National Technical University of Athens
School of Civil Engineering
Department of Transportation Planning and Engineering

Traffic and safety behaviour of drivers with neurological diseases affecting cognitive functions

A Doctoral Thesis by

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Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy

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Διδακτορική Διατριβή του

Δημοσθένη Η. Παύλου

Υποβλήθηκε σε μερική εκπλήρωση των απαιτήσεων για την απονομή του Διδακτορικού

Συμβουλευτική επιτροπή:
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If you can dream it…

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» "**DISTRACT** - Causes and impacts of driver distraction: a driving simulator study" within the Research Program THALES.
» "**DriverBRAIN** - Performance of drivers with cerebral diseases at unexpected incidents" within the Research Program ARISTEIA.

Contact

Colleagues, students or everyone who may search for information in this PhD dissertation and have any questions, they are more than welcome to contact me for any clarification.

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Abstract

The objective of the present inter-disciplinary PhD dissertation is the analysis of traffic and safety behaviour of drivers with neurological diseases affecting cognitive functions. More specifically, the impact of brain pathologies on reaction time, accident probability, driving errors, and driving performance is under investigation. The driving behaviour is examined in terms of both traffic and safety behaviour and the neurological diseases affecting cognitive functions concern Alzheimer's disease (AD), Parkinson's disease (PD), and Mild Cognitive Impairment (MCI). A large-scale driving simulator experiment was carried out, comprising a medical/neurological and neuropsychological assessment of 225 drivers, and a set of driving tasks for different scenarios. An innovative statistical analysis methodology has been developed and implemented, based on Regression Models, Principal Component Analysis and Structural Equation Models. Results indicated that the impact of neurological diseases affecting cognitive functions is significantly detrimental on traffic and safety behaviour. The AD group had the worse driving performance profile among the examined brain pathologies and finally, the negative impact of the mobile phone use on driving performance was much more pronounced on drivers with neurological diseases affecting cognitive functions than on healthy controls of similar demographics.

Περίληψη

Ο στόχος της παρούσας διεπιστημονικής Διδακτορικής Διατριβής είναι η ανάλυση της συμπεριφοράς κυκλοφορίας και ασφάλειας οδηγών με νευρολογικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες. Ειδικότερα, είναι υπό διερεύνηση η επιρροή των εγκεφαλικών παθολογιών στον χρόνο αντίδρασης, στην πιθανότητα ατυχήματος, στα οδηγικά λάθη και στην οδηγική επίδοση. Η οδηγική συμπεριφορά εξετάστηκε σε όρους κυκλοφορίας αλλά και οδικής ασφάλειας και οι νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες που εξετάζονται είναι η Νόσος Alzheimer (AD), η Νόσος Parkinson (PD) και η Ήπια Νοητική Εξασθένηση (MCI). Πραγματοποιήθηκε ένα μεγάλης κλίμακας πείραμα σε προσομοιωτή οδήγησης, το οποίο περιελάμβανε ιατρική/νευρολογική και νευροψυχολογική αξιολόγηση 225 οδηγών, καθώς και οδήγηση σε διαφορετικές συνθήκες. Αναπτύχθηκε και εφαρμόστηκε μια πρωτότυπη μεθοδολογία στατιστικής ανάλυσης βασισμένη σε Μοντέλα Παλινδρόμησης, Ανάλυση Κύριων Παραγόντων και Δομικά Μοντέλα Εξισώσεων. Τα αποτελέσματα έδειξαν ότι η επιρροή των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες είναι σημαντικά επιζήμια στην κυκλοφοριακή και οδηγική συμπεριφορά. Η ομάδα των ασθενών με AD είχαν το χειρότερο προφίλ οδηγικής επίδοσης ανάμεσα στις εξεταζόμενες ασθένειες και τέλος, η αρνητική επίδραση της χρήσης του κινητού τηλεφώνου στην οδηγική επίδοση ήταν πολύ εντονότερη στους ασθενείς με εγκεφαλική νευρολογική παθολογία σε σχέση με τους υγιείς με παρόμοια δημογραφικά χαρακτηριστικά.

Summary

This research is an inter-disciplinary effort entering the scientific fields of traffic and safety behaviour of drivers on one hand and neurological disease affecting cognitive functions on the other. The objective of the present inter-disciplinary PhD thesis is **the analysis of traffic and safety behaviour of drivers with neurological diseases affecting cognitive functions**. More specifically, the impact of certain brain pathologies on driving performance, driving errors, reaction time and accident probability is under investigation. The driving behaviour is examined in terms of both traffic and safety behaviour and the neurological diseases affecting cognitive functions concern diseases with high prevalence in the general population: Alzheimer's disease (AD), Parkinson's disease (PD), and Mild Cognitive Impairment (MCI). The central objective of this PhD dissertation was addressed by:

» designing and implementing **a large driving simulator experiment**,
» developing an **original methodology** for the assessment of the impact of drivers' neurological diseases affecting cognitive functions on their driving performance taking also into account their neuropsychological and demographic characteristics as well as the main road safety and traffic characteristics,
» quantifying **the impact of neurological diseases affecting cognitive functions** directly on driving performance, driving errors, reaction time and accident probability,
» **comparing the driving performance** of drivers with different neurological diseases,
» examining **the impact of driver distraction** on the performance of drivers with cerebral diseases.

The PhD thesis aims to capture the interaction of neurological diseases affecting cognitive functions, other related parameters (i.e. demographic, medical, and neuropsychological) as well as road and traffic conditions, and driver distraction with respect to driving behaviour. The **combined effect of these key parameters** on driving performance, driving errors, reaction time and accident probability might provide useful insight on driver traffic and safety behaviour analysis. Given the interaction of several scientific areas in research of impaired driving due to neurological diseases affecting cognitive functions (transportation engineering, neurology and neuropsychology), this PhD thesis covers a field of research with an **obvious and unique interdisciplinary nature**, which has not been examined in the past. The analysis of the neurological diseases affecting cognitive functions and other demographic and neuropsychological characteristics in combination with the driving performance of the general population, is a very crucial domain and a scientific challenge at the same time. In order to achieve

the objectives of this PhD dissertation, four discrete methodological steps were followed: 1st) Extensive **literature review**, 2nd) **Methodological approach**, 3rd) Design and implementation of a **large driving simulator experiment**, and 4th) Development and application of an innovative **statistical analysis**.

Firstly, **an exhaustive literature review was carried out** examining in a comprehensive way driving behaviour and road safety, ways to assess driving behaviour, driving simulator characteristics as well as neurological diseases affecting cognitive functions (MCI, AD and PD) and how these cerebral diseases affect driving performance. Reviewing studies about patients with MCI, of those studies assessing driving performance through on road testing, it seems that MCI patients, although they experience subtle changes in their driving competence are still able to drive. However, a level of impairment compared to healthy controls is generally being reported meaning that they still constitute a population at risk that warrants close supervision. Reviewing studies about patients with AD, driving performance declines considerably in individuals with AD and several on-road and simulator studies indicated worse driving performance for AD group compared to healthy controls in several driving measures. Reviewing studies about patients with PD, several lines of previous research indicate that driving capacity in patients with PD is mainly compromised due to cognitive deficits. Moreover, pronounced difficulties in several driving indexes seem to appear in drivers with PD under demanding driving conditions that involve increased cognitive load.

Moving on, an **innovative statistical analysis methodology** in the field of assessing driving behaviour of drivers with cerebral diseases was developed. This innovative methodological approach is based on literature review regarding simulator experiment, neurological and neuropsychological design principles, driving performance, cognitive and neurological state measures and statistical analysis methods. Methodological review indicated that **latent model analysis and especially structural equation models have never been implemented** in the field of driver behaviour of patients with neurological diseases affecting cognitive functions. For that reason and within the framework of this PhD dissertation, an innovative statistical analysis methodology has been developed, and consists of five steps: a) Descriptive Analysis, b) Analysis Of Variance (ANOVA), c) Regression Models (Generalized Linear Models), d) Principal Component Analysis (PCA), and e) Structural Equation Models (SEMs).

Moving on, based on the literature and methodology review, **a large driving simulator experiment was carried out** at the Department of Transportation Planning and

Engineering of the NTUA, aiming to assess driving performance of patients with neurological diseases affecting cognitive functions. The experiment was designed in an **inter-disciplinary way** and included three scientific branches:

» **Driving at the simulator**: The first assessment concerns a set of driving tasks into a driving simulator for different driving scenarios: two different driving areas (rural/urban), two different traffic volumes (moderate/high), three distraction conditions (undistracted driving, driving while conversing with a passenger, and while conversing on a hand-held mobile phone), while unexpected incidents happened in front of them (sudden appearance of an animal or of a child chasing a ball or of a car suddenly getting out of a parking position).

» **Medical / neurological assessment**: The second assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of the examined disorders (MCI, AD, PD).

» **Neuropsychological assessment**: The third 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.

The sampling scheme included 225 participants (76% males - 24% females):

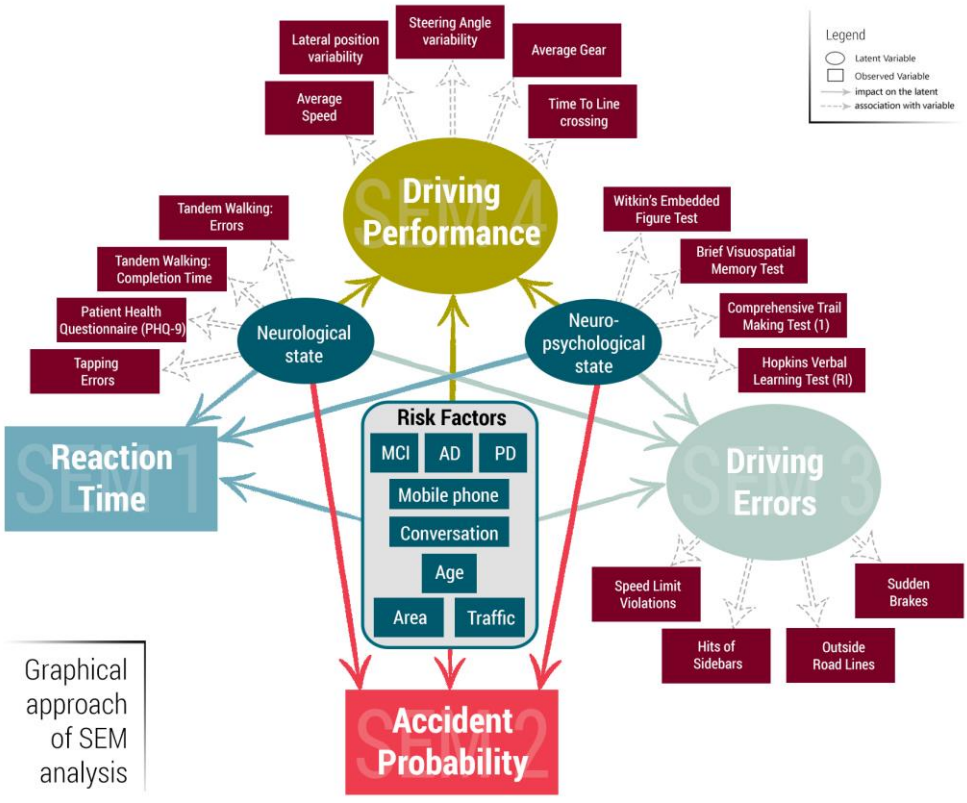
» **133 "patients"** with a neurological disease affecting cognitive functions (28 AD, 45 MCI, 25 PD patients, and 35 patients with other cognitive disorders)

» **92 "Controls"** without any cognitive disorder

Then, **six discrete Driving Simulator Data Processing Levels (PL)** were developed, in order to suitably deal with the large and diversified amount of data collected and to conclude to an "All Drivers and All Assessments Processed Data File" which was analyzed by means of **a dedicated and innovative statistical analysis method**. In the first step, the **descriptive analysis** correlated mean speed, time headway, lateral position, steering angle variability, reaction time at unexpected incidents, accident probability, and driving errors, with traffic volume, driving area, regarding age and cerebral disease of the participants. Then, **two Analysis Of Variance (ANOVA)** were extracted regarding identification of significant differences in the driving performance indexes extracted from the driving simulator assessment and in the answers extracted from the behaviour questionnaire, between two groups: groups of healthy controls and patients with neurological diseases affecting cognitive functions. In the third step, within the

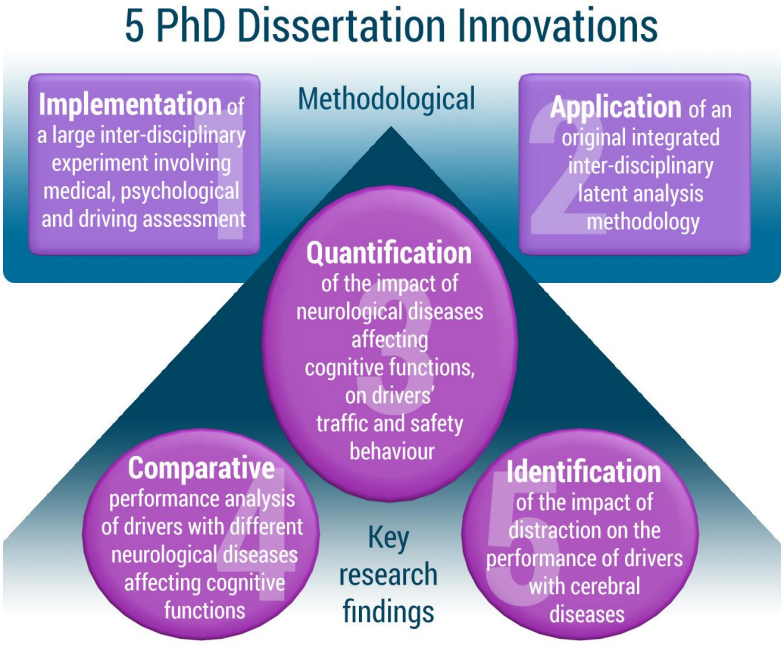
framework of the explanatory analysis, the development of **a series of Regression Models** took place regarding key performance parameters in order to estimate the effect of cerebral diseases and driving characteristics on specific driving performance parameters and indirectly on driving behaviour and road safety.

In the fourth step, **four Principal Component Analyses (PCA)** were implemented regarding driving performance, driving errors, neuropsychological state and neurological state, in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data. In the fifth and final step, the core statistical analysis of the present PhD thesis took place, including the implementation of **four Structural Equation Models (SEMs)** for the first time in the scientific field of driving behaviour of drivers with neurological diseases affecting cognitive functions. Within the framework of latent analysis and based on the factor loadings that were extracted from the PCA analyses, **four latent variables were developed** namely, "driving performance", "driving errors", "neurological state" and "neuropsychological state" in order to implement four SEMs. The four SEMs were developed aiming to quantify the impact of MCI, AD and PD, driver distraction, driver characteristics, "neurological state", "neuropsychological state" as well as road and traffic environment directly on the observed variables "reaction time" and "accident probability" and on the latent variables "driving performance" and "driving errors".



