriate legislation and awareness campaigns.

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