In the **first and the second SEMs**, the objective is the quantification of the impact of neurological diseases affecting cognitive functions, distraction, age and road and traffic environment on the observed variables "**reaction time**" and "**accident probability**". Additionally, the quantified impact of two latent variables regarding neurological state and neuropsychological state of the drivers on the observed variables is analyzed. In the **third and fourth SEMs**, the key latent variables reflects the underlying "**driving errors**" and "**driving performance**" and the objective is the quantification of the impact of neurological disease affecting cognitive functions, distraction, driver characteristics and road and traffic environment on "driving errors" and "driving performance". Additionally, the quantified impact of latent variable regarding "neurological state" and latent variable regarding "neuropsychological state" of the drivers on the latent variables "driving errors" and "driving performance" is analyzed.

The synthesis of the key research findings that were extracted within the framework of this PhD dissertation lead to several conclusions of great significance with five innovative scientific contribution points.



<u>The first innovation</u> of this PhD dissertation is methodological. **The design and implementation of a large scale inter-disciplinary experiment** which includes two scientific branches, a traffic engineering, and a medical (neurological and neuropsychological), is a central component of the present PhD thesis. Because of the integration of these different scientific disciplines involved in impaired driving research (**traffic engineering, neurology and neuropsychology**), this PhD dissertation covers a research field with an obvious but not previously exploited multidisciplinary nature.

<u>The second innovation</u> of this PhD dissertation is also methodological, suggesting the implementation of **four latent variables covering all three fields of this inter-disciplinary PhD thesis**: "driving performance" and "driving errors" extracted from the

driving simulator experiment, "neurological state" extracted from the neurological database and "neuropsychological state" extracted from the neuropsychological database, in order to **construct four Structural Equation Models (SEMs)**. The four latent variables were developed using the most critical indexes (neurological, neuropsychological, and driving measures) extracted from the PCA analyses.

Latent analysis allowed an important scientific step forward from piecemeal analyses to a sound combined analysis of the **inter-disciplinary interrelationship** between risk factors, neurological state, neuropsychological state, driving performance, driving error and accident probability at unexpected incidents. **It is the first time and it is also considered a methodological originality of this PhD dissertation**, that latent variables reflecting neurological and neuropsychological status (neurological state and neuropsychological state) interact with other latent driving variables (driving performance an driving errors) and with other observed driving variables such as reaction time and accident probability.

The third innovation is the quantification of the impact of neurological diseases affecting cognitive functions, on drivers' traffic and safety behaviour, which is considered to be the core of this PhD dissertation, regarding the key research findings. The first three statistical steps, indicated **statistically significant differences between the group of patients with neurological diseases affecting cognitive functions and the healthy controls** of similar demographics in several driving performance measures. Patients were found to drive at significantly lower mean speed and had larger time headway compared to the healthy drivers. Analyzing the lateral control measures it was observed that patients with MCI drove more closely to the right border of the road (slightly yet significantly). It was observed that patients had significantly larger reaction times in all examined conditions compared with the cognitively intact group. Moving on to the accident probability, significantly higher accident probability was detected for the AD group in all examined conditions and for the MCI and PD groups only in urban area. Finally, the ANOVA investigated the self-stated questionnaires and indicated that drivers with MCI, AD and PD **are aware of their deterioration of their driving performance**.

Moving on to the SEM analysis, it was indicated that **drivers with MCI, AD and PD overall performed significantly worse than the healthy controls regarding the four examined driver behaviour characteristics**. More precisely, they were associated with significantly lower levels of the latent variable "driving performance" that reflected a broad range of driving indexes and were associated with significantly worse "reaction

time". Also, the clinical conditions of AD and PD were associated with a negative impact on accident probability. Finally, none of the clinical groups showed a significantly increased amount of driving errors. Latent variable **"neuropsychological state"** had a positive effect on all outcome variables. Latent variable **"neurological state"** had a significant positive effect on "driving performance", "driving errors" and reaction time, whereas, its impact on accident risk was not statistically significant.

Moving on to the impact of other risk factors on driver behaviour, **conversation with the passenger** was not found to have a critical impact on driving performance, driving errors and accident probability, indicating that drivers don't alter their driving behaviour in an important way under this type of distraction, but they have worse reaction time. On the other hand, **mobile phone use** had a significant negative effect on "driving performance", "accident probability" and "reaction time" but not on "driving errors". **Advanced age** had a significant negative impact on "driving performance", "driving errors" and reaction time, whereas, its impact on accident risk was not statistically significant. **Urban area** had a significant negative impact on "driving performance", whereas its impact on "driving errors", reaction time and accident probability was positive. **Low traffic conditions** affected positively the "driving performance", whereas it hadn't any significant impact on "driving errors", reaction time and accident probability. Nonetheless, **the parameter that renders originality to this analysis** is the development of latent variables for the evaluation of driving behaviour that encompasses a variety of indexes. In addition, another novel element is the application of multivariate SEM models that make the exploration of the **unique impact** of neurological diseases affecting cognitive functions feasible on driving behaviour.

The fourth innovation of this PhD dissertation is derived also from the key research findings and concerns the comparative performance analysis of drivers with different neurological diseases affecting cognitive functions. The results indicated **AD as the riskiest group of drivers** (had the greatest impact on accident probability and driving performance and almost the greatest on reaction time), **followed by PD**, whereas the group of MCI is considered as safer compared to the other two examined brain pathologies.

Finally, the fifth innovation of this PhD dissertation concerns the effect of distraction the performance of drivers with MCI, AD and PD, by exploring driving while conversing with a co-passenger and driving while conversing through a handheld mobile phone. Exploring and quantifying the impact of distraction on drivers with MCI, AD and PD has

not been addressed so far among the international scientific community. It appeared that overall, the distraction conditions didn't have such a significant impact on driving performance measures in the group of controls, in contrast with the findings extracted from the **patients' groups regression analyses in which the impact of distraction and especially the mobile phone use, was detrimental**. In particular, the **reaction time** of drivers with brain pathologies **increased more than 30%** under the driving condition with the use of **mobile phone**, whereas in the group of cognitively intact drivers the equivalent increase was about 10%. Moreover, the group of drivers with neurological diseases affecting cognitive functions had a striking increase of the risk of being engaged in a car accident when using a mobile phone. Also, the presence of a **conversation with a passenger had an impact** on the driving performance of the patients, but of **a smaller magnitude** as compared to the case of the mobile phone use.

The results of this PhD dissertation **can be exploited in the development of recommendations and measures** for addressing all aspects of impaired driving due to neurological diseases affecting cognitive functions. The application of this methodology revealed also a number of open issues for further research in the inter-disciplinary field of driving behaviour and brain pathologies (i.e. **periodically assess** the driving behaviour of patients with cerebral diseases over time). It is important to mention that **every driver with a neurological disease affecting cognitive functions 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. Additionally, it should be in positive direction an effective monitoring of drivers that are at-risk for developing an underlying neurological condition that is associated with unsafe driving and the development of interventions that have the capacity to improve or preserve the driving fitness of older individuals and of drivers with cerebral diseases.

Overall, the results of this PhD thesis can potentially contribute to a significant reduction of road accidents and fatalities, if the data and the results **be exploited by the authorities in order to implement appropriate road safety policy directions regarding the vulnerable group** of drivers with neurological diseases affecting cognitive functions. Enhanced understanding of the medical, behavioural and social issues related to impaired driving due to neurological diseases affecting cognitive functions 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.

Εκτεταμένη Περίληψη

Η παρούσα Διδακτορική Διατριβή αποτελεί μία διεπιστημονική πραγματεία των ερευνητικών πεδίων της κυκλοφοριακής συμπεριφοράς και συμπεριφοράς οδικής ασφάλειας από τη μία, και των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες από την άλλη. Ο στόχος της Διδακτορικής Διατριβής είναι **η ανάλυση της συμπεριφοράς κυκλοφορίας και ασφάλειας οδηγών με νευρολογικές παθήσεις, που επηρεάζουν τις νοητικές λειτουργίες**. Ειδικότερα, είναι υπό διερεύνηση η επιρροή συγκεκριμένων εγκεφαλικών παθήσεων στην οδηγική επίδοση, στα οδηγικά λάθη, στο χρόνο αντίδρασης και στην πιθανότητα ατυχήματος. Η οδηγική συμπεριφορά εξετάζεται σε όρους κυκλοφορίας και ασφάλειας και οι νευρολογικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες αφορούν ασθενείς με μεγάλη συχνότητα εμφάνισης στο γενικό πληθυσμό, όπως η Νόσος Alzheimer (AD), η Νόσος Parkinson (PD) και η Ήπια Νοητική Εξασθένηση (MCI).

Ο στόχος της Διδακτορικής Διατριβής καλύφθηκε ως εξής:

» σχεδιάζοντας και εφαρμόζοντας ένα **μεγάλης κλίμακας πείραμα** σε προσομοιωτή οδήγησης
» αναπτύσσοντας μια **πρωτότυπη μεθοδολογία** για την αξιολόγηση της επιρροής των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες στην οδηγική επίδοση, λαμβάνοντας υπόψιν τα νευροψυχολογικά και δημογραφικά χαρακτηριστικά των οδηγών καθώς και τα χαρακτηριστικά κυκλοφορίας και οδικής ασφάλειας
» ποσοτικοποιώντας **την επιρροή των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες απευθείας** στην οδηγική επίδοση, στα οδηγικά λάθη, στο χρόνο αντίδρασης και στην πιθανότητα ατυχήματος
» **συγκρίνοντας την οδηγική επίδοση** των οδηγών με διαφορετικές νευρολογικές ασθένειες και
» εξετάζοντας **την επιρροή της απόσπασης της προσοχής του οδηγού** στις επιδόσεις των οδηγών με νοητικές διαταραχές.

Η παρούσα Διδακτορική Διατριβή μελετά την αλληλεπίδραση των νευρολογικών ασθενειών που επηρεάζουν τις νοητικές λειτουργίες, άλλων σχετικών παραμέτρων (δημογραφικών, ιατρικών και νευροψυχολογικών κ.α.), όπως επίσης οδικών και κυκλοφοριακών συνθηκών και της απόσπασης της προσοχής σε σχέση με την οδηγική συμπεριφορά. Η **συνδυαστική επιρροή αυτών των παραμέτρων «κλειδιά»** στην οδηγική επίδοση, στα οδηγικά λάθη, στο χρόνο αντίδρασης και στην

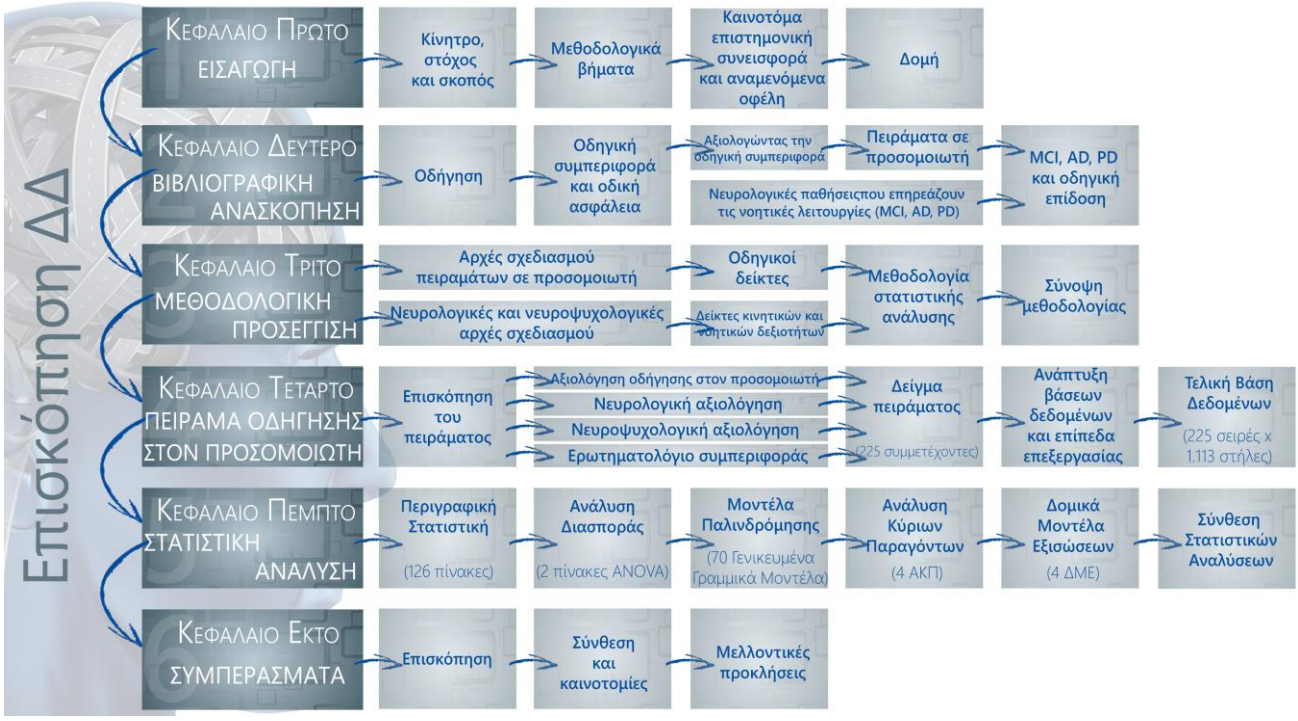
πιθανότητα ατυχήματος θα προσδώσουν γνώση που θα είναι ιδιαιτέρως χρήσιμη στην ανάλυση κυκλοφορίας και ασφάλειας των οδηγών.

Δεδομένης της **αλληλεπίδρασης διαφόρων επιστημονικών πεδίων** στη διερεύνηση της μειωμένης οδηγικής επίδοσης λόγω νευρολογικών ασθενειών που επηρεάζουν τις νοητικές λειτουργίες (αντικείμενο συγκοινωνιολόγου μηχανικού, νευρολόγου και νευροψυχολόγου), η Διδακτορική Διατριβή αυτή καλύπτει ένα ερευνητικό πεδίο μιας **προφανούς και μοναδικής διεπιστημονικής φύσης**, το οποίο όμως δεν έχει ερευνηθεί στο παρελθόν. Η ανάλυση των νευρολογικών ασθενειών που επηρεάζουν τις νοητικές λειτουργίες και δημογραφικών και νευροψυχολογικών χαρακτηριστικών σε συνδυασμό με την οδηγική επίδοση του γενικού πληθυσμού αποτελεί έναν πολύ κρίσιμο τομέα και ταυτόχρονα μια μεγάλη ερευνητική πρόκληση.

Προκειμένου να επιτευχθούν οι στόχοι της Διδακτορικής Διατριβής, ακολουθήθηκαν **τέσσερα διακριτά μεθοδολογικά βήματα**:

1ο. Εκτενής βιβλιογραφική ανασκόπηση,
2ο. Μεθοδολογική προσέγγιση,
3ο. Σχεδιασμός και εφαρμογή ενός μεγάλης κλίμακας πειράματος σε προσομοιωτή οδήγησης, και
4ο. Ανάπτυξη και εφαρμογή μιας καινοτόμου στατιστικής μεθοδολογίας και ανάλυσης.

Η επισκόπηση της Διδακτορικής Διατριβής παρουσιάζεται στο επόμενο σχήμα:



Αρχικά, στα πλαίσια του Κεφαλαίου 2, **πραγματοποιήθηκε μια εκτενής βιβλιογραφική ανασκόπηση**, εξετάζοντας την οδηγική συμπεριφορά και οδική ασφάλεια, τρόπους αξιολόγησης της οδηγικής συμπεριφοράς, τα χαρακτηριστικά των προσομοιωτών οδήγησης, τις νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες (MCI, AD, PD) και πώς αυτές οι παθήσεις επηρεάζουν την οδηγική επίδοση.

Πιο συγκεκριμένα, μετά από μερικά ιστορικά στοιχεία για την οδήγηση αυτοκινήτου και τα βασικά χαρακτηριστικά και τις δεξιότητες που ένας οδηγός θα πρέπει να έχει, παρουσιάστηκε μια εισαγωγή για την **οδική ασφάλεια και την οδηγική συμπεριφορά**, με ιδιαίτερη έμφαση στη **σημασία του ανθρώπινου παράγοντα και της νοητικής λειτουργίας σε αυτές**. Επιπλέον, υπογραμμίστηκαν οι κίνδυνοι της απόσπασης της προσοχής του οδηγού κατά την οδήγηση και οι πιθανές αντισταθμιστικές στρατηγικές τις οποίες οι οδηγοί χρησιμοποιούν σε αυτές τις συνθήκες οδήγησης. Στη συνέχεια, προχωρώντας προς τους τρόπους που η επιστημονική κοινότητα αποτιμά και αξιολογεί την οδηγική συμπεριφορά, εξετάστηκαν τα πλεονεκτήματα και οι περιορισμοί των πειραμάτων σε πραγματικές συνθήκες στο δρόμο, και πειραμάτων σε προσομοιωτή, σε βάθος μελέτες και έρευνες και ερωτηματολόγια, και καταλήξαμε στο συμπέρασμα ότι η οδήγηση σε πειράματα προσομοιωτή προσφέρει ένα ασφαλές περιβάλλον, μεγαλύτερο δείγμα ελέγχου, και μεγάλη ποικιλία από συνθήκες δοκιμών, όμως πάσχει από προβλήματα «learning effects», «ζαλάδα στον προσομοιωτή», και υψηλό κόστος.

Παράλληλα, η ανασκόπηση της βιβλιογραφίας εισχώρησε σε τομείς των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες και επικεντρώθηκε στις εξής τρεις: **Ήπια Νοητική Εξασθένηση (MCI), Νόσο του Alzheimer (AD), και Νόσο του Parkinson (PD)**. Το κύριο μέρος της ανασκόπησης αυτής περιελάμβανε αρκετές μελέτες, οι οποίες επέτρεψαν την εξαγωγή συμπερασμάτων σχετικά με τις οδηγικές δυσκολίες των οδηγών που πάσχουν από MCI, AD και PD.

Μελετώντας εργασίες με οδηγούς με MCI, αυτές που εξετάζουν την οδηγική επίδοση μέσω πειραμάτων οδήγησης σε πραγματικές συνθήκες, διαπιστώνεται πως οι ασθενείς αυτοί, παρόλο που βιώνουν ανεπαίσθητες αλλαγές όσον αφορά τις οδηγικές τους επιδόσεις, είναι σε θέση να οδηγούν με ασφάλεια. Ωστόσο, εντοπίζεται ένα επίπεδο δυσλειτουργίας συγκριτικά με τους υγιείς μάρτυρες, πράγμα που

σημαίνει ότι εξακολουθούν να αποτελούν μια ομάδα ρίσκου όσον αφορά της οδήγησή τους, που δικαιολογεί τη στενή επίβλεψή τους.

Εξετάζοντας μελέτες για ασθενείς με AD, η οδηγική τους απόδοση μειώνεται σημαντικά στα πειράματα σε πραγματικές οδηγικές συνθήκες, αλλά και πειράματα σε προσομοιωτή οδήγησης αναφέρουν χειρότερες επιδόσεις οδήγησης σε σύγκριση με τους υγιείς μάρτυρες σε διάφορες οδηγικές παραμέτρους.

Οι μελέτες για τους ασθενείς με PD, αναφέρουν ότι η ικανότητα οδήγησής τους είναι προβληματική, κυρίως λόγω νοητικής εξασθένησης. Επιπλέον, «ηχηρές» δυσκολίες σε πολλές οδηγικές παραμέτρους φαίνεται να υπάρχουν σε οδηγούς με PD κάτω από απαιτητικές συνθήκες οδήγησης, οι οποίες περιλαμβάνουν αυξημένο γνωστικό φορτίο.

Εν συνεχεία, αναπτύχθηκε μια καινοτόμα μεθοδολογία στατιστικής ανάλυσης στον τομέα της αξιολόγησης της οδηγικής συμπεριφοράς ασθενών με νοητικές παθήσεις νευρολογικών αιτιών. Αυτή η **καινοτόμα μεθοδολογική προσέγγιση** βασίστηκε αρχικά στη βιβλιογραφική ανασκόπηση όσον αφορά στις αρχές σχεδιασμού πειραμάτων προσομοιωτή οδήγησης, νευρολογικών και νευροψυχολογικών πειραμάτων, παραμέτρους ανάλυσης οδηγικής επίδοσης, παραμέτρους νευρολογικής και νευροψυχολογικής κατάστασης και μεθόδους στατιστικής ανάλυσης.

Πιο συγκεκριμένα, όσον αφορά τη μεθοδολογική προσέγγιση, αποκαλύφθηκε ότι **ο πειραματικός σχεδιασμός ενός πειράματος σε προσομοιωτή οδήγησης** θα μπορούσε να είναι «within» ή «between-subject» ή «full factorial» και υπάρχουν πιθανές μεθοδολογικές «απειλές» που πρέπει να ληφθούν υπόψη κατά το σχεδιασμό ενός πειράματος. Η συμπεριφορά του οδηγού είναι ένα πολυδιάστατο φαινόμενο, το οποίο σημαίνει ότι δεν υπάρχει μια συγκεκριμένη και μεμονωμένη οδηγική παράμετρος, που να μπορεί να συλλάβει την επιρροή των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες στην οδήγηση. Για το λόγο αυτό, υπάρχουν πολλές διαφορετικές μέθοδοι και δείκτες αξιολόγησης της οδηγικής επίδοσης, οι συνηθέστεροι από τους οποίους περιλαμβάνουν **πλευρικούς δείκτες οδήγησης, κατά μήκος δείκτες οδήγησης, χρόνους αντίδρασης, κίνηση των ματιών στην οδήγηση και δείκτες λειτουργίας του εγκεφάλου.**

Παράλληλα, προκειμένου να αξιολογηθεί η οδηγική επίδοση των ασθενών με νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες, εκτός από το

πείραμα οδήγησης, είναι απαραίτητος και **ο σχεδιασμός νευρολογικών και νευροψυχολογικών πειραμάτων**. Ο νευρολογικός πειραματικός σχεδιασμός θα πρέπει να ασχοληθεί με πολλούς τομείς: μνήμης, προσανατολισμού στο χρόνο και στο χώρο, με το νευρικό ανθρώπινο σύστημα, τις καθημερινές δραστηριότητες, τη συναισθηματική κατάσταση, τη συμπεριφορά ύπνου και τις κινητικές ικανότητες. Ο νευροψυχολογικός πειραματικός σχεδιασμός θα πρέπει να ασχοληθεί με τα γνωστικά πεδία: συνολική νοητική κατάσταση, λεκτική μνήμη και μάθηση, τη λεκτική μνήμη εργασίας, την οπτική σάρωση, χωρική μνήμη και μάθηση, οπτικοχωρική αντίληψη και μνήμη εργασίας, κατασκευαστική ικανότητα, προσοχή/πληροφορίες για την ταχύτητα επεξεργασίας/αντίληψης, επιλεκτική και διαιρούμενη προσοχή, εκτελεστικές λειτουργίες και ψυχοκινητική επαγρύπνηση.

Η μεθοδολογική ανασκόπηση έδειξε ότι ανάλυση λανθανουσών μεταβλητών και ειδικότερα τεχνικές μοντελοποίησης με χρήση δομικών μοντέλων εξισώσεων δεν έχει ποτέ πραγματοποιηθεί στο παρελθόν στον τομέα της οδηγικής συμπεριφοράς οδηγών με νευρολογικές παθήσεις, που επηρεάζουν τις νοητικές λειτουργίες. Για το λόγο αυτό και στα πλαίσια της παρούσας Διδακτορικής Διατριβής, **αναπτύχθηκε μια πρωτότυπη στατιστική μεθοδολογία, η οποία αποτελείται από πέντε βήματα**: α) Περιγραφική Στατιστική, β) Ανάλυση Διασποράς, γ) Μοντέλα Παλινδρόμησης, δ) Ανάλυση Κύριων Παραγόντων, και ε) Δομικά Μοντέλα Εξισώσεων.

Εν συνεχεία, στα πλαίσια του Κεφαλαίου 4, βασιζόμενοι στη βιβλιογραφική και μεθοδολογική ανασκόπηση, **σχεδιάστηκε και πραγματοποιήθηκε ένα μεγάλης κλίμακας πείραμα σε προσομοιωτή οδήγησης** στον Τομέα Μεταφορών και Συγκοινωνιακής Υποδομής του Ε.Μ.Π., που ως στόχο είχε την αξιολόγηση της οδηγικής συμπεριφοράς των ασθενών με νευρολογικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες. Ο στόχος του κεφαλαίου αυτού είναι να παρουσιάσει την πειραματική διαδικασία τόσο σε επίπεδο εννοιολογικού πλαισίου και εφαρμογής, καθώς επίσης να αποτυπώσει τις βασικές παραμέτρους καταγραφής και συλλογής των δεδομένων.

Το πείραμα σχεδιάστηκε διεπιστημονικά και περιελάμβανε δυο επιστημονικές ομάδες: **Συγκοινωνιολόγους Μηχανικούς** του Εθνικού Μετσοβίου Πολυτεχνείου (ΕΜΠ), **Νευρολόγους, Νευροψυχολόγους και Ψυχίατρο** της Β' Νευρολογικής Κλινικής του Πανεπιστημίου Αθηνών στο Πανεπιστημιακό Γενικό Νοσοκομείο «ΑΤΤΙΚΟΝ». Οι κλάδοι αξιολόγησης ήταν τρεις:

» **Οδήγηση στον προσομοιωτή**: Αρχικά, πραγματοποιήθηκε ο σχεδιασμός και η εφαρμογή του πειράματος στον προσομοιωτή, καθώς αποτελεί ένα καινοτόμο

στοιχείο της παρούσας Διδακτορικής Διατριβής, επιτρέποντας να καλυφθούν οι πολύπλοκες προκλήσεις της. Όλα τα ατομικά μέρη του πειράματος σχεδιάστηκαν και εφαρμόστηκαν προσεκτικά λαμβάνοντας υπόψιν τους περιορισμούς και τις ανάγκες που εντοπίστηκαν σε αντίστοιχα πειράματα σε προσομοιωτή οδήγησης από άλλες μελέτες.

» **Ιατρική/νευρολογική αξιολόγηση**: Η δεύτερη αξιολόγηση αφορά την πραγματοποίηση μιας πλήρους κλινικής, οφθαλμολογικής και νευρολογικής αξιολόγησης, προκειμένου να καταγραφούν τα χαρακτηριστικά της κάθε εξεταζόμενης εγκεφαλικής πάθησης (MCI, AD, PD) των συμμετεχόντων.

» **Νευροψυχολογική αξιολόγηση**: Η τρίτη αξιολόγηση αφορά τη χορήγηση μιας σειράς νευροψυχολογικών δοκιμασιών και ψυχολογικών ερωτηματολογίων συμπεριφοράς στους συμμετέχοντες. Οι δοκιμές που πραγματοποιήθηκαν καλύπτουν ένα ευρύ φάσμα γνωστικών λειτουργιών: οπτικοχωρική και λεκτική μνήμη, επιλεκτική και διαιρούμενη προσοχή, χρόνο αντίδρασης, ταχύτητα επεξεργασίας, ψυχοκινητική ταχύτητα κλπ.

Η πειραματική διαδικασία περιελάμβανε:

» **Μια δοκιμαστική διαδρομή** (εξοικείωση με τον προσομοιωτή)

» **Μια διαδρομή εκτός πόλης** (2,1km μήκος, μία λωρίδα ανά κατεύθυνση, 3m πλάτος λωρίδας)

» **Μια διαδρομή εντός πόλης** (1,7km μήκος, στο μεγαλύτερο μέρος 2 λωρίδες ανά κατεύθυνση, 3.5m πλάτος λωρίδας)

» **Δυο σενάρια κυκλοφοριακού φόρτου** για κάθε διαδρομή:
  » Q_M: Χαμηλός κυκλοφοριακός φόρτος (Q=300 οχήματα/ώρα)
  » Q_H: Υψηλός κυκλοφοριακός φόρτος (Q=600 οχήματα/ώρα)

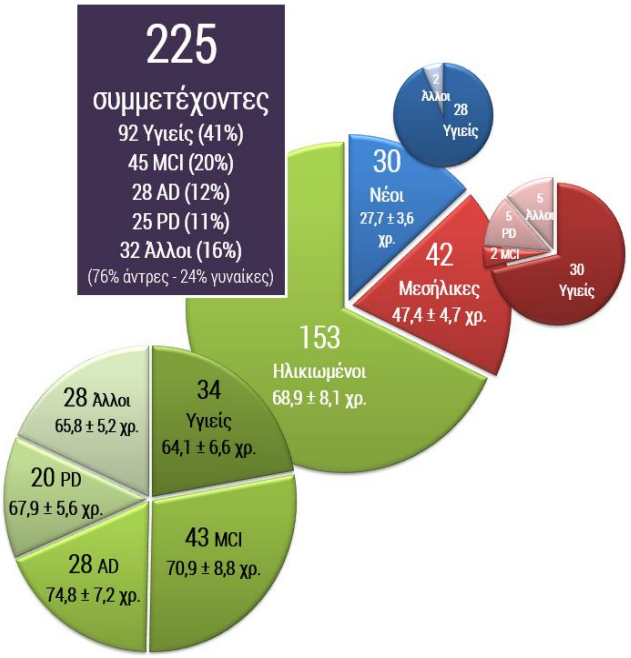
» **Τρεις καταστάσεις απόσπασης προσοχής** για κάθε διαδρομή:
  » Απερίσπαστη οδήγηση
  » Οδήγηση με ταυτόχρονη συνομιλία με συνεπιβάτη
  » Οδήγηση με ταυτόχρονη συνομιλία μέσω κινητού τηλεφώνου

» **Δυο απρόσμενα συμβάντα** για κάθε υπο-διαδρομή:
  » Ξαφνική είσοδος ενός ζώου στο δρόμο (εκτός πόλης)
  » Ξαφνική εμφάνιση ενός παιδιού να κυνηγάει μια μπάλα στο δρόμο ή ενός αυτοκινήτου να εισέρχεται στο δρόμο εξερχόμενο από μια θέση στάθμευσης (εντός πόλης)

Συνολικά η πλήρης πειραματική διαδικασία περιελάμβανε δώδεκα υπο-διαδρομές. Όλες αυτές οι συνθήκες αναλύθηκαν με **«full factorial within-subject»** σχεδιασμό. Επιπλέον, διάφορες άλλες πτυχές του σχεδιασμού παρουσιάστηκαν σχετικά με τη «ζαλάδα στον προσομοιωτή», με τα θέματα συζήτησης, τα συμβάντα, και την τυχαιοποίηση των υπο-διαδρομών, καθώς και το πώς προγραμματίστηκαν τα σενάρια οδήγησης. Επιπλέον, οι νευρολογικές και οι νευροψυχολογικές δοκιμασίες

παρουσιάστηκαν αναλυτικά, καθώς και το ερωτηματολόγιο οδηγικής συμπεριφοράς σχετικά με τις οδηγικές συνήθειες των συμμετεχόντων.

Για τους σκοπούς αυτής της Διδακτορικής Διατριβής, «έλαβαν αύξοντα αριθμό» και ξεκίνησαν την πειραματική διαδικασία που περιγράφηκε νωρίτερα 274 συμμετέχοντες, 49 από τους οποίους αποκλείστηκαν από τη συνέχεια του πειράματος, εξαιτίας του γεγονότος ότι αντιμετώπισαν προβλήματα λόγω ζαλάδας στον προσομοιωτή από την αρχή του πειράματος. Έτσι το δείγμα οδηγών που ολοκλήρωσε την πειραματική διαδικασία **περιλαμβάνει 225 συμμετέχοντες** (76% άντρες - 24% γυναίκες): **133 ασθενείς** με νευρολογική ασθένεια που επηρεάζει τις εγκεφαλικές λειτουργίες (28 ασθενείς με AD, 45 με MCI, 25 με PD, και 35 ασθενείς με κάποια άλλη νευρολογική εγκεφαλική πάθηση) και **92 υγιείς** χωρίς κάποια νευρολογική εγκεφαλική πάθηση. **Από την οπτική γωνία της ηλικίας**, τρείς ηλικιακές ομάδες αναπτύχθησαν και χωρίστηκαν ώς εξής: **30 Νέοι Οδηγοί (ηλικία<34)**, **42 Μεσήλικες Οδηγοί (35<ηλικία<54)** και **153 Ηλικιωμένοι Οδηγοί (ηλικία>55)**



Στη συνέχεια αναπτύχθηκαν **έξι Διακριτά Επίπεδα Επεξεργασίας Δεδομένων Προσομοιωτή Οδήγησης**, προκειμένου να αντιμετωπιστεί κατάλληλα η μεγάλη και διαφοροποιημένη ποσότητα των δεδομένων που συλλέχθησαν και να καταλήξουν σε ένα αρχείο, που περιλαμβάνει όλα τα δεδομένα για όλους τους οδηγούς από όλες τις αξιολογήσεις, το οποίο αναλύθηκε μέσω μιας **ειδικής και καινοτόμου μεθόδου στατιστικής ανάλυσης**:

» **PL0.** Traffic Session Original Log Αρχεία (900.txt αρχεία συνολικά ~ 60.000 σειρές το καθένα)
» **PL1.**Driver Original Data Excel Αρχεία (225.xls αρχεία συνολ.~4 φύλλα~60.000 σειρές το καθένα)
» **PL2.**Driver Processed Data Excel Αρχεία (225.xls αρχεία συνολ.~2 φύλλα~60.000 σειρές το καθένα)
» **PL3.** All Drivers Processed Data Excel Αρχείο (1 .accdb αρχείο ~ 20 εκατ. σειρές x 40 στήλες)
» **PL4.** All Drivers Summary Data Excel Αρχείο (1 .xls αρχείο~ 2.700 σειρές x 40 στήλες)
» **PL5.** All Assessments Processed Data Αρχείο (1 .xls αρχείο~225 σειρές x 1.113 στήλες)

Στα πλαίσια εργασιών του Κεφαλαίου 5, το αρχείο «All Drivers and All Assessments Processed Data», αναλύθηκε στατιστικά μέσω μιας **ειδικής και πρωτότυπης στατιστικής μεθοδολογίας ανάλυσης**. Στο πρώτο βήμα, έλαβε χώρα **η περιγραφική στατιστική όλων των δεδομένων του πειράματος**, η οποία επιτρέπει μια πρώτη προσέγγιση και κατανόηση του μεγάλου αριθμού των παραμέτρων που εξετάστηκαν. Ειδικότερα, πραγματοποιήθηκε μια επισκόπηση όλων των μεταβλητών που εξάγει ο προσομοιωτής, ερευνώντας την επιρροή συγκεκριμένων οδηγικών χαρακτηριστικών σε επιλεγμένες οδηγικές παραμέτρους. Αναπτύχθηκαν 126 διαγράμματα «boxplots» συσχετίζοντας τη μέση ταχύτητα, τη χρονοαπόσταση, την πλευρική θέση, τη διακύμανση της γωνίας του τιμονιού, το χρόνο αντίδρασης, την πιθανότητα ατυχήματος και τα οδηγικά λάθη, με τον κυκλοφοριακό φόρτο, και την περιοχή οδήγησης, ανάλογα με την ηλικία ή την εγκεφαλική κατάσταση των συμμετεχόντων.

Στο δεύτερο βήμα, πραγματοποιήθηκε **Ανάλυση Διακύμανσης (ANOVA)** προκειμένου να προκύψουν οι στατιστικά σημαντικές διαφορές στους διάφορους δείκτες οδηγικής επίδοσης, που εξάγονται από την οδήγηση στον προσομοιωτή. Ακριβέστερα, πραγματοποιήθηκαν δύο Αναλύσεις Διακύμανσης (ANOVA) για τον προσδιορισμό των στατιστικά σημαντικών διαφορών στους δείκτες οδηγικής επίδοσης, που εξήχθησαν από την οδήγηση στον προσομοιωτή και από τις απαντήσεις που εξήχθησαν από τα ερωτηματολόγια συμπεριφοράς, μεταξύ των δύο ομάδων: ομάδα ελέγχου των υγιών και ομάδα ασθενών.

Στο τρίτο στάδιο, στο πλαίσιο της προκαταρκτικής ανάλυσης, πραγματοποιήθηκε η **ανάπτυξη σειράς Μοντέλων Παλινδρόμησης** σχετικά με τις βασικές παραμέτρους οδηγικής επίδοσης, προκειμένου να εκτιμηθεί η επιρροή των εγκεφαλικών νόσων και των χαρακτηριστικών οδήγησης σε ειδικές παραμέτρους οδηγικής επιδόσης και έμμεσα στην οδηγική συμπεριφορά και την οδική ασφάλεια. Πιο συγκεκριμένα εξήχθησαν 28 Γενικά Γραμμικά Μοντέλα (GLM) σχετικά με την επίδραση των MCI, AD και PD στη: μέση ταχύτητα, χρονοαπόσταση, πλευρική θέση, διακύμανση γωνίας τιμονιού, χρόνο αντίδρασης σε απρόσμενα συμβάντα, πιθανότητα ατυχήματος, και οδηγικά λάθη και 42 Γενικά Γραμμικά Μοντέλα σχετικά με την επίδραση της απόσπασης της προσοχής για τους ίδιους δείκτες οδηγικής επίδοσης με προηγούμενα, των ασθενών με MCI, AD και PD και των υγιών.

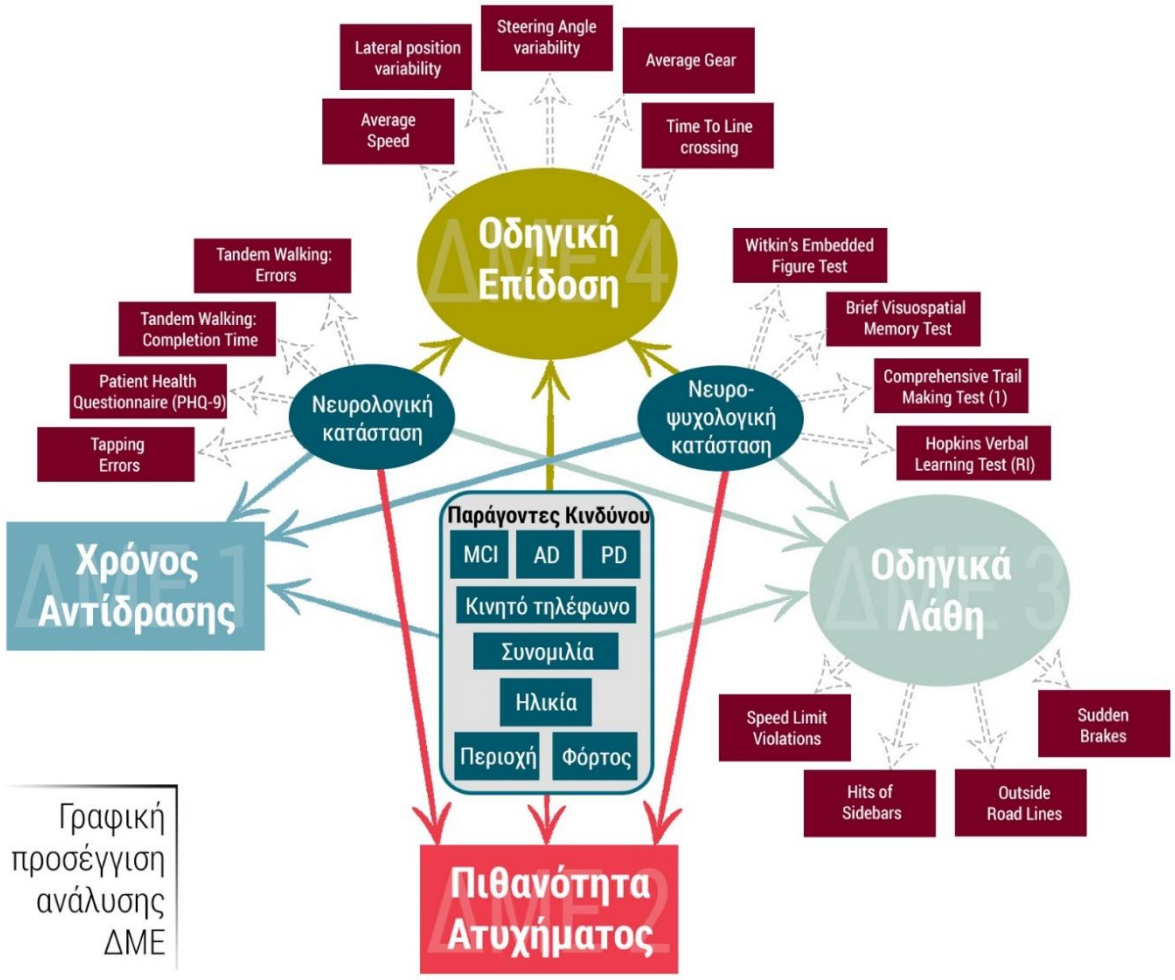
Στο τέταρτο στάδιο, υλοποιήθηκαν **τέσσερις Αναλύσεις Κύριων Παραγόντων** σχετικά με την οδηγική επίδοση, τα οδηγικά λάθη, τη νευροψυχολογική κατάσταση

και τη νευρολογική κατάσταση, προκειμένου να διερευνηθεί ποιες «παρατηρούμενες» μεταβλητές είναι πιο υψηλά συσχετισμένες με τους κύριους παράγοντες και πόσοι παράγοντες απαιτούνται για να περιγράψουν με επάρκεια τα δεδομένα.

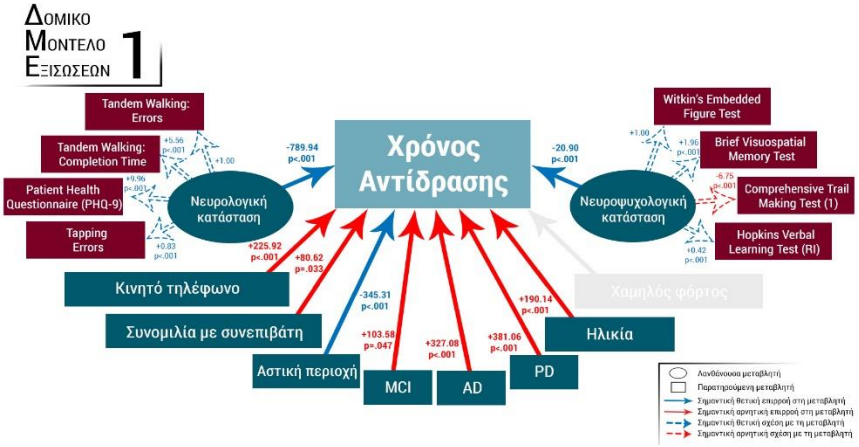
Το πέμπτο και τελευταίο βήμα, που αποτελεί και τον πυρήνα της στατιστικής ανάλυσης, περιλαμβάνει της εφαρμογή **τεσσάρων Δομικών Μοντέλων Εξισώσεων (ΔΜΕ)** για πρώτη φορά στο επιστημονικό πεδίο της οδηγικής συμπεριφοράς των οδηγών με νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες. Στο πλαίσιο της ανάλυσης λανθανουσών μεταβλητών και με βάση τους παράγοντες που εξήχθησαν από την προηγούμενη ανάλυση, **αναπτύχθηκαν τέσσερις λανθάνουσες μεταβλητές**: «οδηγική επίδοση», «οδηγικά λάθη», «νευρολογική κατάσταση» και «νευροψυχολογική κατάσταση», προκειμένου να εισαχθούν στα τέσσερα ΔΜΕ.

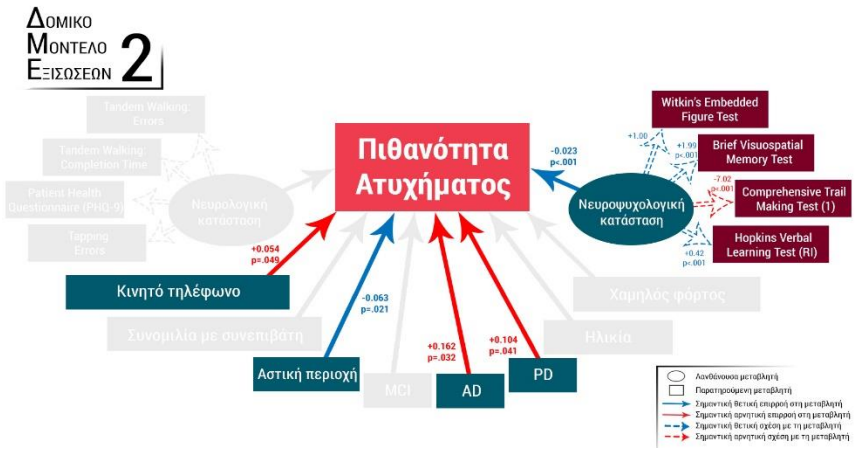
Οι ακόλουθοι πέντε οδηγικοί δείκτες σχηματίζουν την παράμετρο που αντανακλά τη **λανθάνουσα μεταβλητή «οδηγική επίδοση»**: α) μέση ταχύτητα, β) διακύμανση πλευρικής θέσης, γ) διακύμανση γωνίας τιμονιού, δ) μέση σχέση στο κιβώτιο ταχυτήτων, και ε) χρόνος για αλλαγή λωρίδας. Οι ακόλουθοι τέσσερις οδηγικοί δείκτες σχηματίζουν την παράμετρο που αντανακλά τη **λανθάνουσα μεταβλητή «οδηγικά λάθη»**: α) εκτός της λωρίδας, β) χτυπήματα στο στηθαίο ασφαλείας/προστατευτικά κολωνάκια, γ) παραβιάσεις του ορίου ταχύτητας και δ) απότομα φρεναρίσματα. Οι ακόλουθοι τέσσερις νευροψυχολογικοί δείκτες σχηματίζουν την παράμετρο που αντανακλά τη **λανθάνουσα μεταβλητή «νευροψυχολογική κατάσταση»**: α) Witkin's Embedded Figure Test, β) Brief Visuospatial Memory Test, γ) Comprehensive Trail Making Test - 1, και δ) Hopkins Verbal Learning Test. Τέλος, οι ακόλουθοι τέσσερις νευρολογικοί δείκτες σχηματίζουν την παράμετρο που αντανακλά τη **λανθάνουσα μεταβλητή «νευρολογική κατάσταση»**: α) Tandem Walking Errors, β) Tandem Walking Time, γ) Patient Health Questionnaire (PHQ-9) και δ) Foot Tapping Errors.

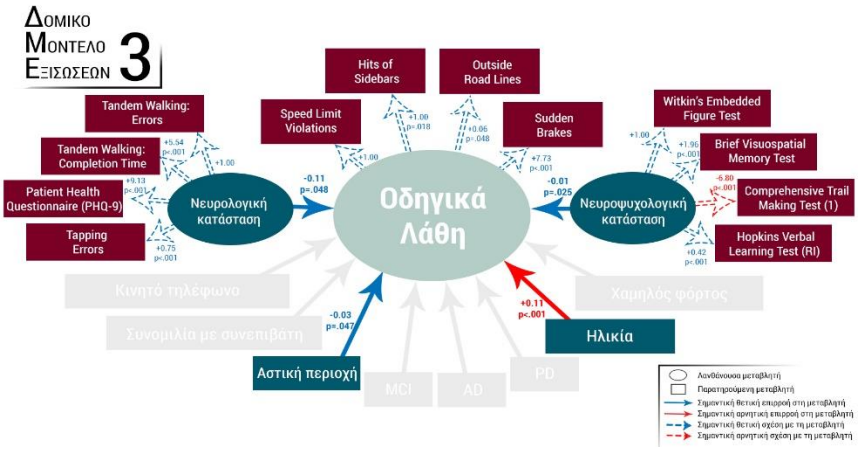
Τα τέσσερα ΔΜΕ αναπτύχθηκαν με στόχο την ποσοτικοποίηση της επιρροής των MCI, AD και PD, της απόσπασης της προσοχής του οδηγού, των χαρακτηριστικών του οδηγού, της νευρολογικής και νευροψυχολογικής κατάστασης, καθώς και των οδικών και κυκλοφοριακών συνθηκών **απευθείας στην οδηγική συμπεριφορά, η οποία εκφράζεται με τις παρατηρούμενες μεταβλητές χρόνος αντίδρασης και πιθανότητα ατυχήματος και με τις λανθάνουσες μεταβλητές «οδηγική επίδοση» και «οδηγικά λάθη»**. Τα τέσσερα διαφορετικά ΔΜΕ αναπτύσσονται όπως περιγράφονται γραφικά στο ακόλουθο σχήμα και επεξηγούνται κάτωθι:

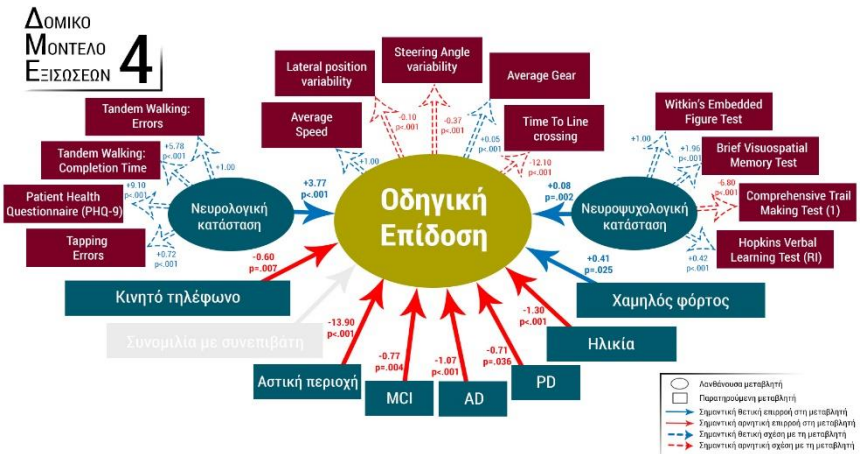


Στο **πρώτο και το δεύτερο ΔΜΕ**, ο στόχος είναι η ποσοτικοποίηση της επιρροής των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες, της απόσπασης της προσοχής του οδηγού, της ηλικίας, του κυκλοφοριακού φόρτου και του οδικού περιβάλλοντος για τις παρατηρούμενες μεταβλητές **«χρόνος αντίδρασης» και «πιθανότητα ατυχήματος»**. Επιπλέον, αναλύεται η ποσοτικοποιημένη επιρροή των δύο λανθανουσών μεταβλητών σχετικά με τη νευρολογική και νευροψυχολογική κατάσταση των οδηγών στις παρατηρούμενες μεταβλητές. Στο **τρίτο και τέταρτο ΔΜΕ**, οι βασικές λανθάνουσες μεταβλητές αντανακλούν την **«οδηγική επίδοση»** και τα **«οδηγικά λάθη»** και ο στόχος είναι η ποσοτικοποίηση της επιρροής των νευρολογικών ασθενειών που επηρεάζουν τις νοητικές λειτουργίες, της απόσπασης της προσοχής, των χαρακτηριστικών του οδηγού, του κυκλοφοριακού φόρτου και του οδικού περιβάλλοντος στην «οδηγική επίδοση» και τα «οδηγικά λάθη». Επιπροσθέτως, αναλύεται η ποσοτικοποιημένη επιρροή της λανθάνουσας μεταβλητής «νευρολογική κατάσταση» και της λανθάνουσας μεταβλητής «νευροψυχολογική κατάσταση» των οδηγών στις λανθάνουσες μεταβλητές «οδηγική επίδοση» και «οδηγικά λάθη».


Δομικο Μοντελο Εξισωσεων 1
Tandem Walking: Errors
Tandem Walking: Completion Time
Patient Health Questionnaire (PHQ-9)
Tapping Errors
Νευρολογική κατάσταση
Χρόνος Αντίδρασης
Witkin's Embedded Figure Test
Brief Visuospatial Memory Test
Comprehensive Trail Making Test (1)
Hopkins Verbal Learning Test (RI)
Νευροψυχολογική κατάσταση
Κινητό τηλέφωνο
Συνομιλία με συνεπιβάτη
Αστική περιοχή
Χαμηλός φόρτος
Ηλικία
MCI
AD
PD


Δομικο Μοντελο Εξισωσεων 2
Πιθανότητα Ατυχήματος
Witkin's Embedded Figure Test
Brief Visuospatial Memory Test
Comprehensive Trail Making Test (1)
Hopkins Verbal Learning Test (RI)
Νευροψυχολογική κατάσταση
Κινητό τηλέφωνο
Αστική περιοχή
AD
PD


Δομικο Μοντελο Εξισωσεων 3
Hits of Sidebars
Outside Road Lines
Speed Limit Violations
Sudden Brakes
Tandem Walking: Errors
Tandem Walking: Completion Time
Patient Health Questionnaire (PHQ-9)
Tapping Errors
Νευρολογική κατάσταση
Οδηγικά Λάθη
Witkin's Embedded Figure Test
Brief Visuospatial Memory Test
Comprehensive Trail Making Test (1)
Hopkins Verbal Learning Test (RI)
Νευροψυχολογική κατάσταση
Ηλικία
Αστική περιοχή


Δομικο Μοντελο Εξισωσεων 4
Lateral position variability
Steering Angle variability
Average Gear
Average Speed
Time To Line crossing
Tandem Walking: Errors
Tandem Walking: Completion Time
Patient Health Questionnaire (PHQ-9)
Tapping Errors
Νευρολογική κατάσταση
Οδηγική Επίδοση
Witkin's Embedded Figure Test
Brief Visuospatial Memory Test
Comprehensive Trail Making Test (1)
Hopkins Verbal Learning Test (RI)
Νευροψυχολογική κατάσταση
Κινητό τηλέφωνο
Χαμηλός φόρτος
Ηλικία
Αστική περιοχή
MCI
AD
PD

Στο σημείο αυτό θα παρουσιαστούν τα κυριότερα συμπεράσματα που εξήχθησαν από την παρούσα Διδακτορική Διατριβή, **εστιάζοντας στην καινοτόμα επιστημονική συνεισφορά και στη σύνθεση των πλέον αξιοπρόσεκτων και ενδιαφερόντων αποτελεσμάτων της έρευνας αυτής**. Το καινοτόμο επιστημονικό προϊόν της παρούσας Διδακτορικής Διατριβής συγκεντρώνεται σε πέντε πρωτοτυπίες, όπως παρουσιάζονται κάτωθι:

Υλοποίηση ενός μεγάλου διεπιστημονικού πειράματος, που περιλαμβάνει ιατρική, ψυχολογική και οδηγική αξιολόγηση

Η πρώτη καινοτομία της παρούσας Διδακτορικής Διατριβής είναι μεθοδολογικού περιεχομένου. **Ο σχεδιασμός και η υλοποίηση ενός μεγάλης κλίμακας διεπιστημονικού πειράματος,** που περιλαμβάνει δύο επιστημονικούς κλάδους, έναν ενδιαφέροντος συγκοινωνιολόγου μηχανικού, και έναν ιατρικού ενδιαφέροντος (νευρολογικού και νευροψυχολογικού), αποτελεί **κεντρική συνιστώσα** της παρούσας Διδακτορικής Διατριβής. Λόγω της συμμετοχής αυτών των διαφορετικών επιστημονικών κλάδων που εμπλέκονται στην παρούσα έρευνα λόγω της οδήγησης των νευρολογικών ασθενειών που επηρεάζουν τις νοητικές λειτουργίες (αντικείμενο ενδιαφέροντος συγκοινωνιολόγου μηχανικού, νευρολόγου και νευροψυχολόγου), αυτή η Διδακτορική Διατριβή καλύπτει ένα πεδίο έρευνας με προφανή, αλλά όχι

προηγουμένως εξεταζόμενη διεπιστημονική φύση. Πιο συγκεκριμένα, οι πτυχές της οδηγικής συμπεριφοράς και ασφάλειας που εξετάστηκαν ήταν εγγενώς διεπιστημονικές, και το πείραμα που σχεδιάστηκε περιλαμβάνει τρεις τύπους αξιολόγησης:

» **Οδήγηση στον προσομοιωτή (12 υπο-διαδρομές οδήγησης ~ 1,5 ώρα**[1]**)**: Η πρώτη αξιολόγηση αφορά την οδηγική συμπεριφορά προγραμματίζοντας ένα «σετ» διαδρομών για οδήγηση στον προσομοιωτή οδήγησης σε διαφορετικές συνθήκες περιοχών και κυκλοφορίας. Η τυχαιοποίηση της σειράς με την οποία οδήγησαν τις επιμέρους διαδρομές οι συμμετέχοντες, ο αρκετός χρόνος δοκιμαστικής οδήγησης για εξοικείωση με το περιβάλλον του προσομοιωτή, και η έρευνα για το βέλτιστο αριθμό διαφορετικών συνθηκών οδήγησης θεωρούνται σχεδιαστικές καινοτομίες του πειράματος.
» **Ιατρική/νευρολογική αξιολόγηση (19 τέστ ~ 2 ώρες)**: Η δεύτερη αξιολόγηση αφορά την πραγματοποίηση μιας πλήρους κλινικής, οφθαλμολογικής και νευρολογικής αξιολόγησης, προκειμένου να καταγραφούν τα χαρακτηριστικά της κάθε εξεταζόμενης εγκεφαλικής πάθησης (MCI, AD, PD) των συμμετεχόντων.
» **Νευροψυχολογική αξιολόγηση (20 τέστ ~ 2,5 ώρες)**: Η τρίτη αξιολόγηση αφορά τη χορήγηση μιας σειράς νευροψυχολογικών δοκιμασιών και ψυχολογικών ερωτηματολογίων συμπεριφοράς στους συμμετέχοντες. Οι δοκιμασίες που πραγματοποιήθηκαν καλύπτουν ένα ευρύ φάσμα γνωστικών λειτουργιών: οπτικοχωρική και λεκτική μνήμη, επιλεκτική και διαιρούμενη προσοχή, χρόνο αντίδρασης, ταχύτητα επεξεργασίας, ψυχοκινητική ταχύτητα κλπ.

Συνολικά, **225 οδηγοί** (133 ασθενείς με MCI, AD και PD και 92 υγιείς μάρτυρες) πέρασαν όλη την πειραματική διαδικασία μέσα σε διάστημα 2 ετών. Το μέγεθος αυτό του δείγματος θεωρείται **μεγάλο και αντιπροσωπευτικό**, το οποίο έχει μεγάλη σημασία, λαμβάνοντας υπόψη τους περιορισμούς του σχεδιασμού που προέρχονται από τη διεθνή βιβλιογραφία. Ο πρωταρχικός στόχος για το σχεδιασμό του πειράματος ήταν από τη μία πλευρά να είναι σε θέση όλοι οι συμμετέχοντες να περάσουν από όλες τις απαιτούμενες νευρολογικές και νευροψυχολογικές αξιολογήσεις, τα ερωτηματολόγια και το πείραμα στον προσομοιωτή οδήγησης και από την άλλη πλευρά η διαδικασία **να μην είναι πολύ απαιτητική για τους συμμετέχοντες είτε σωματικά είτε ψυχικά** (ειδικά για τα άτομα με νευρολογικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες). Για το σκοπό αυτό οι 6 ώρες των

[1] Περίπου 40' καθαρής οδήγησης + 15' δοκιμαστικής οδήγησης + 35' μικρών διαλειμμάτων

συνολικών ιατρικών, νευροψυχολογικών και οδήγησης στον προσομοιωτή δοκιμασιών χωρίστηκαν σε τρεις ημέρες.

Εφαρμογή μιας πρωτότυπης και ολοκληρωμένης διεπιστημονικής μεθοδολογίας στατιστικής ανάλυσης λανθανουσών μεταβλητών

Η δεύτερη καινοτομία της παρούσας Διδακτορικής Διατριβής είναι επίσης μεθοδολογική, προτείνοντας την εφαρμογή **τεσσάρων λανθανουσών μεταβλητών, που καλύπτουν και τους τρεις τομείς αυτής της διεπιστημονικής Διδακτορικής Διατριβής**: «**οδηγική επίδοση»** και **«οδηγικά λάθη»**, που προέρχονται από το πείραμα στον προσομοιωτή οδήγησης, **«νευρολογική κατάσταση»** που εξάγεται από τη νευρολογική βάση δεδομένων και **«νευροψυχολογική κατάσταση»** που προέρχεται από τη νευροψυχολογική βάση δεδομένων, προκειμένου να δημιουργήσουν τέσσερα ΔΜΕ. Οι τέσσερις λανθάνουσες μεταβλητές αναπτύχθηκαν με τη χρήση των πιο κρίσιμων δεικτών (νευρολογικοί, νευροψυχολογικοί, και οδηγικοί) που προέρχονται από τις Αναλύσεις Κύριων Παραγόντων.

Διερευνητική Ανάλυση Κύριων Παραγόντων πραγματοποιήθηκε για να προσδιοριστεί ποιοι οδηγικοί δείκτες είχαν τη μεγαλύτερη συνεισφορά στο να περιγράψουν και να ερμηνεύσουν με τη μεγαλύτερη ακρίβεια τη λανθάνουσα μεταβλητή **«οδηγική επίδοση»**. Οι ακόλουθοι πέντε οδηγικοί δείκτες σχηματίζουν την παράμετρο που **αντανακλά τη λανθάνουσα μεταβλητή «οδηγική επίδοση»:** α) μέση ταχύτητα, β) διακύμανση πλευρικής θέσης, γ) διακύμανση γωνίας τιμονιού, δ) μέση σχέση στο κιβώτιο, και ε) χρόνος για αλλαγή λωρίδας.

Επιπρόσθετα, διερευνητική Ανάλυση Κύριων Παραγόντων πραγματοποιήθηκε για να προσδιοριστεί ποιοι οδηγικοί δείκτες είχαν τη μεγαλύτερη συνεισφορά στο να περιγράψουν και να ερμηνεύσουν με τη μεγαλύτερη ακρίβεια τη λανθάνουσα μεταβλητή **«οδηγικά λάθη»**. Οι ακόλουθοι τέσσερις οδηγικοί δείκτες σχηματίζουν την παράμετρο που αντανακλά **τη λανθάνουσα μεταβλητή «οδηγικά λάθη»:** α) εκτός της λωρίδας, β) χτυπήματα στο στηθαίο ασφαλείας/προστατευτικά κολωνάκια, γ) παραβιάσεις του ορίου ταχύτητας και δ) απότομα φρεναρίσματα.

Βασιζόμενοι στην ίδια προσέγγιση, πραγματοποιήθηκε διερευνητική Ανάλυση Κύριων Παραγόντων για να προσδιοριστεί ποιοι νευροψυχολογικοί δείκτες είχαν τη μεγαλύτερη συνεισφορά στο να περιγράψουν και να ερμηνεύσουν με τη μεγαλύτερη ακρίβεια τη λανθάνουσα μεταβλητή **«νευροψυχολογική κατάσταση»**. Οι ακόλουθοι τέσσερις νευροψυχολογικοί δείκτες σχηματίζουν την παράμετρο που αντανακλά τη **λανθάνουσα μεταβλητή «νευροψυχολογική κατάσταση»**: α) Witkin's Embedded

Figure Test, β) Brief Visuospatial Memory Test, γ) Comprehensive Trail Making Test - 1, και δ) Hopkins Verbal Learning Test.

Επιπροσθέτως, διερευνητική Ανάλυση Κύριων Παραγόντων πραγματοποιήθηκε για να προσδιοριστεί ποιοι νευρολογικοί δείκτες είχαν τη μεγαλύτερη συνεισφορά στο να περιγράψουν και να ερμηνεύσουν με τη μεγαλύτερη ακρίβεια τη λανθάνουσα μεταβλητή **«νευρολογική κατάσταση»**. Τέλος, οι ακόλουθοι τέσσερις νευρολογικοί δείκτες σχηματίζουν την παράμετρο που αντανακλά τη **λανθάνουσα μεταβλητή «νευρολογική κατάσταση»**: α) Tandem Walking Errors, β) Tandem Walking Time, γ) Patient Health Questionnaire (PHQ-9) και δ) Foot Tapping Errors.

Η ανάλυση λανθανουσών μεταβλητών επέτρεψε ένα σημαντικό επιστημονικό βήμα προς τα εμπρός, από αποσπασματικές αναλύσεις σε μια βαθύτερη και συνδυαστική ανάλυση **της διεπιστημονικής αλληλεπίδρασης** μεταξύ των παραγόντων κινδύνου, της νευρολογικής κατάστασης, της νευροψυχολογικής κατάστασης, των οδηγικών επιδόσεων, των οδηγικών λαθών, του χρόνου αντίδρασης και της πιθανότητας ατυχήματος σε απρόσμενα συμβάντα.

Θεωρείται μια μεθοδολογική πρωτοτυπία της Διδακτορικής Διατριβής, ότι οι λανθάνουσες μεταβλητές που αντανακλούν το νευρολογικό και νευροψυχολογικό επίπεδο (νευρολογική κατάσταση και νευροψυχολογική κατάσταση) αλληλεπιδρούν με άλλες λανθάνουσες μεταβλητές οδήγησης (οδηγικές επιδόσεις, λάθη οδήγησης) και με άλλες παρατηρούμενες οδηγικές μεταβλητές όπως ο χρόνος αντίδρασης και η πιθανότητα ατυχήματος.

Ποσοτικοποίηση της επιρροής των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες, στη συμπεριφορά κυκλοφορίας και ασφάλειας των οδηγών

Η τρίτη καινοτομία είναι η ποσοτικοποίηση της επιρροής των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες, στη συμπεριφορά κυκλοφορίας και ασφάλειας των οδηγών, κάτι που θεωρείται ότι είναι ο πυρήνας αυτής της Διδακτορικής Διατριβής, σχετικά με τα βασικά ερευνητικά ερωτήματα. Τα τρία πρώτα βήματα στατιστικής ανάλυσης, αποκαλύπτουν **στατιστικά σημαντικές διαφορές μεταξύ της ομάδας των ασθενών με νευρολογικές παθήσεις που προσβάλλουν τις νοητικές λειτουργίες και των υγιών με παρόμοια δημογραφικά χαρακτηριστικά σε αρκετές παραμέτρους οδηγικής επίδοσης**.

Ειδικότερα τα Γενικευμένα Γραμμικά Μοντέλα Παλινδρόμησης που εξήχθησαν, έδειξαν ότι και **οι τρεις ομάδες ασθενών βρέθηκαν να οδηγούν σε σημαντικά χαμηλότερη μέση ταχύτητα** (πάνω από 20% χαμηλότερη) και διατηρούσαν μεγαλύτερες χρονοαποστάσεις (πάνω από 20% μεγαλύτερες) σε σύγκριση με τους υγιείς οδηγούς της ομάδας ελέγχου στις αγροτικές και αστικές οδούς, τόσο σε χαμηλούς όσο και σε υψηλούς κυκλοφοριακούς φόρτους. Αναλύοντας τα πλευρικά μέτρα ελέγχου παρατηρήθηκε ότι **οι ασθενείς με MCI οδήγησαν πιο κοντά στο δεξιό άκρο του δρόμου** στην αστική περιοχή και στους δύο κυκλοφοριακούς φόρτους και, στην αγροτική περιοχή, η ομάδα PD είχε χαμηλή διακύμανση της γωνίας του τιμονιού σε υψηλό φόρτο κυκλοφορίας λόγω της χαμηλής τους ταχύτητας, της συντηρητικής οδήγησής τους και ίσως αυτό να είναι μια αντισταθμιστική συμπεριφορά.

Με τη χρήση των Γενικευμένων Γραμμικών Μοντέλων Παλινδρόμησης αναφορικά με το χρόνο αντίδρασης των ασθενών σε απρόσμενα συμβάντα, παρατηρήθηκε **ότι οι ασθενείς είχαν σημαντικά μεγαλύτερους χρόνους αντίδρασης σε όλες τις συνθήκες που εξετάστηκαν,** σε σύγκριση με την ανέπαφη νοητικά ομάδα. Αξίζει να επισημανθεί ότι οι χρόνοι αντίδρασής τους ήταν περισσότερο από 40% χειρότεροι από εκείνους της ομάδας ελέγχου. Προχωρώντας στην πιθανότητα ατυχήματος, **σημαντικά υψηλότερη πιθανότητα ατυχήματος ανιχνεύθηκε για την ομάδα AD** σε όλες τις εξεταζόμενες συνθήκες (η πιθανότητα ατυχήματος για την ομάδα AD ήταν πάνω από 20%) και για την ομάδα των MCI και PD μόνο σε αστική περιοχή. Αντίθετα, οι ασθενείς και οι υγιείς δεν είχαν διαφορές στα οδηγικά λάθη που έκαναν κατά τη διάρκεια της οδήγησης στο πείραμα του προσομοιωτή οδήγησης.

Αυτό το μέρος της ανάλυσης δείχνει περαιτέρω πως η εξέλιξη της νόσου (δηλαδή από την MCI στην AD) οδηγεί σε περισσότερο έντονα προβλήματα και δυσκολίες στην οδήγηση σε αρκετές οδηγικές παραμέτρους ελέγχου. Ενώ η μειωμένη μέση ταχύτητα, οι αυξημένοι χρονικοί διαχωρισμοί και η οδήγηση πιο κοντά στο δεξί σύνορο του δρόμου μπορεί να θεωρηθεί επωφελής για την οδική ασφάλεια, δεδομένου ότι αντανακλά ένα πιο συντηρητικό και προσεκτικό μοτίβο οδήγησης, **η αρνητική επίδραση στο χρόνο αντίδρασης και την πιθανότητας ατυχήματος υπερνικά όλα αυτά και οδηγεί σε συνολικά επικίνδυνη οδηγική συμπεριφορά.**

Η ανάλυση διακύμανσης ANOVA διερεύνησε τα ερωτηματολόγια συμπεριφοράς και ανέφερε ότι οι οδηγοί με MCI, AD και PD **έχουν επίγνωση των μειωμένων οδηγικών τους επιδόσεων**. Με βάση τα παραπάνω, εξάγεται το συμπέρασμα ότι οι εξεταζόμενες νοητικές διαταραχές οδηγούν σε προβληματική οδηγική συμπεριφορά

που όμως **αναπτύσσει στρατηγικές αντιστάθμισης της οδηγικής συμπεριφοράς**, λόγω της επίγνωσης των οδηγών για την οδηγική τους επίδοση, που εκφράζεται με μειωμένη ταχύτητα, αύξηση των χρονικών διαχωρισμών από τον προπορευόμενο, πιο συντηρητική τοποθέτηση του οχήματος (και, κατά συνέπεια, λιγότερους ελιγμούς και προσπεράσεις).

Τέλος, προχωρούμε στην ανάλυση ΔΜΕ σχετικά με τα **χαρακτηριστικά της συμπεριφοράς των οδηγών** (παρατηρούμενες μεταβλητές «χρόνος αντίδρασης» και «πιθανότητα ατυχήματος», και λανθάνουσες μεταβλητές «οδηγική επίδοση» και «οδηγικά λάθη»), τα βασικά ποσοτικά συμπεράσματα για τους προβλεπτικούς παράγοντες της ανάλυσης ΔΜΕ σχετικά με νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες.

Οι οδηγοί με MCI, AD και PD συνολικά οδήγησαν σημαντικά χειρότερα από ό,τι οι υγιείς μάρτυρες σχετικά με τις τέσσερις εξεταζόμενες παραμέτρους οδηγικής συμπεριφοράς. Πιο συγκεκριμένα, συνδέθηκαν με σημαντικά χαμηλότερα επίπεδα της λανθάνουσας μεταβλητής «οδηγική επίδοση», που αντανακλούσε ένα ευρύ φάσμα δεικτών οδήγησης και συσχετίστηκαν με σημαντικά χειρότερο «χρόνο αντίδρασης». Επίσης, οι κλινικές συνθήκες της AD και PD συνδέθηκαν με αρνητική επιρροή στην «πιθανότητα ατυχήματος». Τέλος, καμία από τις κλινικές ομάδες δεν έδειξε σημαντικά αυξημένη ποσότητα «οδηγικών λαθών».

Τα ευρήματα σχετικά με τους ασθενείς με AD και PD ήταν στην αναμενόμενη κατεύθυνση και είναι σύμφωνα με προηγούμενες έρευνες που δείχνουν δυσκολίες στην οδηγική επίδοση των δύο κλινικών ομάδων τόσο στην περίπτωση της οδήγησης σε προσομοιωτή όσο και σε περιπτώσεις αξιολόγησης της οδήγησης σε πραγματικές συνθήκες στο δρόμο. Όσον αφορά τους ασθενείς με MCI, η παρούσα ανάλυση με τη χρήση λανθανουσών μεταβλητών που αξιολογούν ένα ευρύ φάσμα οδηγικών δεικτών, δείχνει **μια σημαντικά χειρότερη οδηγική επίδοση** σε σύγκριση με τους υγιείς μάρτυρες. Διαπιστώθηκε ότι παρά τους χειρότερους χρόνους αντίδρασης, τις οδηγικές τους επιδόσεις και την πιθανότητα ατυχήματος, τα οδηγικά τους λάθη δε διέφεραν σημαντικά από τις υγιείς μάρτυρες.

Παρόλα αυτά, **η παράμετρος που καθιστά πρωτότυπη την ανάλυση αυτή** είναι η ανάπτυξη λανθανουσών μεταβλητών για την αξιολόγηση της οδηγικής συμπεριφοράς, που περιλαμβάνει μια ποικιλία δεικτών. Επιπλέον, ένα άλλο καινοτόμο στοιχείο είναι η εφαρμογή των πολυμεταβλητών ΔΜΕ, που κάνουν την εξερεύνηση της **μοναδικής και εξατομικευμένης επίπτωσης** των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες εφικτή στην οδηγική συμπεριφορά.

Η λανθάνουσα μεταβλητή **«νευροψυχολογική κατάσταση»** είχε θετική επίδραση σε όλες τις μεταβλητές οδηγικής συμπεριφοράς. Η λανθάνουσα μεταβλητή **«νευρολογική κατάσταση»** είχε σημαντική θετική επίδραση στην «οδηγική επίδοση», στα «οδηγικά λάθη» και στο χρόνο αντίδρασης, ενώ η επίδρασή της στην πιθανότητα ατυχήματος δεν ήταν στατιστικά σημαντική. Η νευρολογική και νευροψυχολογική κατάσταση φαίνεται να επηρεάζει την οδηγική συμπεριφορά καθώς αντανακλά το επίπεδο του συντονισμού των κινήσεων του ανθρώπινου σώματος και της σταθερότητας της συμπεριφοράς αφενός, και αφετέρου λειτουργεί σε γνωστικά πεδία, όπως η μνήμη εργασίας, πληροφορίες για την ταχύτητα επεξεργασίας και την οπτική προσοχή.

Η συνομιλία με το συνεπιβάτη δε βρέθηκε να έχει κρίσιμη επίδραση στην οδηγική επίδοση, στα οδηγικά λάθη και στην πιθανότητα ατυχήματος, αποδεικνύοντας ότι οι οδηγοί δε μεταβάλλουν την οδηγική συμπεριφορά τους κάτω από αυτό το είδος της απόσπασης της προσοχής, αλλά έχουν χειρότερο χρόνο αντίδρασης. Από την άλλη πλευρά, **η χρήση του κινητού τηλεφώνου** είχε σημαντική αρνητική επίπτωση στην «οδηγική επίδοση», στο «χρόνο αντίδρασης», στην «πιθανότητα ατυχήματος» αλλά όχι στα «οδηγικά λάθη». Η αρνητική επίδραση της χρήσης του κινητού τηλεφώνου στην οδηγική συμπεριφορά μπορεί να εξηγηθεί **προσθέτοντας το ρόλο δύο συνεργατικών μηχανισμών**: πρώτον, λόγω του όγκου των σωματικών και νοητικών πόρων, που οι οδηγοί διαθέτουν για να οδηγήσουν και να μιλήσουν ταυτόχρονα και στο κινητό τηλέφωνο και δεύτερον, υιοθετώντας μια αντισταθμιστική συμπεριφορά, που ισοφαρίζει μόνο εν μέρει τις επιπτώσεις της απόσπασης της προσοχής στη συνολική οδηγική συμπεριφορά.

Η προχωρημένη ηλικία είχε σημαντική αρνητική επίπτωση στην «οδηγική επίδοση», στα «οδηγικά λάθη» και στο χρόνο αντίδρασης, ενώ ο αντίκτυπός της στην πιθανότητα ατυχήματος δεν ήταν στατιστικά σημαντικός. Όπως υποδεικνύεται από την σημαντική αρνητική επιρροή που παρατηρήθηκε στα τρια μοντέλα ΔΜΕ, ο ρόλος της προχωρημένης ηλικίας στην οδηγική συμπεριφορά φαίνεται να γενικεύεται και στην ομάδα ελέγχου της μελέτης, η οποία περιελάμβανε τα νοητικά άθικτα άτομα.

Η αστική περιοχή είχε σημαντική αρνητική επίπτωση στην «οδηγική επίδοση», ενώ ο αντίκτυπός της στα «οδηγικά λάθη», στο χρόνο αντίδρασης και στην πιθανότητα ατυχήματος ήταν θετική. Ενδεχομένως, το πιο σύνθετο περιβάλλον της αστικής περιοχής **αύξησε τα επίπεδα προσοχής**, οδηγώντας έτσι σε λιγότερα λάθη οδήγησης, καλύτερους χρόνους αντίδρασης και μικρότερη πιθανότητα ατυχήματος.

Οι κυκλοφοριακές συνθήκες χαμηλού φόρτου επηρέασαν θετικά την «οδηγική επίδοση», ενώ δεν είχε καμία σημαντική επίδραση στα «οδηγικά λάθη», στο χρόνο αντίδρασης και στην πιθανότητα ατυχήματος, το οποίο ήταν ένα ενδιαφέρον εύρημα. Σε συνθήκες υψηλού κυκλοφοριακού φόρτου, το πολύπλοκο οδικό περιβάλλον, συμπεριλαμβανομένων **πολλών αλληλεπιδράσεων μεταξύ των οχημάτων** έχει μια εντελώς αρνητική επίδραση στην οδηγική επίδοση.

Συγκριτική ανάλυση επίδοσης οδηγών με διαφορετικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες

Η τέταρτη καινοτομία της παρούσας Διδακτορικής Διατριβής παράγεται επίσης από τα βασικά ερευνητικά ερωτήματα και αφορά **τη συγκριτική ανάλυση των επιδόσεων** των οδηγών με διάφορες νευρολογικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες. Στο προηγούμενο υποκεφάλαιο, τα τέσσερα ΔΜΕ που περιλαμβάνουν τις τρεις εξεταζόμενες νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες έδειξαν **σημαντικά χειρότερο χρόνο αντίδρασης και «οδηγικές επιδόσεις»** για τους οδηγούς με MCI, AD και PD σε σύγκριση με τους υγιείς μάρτυρες. Επιπλέον, οι κλινικές συνθήκες AD και PD συνδέθηκαν με **αρνητική επιρροή για την πιθανότητα ατυχήματος**.

Πηγαίνοντας ένα βήμα προς τα εμπρός, οι εκτιμήσεις των παραμέτρων των τεσσάρων ΔΜΕ δίνει την ευκαιρία να συγκριθούν οι τρεις εξεταζόμενες νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες μεταξύ τους, όσον αφορά την επιρροή τους στα τέσσερα εξεταζόμενα χαρακτηριστικά οδηγικής συμπεριφοράς. Πρώτον, **η επίδραση των PD και AD είναι πολύ πιο επιζήμια όσον αφορά το χρόνο αντίδρασης**, σε σύγκριση με τις επιπτώσεις της MCI. Ειδικότερα, η PD οδηγεί σε αύξηση 0,38 δευτερολέπτων του χρόνου αντίδρασης, η AD οδηγεί σε αύξηση περίπου 0,33 δευτερολέπτων του χρόνου αντίδρασης και η MCI σε αύξηση 0.1 δευτερολέπτου. Η διαπίστωση αυτή έχει μεγάλη σημασία όσον αφορά την οδική ασφάλεια, επειδή οι υψηλότεροι χρόνοι αντίδρασης είναι πολύ πιθανόν να οδηγήσουν σε μεγαλύτερη πιθανότητα ατυχήματος.

Πράγματι, προχωρώντας στο επόμενο ΔΜΕ, η συγκριτική ανάλυση των τριών εξεταζόμενων νευρολογικών ασθενειών που επηρεάζουν τις νοητικές λειτουργίες ακολουθεί το ίδιο μοτίβο. Η MCI δεν είχε καμία σημαντική επίδραση στην πιθανότητα ατυχήματος, ενώ **η AD αύξησε την πιθανότητα ατυχήματος κατά 16% και η PD κατά 10%**. Οι χειρότεροι χρόνοι αντίδρασης των ασθενών με AD και PD οδήγησε σε

μεγαλύτερη πιθανότητα ατυχήματος. Είναι αξιοσημείωτο ότι, παρόλο που η PD είχε μεγαλύτερη αρνητική επιρροή στο χρόνο αντίδρασης από την AD, η AD οδήγησε σε 1,6 φορές μεγαλύτερη πιθανότητα ατυχήματος από την PD. Αναφορικά με τα οδηγικά λάθη, καμία από τις τρεις εγκεφαλικές παθήσεις δεν είχε σημαντική επίδραση σε αυτά, ενώ **η AD είχε την ισχυρότερη αρνητική επιρροή στην οδηγική επίδοση**, ακολουθούμενη από την MCI, και έπεται η PD.

Συνοψίζοντας, οι τέσσερις συγκριτικές αναλύσεις οδηγικής συμπεριφοράς των οδηγών με διάφορες νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες, έδειξαν τους ασθενείς με AD ως **την πιο προβληματική ομάδα των οδηγών με το χειρότερο οδηγικό προφίλ** (μεγαλύτερη επιρροή στην πιθανότητα ατυχήματος και στην οδηγική επίδοση, ενώ είχαν και το μεγαλύτερο χρόνο αντίδρασης), ακολουθούμενη από την PD, ενώ η ομάδα των MCI θεωρείται ασφαλέστερη σε σύγκριση με τις άλλες δύο εξεταζόμενες εγκεφαλικές παθολογίες.

Προσδιορισμός της επιρροής της απόσπασης της προσοχής στην οδηγική επίδοση των ασθενών με εγκεφαλικές παθολογίες

Τέλος, **η πέμπτη καινοτομία** αυτής της Διδακτορικής Διατριβής αφορά την επίδραση της απόσπασης της προσοχής στην οδηγική επίδοση των οδηγών με MCI, AD και PD, διερευνώντας την οδήγηση με ταυτόχρονη συνομιλία με ένα υποτιθέμενο συνεπιβάτη και την οδήγηση με ταυτόχρονη συνομιλία με μια φορητή κινητή συσκευή τηλεφώνου. Η διερεύνηση και ποσοτικοποίηση της επίδρασης της απόσπασης της προσοχής στους οδηγούς με MCI, AD και PD δεν έχει αντιμετωπιστεί μέχρι σήμερα από τη διεθνή επιστημονική κοινότητα. Φάνηκε ότι οι καταστάσεις απόσπασης της προσοχής σε γενικές γραμμές δεν είχαν τόσο σημαντική επίδραση σε αρκετούς δείκτες οδηγικής επίδοσης στην ομάδα των υγιών οδηγών, σε αντίθεση με τα ευρήματα που προέκυψαν για τις **ομάδες των ασθενών μέσω των αναλύσεων παλινδρόμησης, στις οποίες η επιρροή της απόσπασης της προσοχής και ιδιαίτερα η χρήση του κινητού τηλεφώνου, ήταν ιδιαιτέρως επιζήμια όσον αφορά την οδηγική συμπεριφορά.**

Ειδικότερα, ο χρόνος αντίδρασης των οδηγών με εγκεφαλικές παθολογίες αυξήθηκε περισσότερο από 30%, στην κατάσταση οδήγησης με τη χρήση του κινητού τηλεφώνου, (οι ασθενείς με AD αύξησαν τους χρόνους αντίδρασής τους κατά 50%, εκτοξεύοντάς τους στα 3.5 δευτερόλεπτα), ενώ στην ομάδα των υγιών, η αντίστοιχη αύξηση ήταν περίπου 10%. Επιπλέον, η ομάδα των οδηγών με νευρολογικές ασθένειες

που επηρεάζουν τις νοητικές λειτουργίες είχε **μια εντυπωσιακή αύξηση του κινδύνου να εμπλακούν σε ατύχημα ενώ χρησιμοποιούσαν το κινητό τηλέφωνο** (στους ασθενείς με AD και PD υπήρχε πάνω από 30% πιθανότητα ατυχήματος). Συγκεκριμένα, παρατηρήθηκε το προαναφερθέν μοτίβο των ευρημάτων, παρά το γεγονός ότι οι οδηγοί με νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες προσπάθησαν να προσαρμόσουν τη συμπεριφορά οδήγησής τους, μειώνοντας σε σημαντικό βαθμό την ταχύτητα οδήγησης και την χρονοαπόσταση κατά τη χρήση του κινητού τηλεφώνου.

Από την άλλη πλευρά, η ομάδα ελέγχου δεν επηρεάστηκε από την απόσπαση της προσοχής με κινητό τηλέφωνο. Επίσης, **η συνομιλία με συνεπιβάτη είχε αντίκτυπο** στην οδηγική επίδοση των ασθενών, **αλλά μικρότερης κλίμακας** σε σύγκριση με την περίπτωση της χρήσης του κινητού τηλεφώνου. Ειδικότερα, στο πλαίσιο αυτής της συνθήκης οδήγησης υπήρχε μια όξυνση της διαφοράς στο χρόνο αντίδρασης και στην πιθανότητα ατυχήματος μεταξύ της ομάδας των ασθενών και των νοητικά ανέπαφων συμμετεχόντων, αλλά μόνο για τις ομάδες MCI και PD σε αστική περιοχή. Συνολικά, η συνομιλία με συνεπιβάτη δε φαίνεται να έχει αρνητικές συνέπειες στην πλειονότητα των εξετασθέντων συνθηκών οδήγησης.

Το οδηγικό προφίλ των ατόμων με νευρολογικές ασθένειες που προσβάλλουν τις νοητικές λειτουργίες, σύμφωνα με τα αποτελέσματα αυτά, **άλλαξε ριζικά υπό την πιο απαιτητική κατάσταση οδήγησης που περιλαμβάνει τη χρήση του κινητού τηλεφώνου**. Συμπεραίνεται ότι η παράλληλη εκτέλεση δύο εργασιών, δηλαδή της οδήγησης και της χρήσης ενός κινητού τηλεφώνου, **τοποθετεί την ομάδα των οδηγών με εγκεφαλικές παθήσεις σε ιδιαίτερα ευάλωτη θέση,** λόγω της ανάγκης διαίρεσης της προσοχής τους (κάτι στο οποίο έχουν δυσκολία) στο πλαίσιο αυτής της απαιτητικής συνθήκης οδήγησης. Σύμφωνα με αυτήν την προσέγγιση, η οδηγική κατάσταση με συνομιλία με συνεπιβάτη, που είναι μέτριας δυσκολίας και απαιτεί επίσης από τους οδηγούς ένα ορισμένο επίπεδο διαίρεσης της προσοχής, είχε αυξημένη αρνητική επιρροή στην οδηγική επίδοση των ατόμων με AD και PD, αλλά σε μικρότερο βαθμό συγκριτικά με την περίπτωση του κινητού τηλεφώνου.

Αξίζει να σημειωθεί ότι στην κατάσταση οδήγησης με τη συνομιλία με κινητό τηλέφωνο, οι οδηγοί με MCI, AD και PD εφάρμοσαν αντισταθμιστική στρατηγική για τη μείωση της ταχύτητας τους, αλλά σε αυτή την περίπτωση το αποτέλεσμα δεν ήταν επιτυχές, όπως φαίνεται από την έντονη αύξηση της πιθανότητας ατυχήματος.

Μελλοντική έρευνα

Στην παρούσα Διδακτορική Διατριβή αναπτύχθηκε μια πρωτότυπη μεθοδολογική και στατιστική ιδέα για την ανάλυση της επίδρασης των νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες, των οδικών και κυκλοφοριακών χαρακτηριστικών και της απόσπασης της προσοχής του οδηγού στην οδηγική συμπεριφορά. Η εφαρμογή αυτής της μεθοδολογίας αποκάλυψε επίσης μια σειρά ανοιχτών θεμάτων για περαιτέρω έρευνα στον διεπιστημονικό τομέα της οδηγικής συμπεριφοράς και των εγκεφαλικών παθολογιών.

Πρώτον, σε μελλοντικές έρευνες θα μπορούσε να ενισχυθεί το μέγεθος του δείγματος **όσον αφορά τον πληθυσμό** (περισσότεροι συμμετέχοντες με MCI, AD και PD), **όσον αφορά το είδος των νευρολογικών παθήσεων** που επηρεάζουν τις νοητικές λειτουργίες (συμμετέχοντες με REM διαταραχή συμπεριφοράς ύπνου, μετωποκροταφική άνοια, εγκεφαλικό επεισόδιο, σκλήρυνση κατά πλάκας κ.λ.π. έχουν μεγάλο ενδιαφέρον όσον αφορά την οδηγική συμπεριφορά τους και θα μπορούσαν να εισαχθούν στην έρευνα) και **όσον αφορά την τοποθεσία και την προέλευση** (οι οδηγοί MCI, AD και PD στην Ελλάδα μπορεί έχουν διαφορές στην οδηγική συμπεριφορά συγκρινόμενοι με οδηγούς των ίδιων παθήσεων του εγκεφάλου που ζουν σε άλλες χώρες).

Επιπλέον, θα είχε ενδιαφέρον μια μελλοντική έρευνα που θα **αξιολογεί περιοδικά** την οδηγική συμπεριφορά των ασθενών με εγκεφαλικές παθήσεις σε βάθος χρόνου (π.χ. πείραμα προσομοιωτή οδήγησης σε συνδυασμό με νευρολογικές και νευροψυχολογικές αξιολογήσεις, κάθε χρόνο), προκειμένου **να προσδιοριστεί σε ποιο βαθμό η εξέλιξη της νόσου επιδεινώνει τους διάφορους οδηγικούς δείκτες.**

Η πρωτοποριακή μεθοδολογική προσέγγιση, η οποία αποτελείται από την εφαρμογή των ΔΜΕ βασιζόμενη στη δημιουργία λανθανουσών (μη παρατηρούμενων) μεταβλητών, θα μπορούσε να αναπτυχθεί περαιτέρω και να εφαρμοστεί και σε άλλα πιθανώς γενικότερα επιστημονικά πεδία οδηγικής συμπεριφοράς. Επίσης μπορεί να εκτιμηθεί η επιρροή πολλών **άλλων παραμέτρων οδήγησης, ιατρικών και νευροψυχολογικών** στο χρόνο αντίδρασης, στην πιθανότητα ατυχήματος, στις οδηγικές επιδόσεις, και στα λάθη των οδηγών με εγκεφαλικές διαταραχές, καθώς και άλλων δημογραφικών χαρακτηριστικών όπως το φύλο, το μορφωτικό επίπεδο, και η οδηγική εμπειρία. Επίσης, **θα μπορούσαν να αναπτυχθούν και να διερευνηθούν περισσότερες λανθάνουσες μεταβλητές**, ανάλογα με τη βάση δεδομένων και τα ειδικά ερευνητικά ερωτήματα.

Τέλος, θα πρέπει να αναπτυχθεί αυτή η καινοτόμα μεθοδολογία σε διαφορετικούς τύπους αξιολόγησης της συμπεριφοράς των οδηγών με νευρολογικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες. Πιο συγκεκριμένα, όπως η εφαρμογή των ΔΜΕ χρειάζεται ένα μεγάλο όγκο δεδομένων με αρκετές παραμέτρους, τα ΔΜΕ μπορούν **να αναπτυχθούν σε μελέτες έρευνας πεδίου και σε μελέτες πραγματικής οδήγησης στο δρόμο** προκειμένου να εκτιμηθεί η επιρροή των παραγόντων κινδύνου απευθείας στη συνολική οδηγική επίδοση και συμπεριφορά κυκλοφορίας και ασφάλειας των ασθενών με MCI, AD ή PD.

Μελλοντικές προκλήσεις

Τα οφέλη από την παρούσα Διδακτορική Διατριβή είναι **και επιστημονικά και κοινωνικοοικονομικά**. Τα επιστημονικά οφέλη αφορούν τη βελτίωση της υπάρχουσας γνώσης για τους μηχανισμούς μειωμένης οδηγικής επίδοσης και της οδηγικής επίδοσης σε απρόσμενα συμβάντα, καθώς και τις μεθοδολογίες για το σχεδιασμό και τη διεξαγωγή πειραμάτων σε προσομοιωτή. Τα κοινωνικοοικονομικά οφέλη αφορούν τη βελτίωση της οδικής ασφάλειας, που θα πρέπει να επιτευχθεί μόλις οι μηχανισμοί προβληματικής οδηγικής συμπεριφοράς λόγω νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες γίνουν καλύτερα και βαθύτερα κατανοητοί και αντιμετωπιστούν καταλλήλως.

Τα αποτελέσματα αυτής της Διδακτορικής Διατριβής μπορούν **να αξιοποιηθούν για την ανάπτυξη συστάσεων και μέτρων για την αντιμετώπιση** όλων των πτυχών της προβληματικής οδήγησης λόγω νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες, όπως ο έγκαιρος εντοπισμός του προβλήματος, η αποτελεσματικότητα των μέτρων βελτίωσης της οδηγικής συμπεριφοράς των ηλικιωμένων και των ατόμων με εγκεφαλικές διαταραχές, η εκπαίδευση και τα προγράμματα κατάρτισης για ασφαλή οδήγηση και αντιμετώπιση απρόσμενων συμβάντων, τα ειδικά μέτρα για συγκεκριμένες ομάδες υψηλού κινδύνου και τα ιατρικά και νευρολογικά κριτήρια για την ασφαλή οδήγηση και η παρακολούθηση των «επικίνδυνων» οδηγών.

Μελλοντικός στόχος είναι η βελτίωση της οδηγικής επίδοσης των προβληματικών οδηγών γενικά,αλλά και σε απρόσμενα συμβάντα ειδικότερα, καθώς και **η προώθηση της γνώσης** των καταστάσεων οδήγησης που θα πρέπει να αποφεύγεται από άτομα που ανήκουν σε ευπαθείς ομάδες. Κατά συνέπεια, τα αποτελέσματα της Διδακτορικής Διατριβής, εκτός από έρευνα στους τομείς της οδικής ασφάλειας και της ιατρικής/νευρολογίας, είναι ιδιαίτερου ενδιαφέροντος και στις ακόλουθες ομάδες:

» **Στους ιθύνοντες της οδικής ασφάλειας** που εμπλέκονται στις διαδικασίες εκπαίδευσης των οδηγών, τη χορήγηση αδειών και την αξιολόγησή τους.
» **Στους νευρολόγους ή άλλους επαγγελματίες** που εμπλέκονται στη θεραπεία, παρακολούθηση και αξιολόγηση των ατόμων με νευρολογικές παθήσεις που επηρεάζουν τις νοητικές λειτουργίες.
» **Στις οικογένειες των ηλικιωμένων** και των ατόμων με εγκεφαλικές παθήσεις, (ιδίως μέσω δημόσιων εκστρατειών, της διάχυσης των πληροφοριών κ.λ.π.).

Ο προσδιορισμός επιτυχημένων έγκαιρων προβλεπτικών παραμέτρων της οδηγικής ικανότητας σε άτομα με AD στα αρχικά στάδια ή MCI θα επιτρέψει την ανάπτυξη κατευθυντήριων γραμμών και εθνικών πολιτικών πρακτικών βελτίωσης της οδικής ασφάλειας (Παπαγεωργίου, 2016). Είναι σημαντικό να αναφέρουμε ότι **κάθε οδηγός με νευρολογική ασθένεια που επηρεάζει τις εγκεφαλικές λειτουργίες θα πρέπει να αντιμετωπίζεται ξεχωριστά, μέσα από μια σύγχρονη διεπιστημονική αξιολόγηση οδήγησης** συμπεριλαμβανομένων των ιατρικών, νευρολογικών και νευροψυχολογικών κριτηρίων για την ασφαλή οδήγηση και την αξιολόγηση φυσικά της οδηγικής επίδοσης μέσα από πειράματα σε προσομοιωτή οδήγησης, ή σε πειράματα στο δρόμο σε πραγματικές οδηγικές συνθήκες. Επιπλέον, θα πρέπει να είναι σε θετική κατεύθυνση **μια αποτελεσματική παρακολούθηση** των οδηγών που βρίσκονται σε κίνδυνο για την ανάπτυξη μιας υποκείμενης νευρολογικής πάθησης, που σχετίζεται με μη ασφαλή οδήγηση και την ανάπτυξη παρεμβάσεων, που έχουν την ικανότητα να βελτιώσουν, ή να διατηρήσουν την καταλληλότητα για οδήγηση των ηλικιωμένων ατόμων και των οδηγών με εγκεφαλικές παθήσεις.

Εν κατακλείδι, τα αποτελέσματα της παρούσας Διδακτορικής Διατριβής μπορούν εν δυνάμει να συνεισφέρουν σε σημαντική μείωση των οδικών ατυχημάτων και θανάτων, εάν **τα δεδομένα και τα αποτελέσματα αξιοποιηθούν κατάλληλα από τις αρχές προκειμένου να εφαρμόσουν τις κατάλληλες πολιτικές πρακτικές για την οδική ασφάλεια**, όσον αφορά την ευάλωτη ομάδα οδηγών με νευρολογικές ασθένειες που επηρεάζουν τις νοητικές λειτουργίες. Καλύτερη κατανόηση των ιατρικών, και κοινωνικών θεμάτων και θεμάτων συμπεριφοράς, που σχετίζονται με μειωμένη οδηγική ικανότητα λόγω νευρολογικών παθήσεων που επηρεάζουν τις νοητικές λειτουργίες θα οδηγήσει σε ειδική εκπαίδευση των οδηγών και χορήγηση αδειών οδήγησης, σε πιο συγκεκριμένα και αυστηρά κριτήρια για την ανανέωση της άδειας οδήγησης για τα άτομα που ανήκουν στις αυτές ευπαθείς ομάδες, σε καταλληλότερη νομοθεσία, καθώς και εκστρατείες ευαισθητοποίησης του πληθυσμού.

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Chapter One
Introduction

1.1. Motivation

Road accidents constitute a major social problem in modern societies, accounting for more than one million road accidents per year in EU-28 (2.900 per day) with consequences 1,4 million injured and 26.000 fatalities (70 per day) (WHO, 2015). 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, 2013).

The European Commission has adopted an ambitious Road Safety Programme which aims to **cut road deaths in Europe between 2011 and 2020** (EU Commission-Transport-Road Safety, March 2016) (Figure 1.1). The programme sets out a mix of initiatives, at European and national level, focussing on improving vehicle safety, the safety of infrastructure and road users' behaviour.

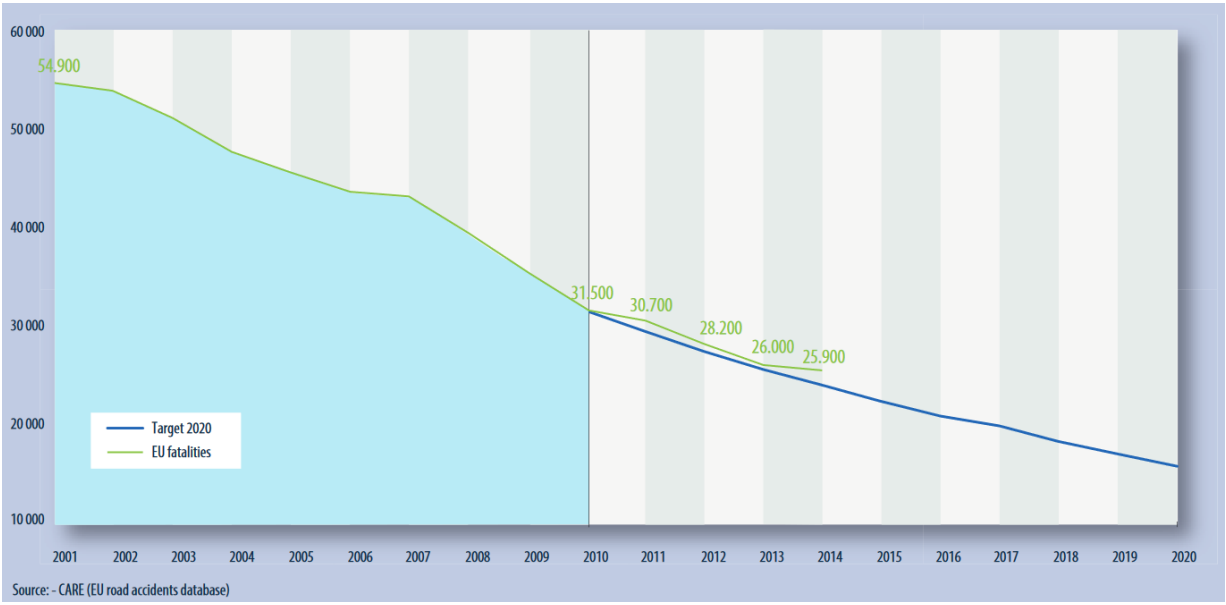


Figure 1.1. Road fatalities in the EU since 2001 (http://ec.europa.eu/roadsafety)

Human factors are the basic causes in 65-95% of road accidents (Sabey and Taylor, 1980; Salmon et al., 2011; Treat, 1980). The accurate evaluation of crash causal factors can provide fundamental information for effective transportation policy, vehicle design, and driver education. Dingus et al., (2016) through a methodology developed at Virginia Tech Transportation Institute (VTTI), suggested that crash causation has shifted dramatically in recent years, with driver-related factors (i.e., error, impairment, fatigue, and distraction) present in almost 90% of crashes. The results also definitively showed that distraction is detrimental to driver safety, with handheld electronic devices having high use rates and risk.

A critical driver-related human factor includes cerebral diseases. A number of **neurological diseases affecting cognitive functions 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).

Executive functions which decline over age are of critical importance regarding driving performance. Diseases affecting a person's brain functioning (e.g. presence of specific brain pathology due to neurological diseases affecting cognitive functions as Alzheimer's disease, Parkinson's disease, cerebrovascular disorders (stroke), effect of pharmaceutical substances used for the treatment of various disturbances), may significantly impair the person's driving performance, especially when unexpected incidents occur. A number of prevalent neurological diseases may be involved, ranging from very mild to severe states that include Parkinson's or Alzheimer's disease, Cerebrovascular disease etc. (Wood et al., 2005; Cordell et al., 2008; Cubo et al., 2009; Frittelli et al., 2009).

Mild Cognitive Impairment (MCI), which is considered to be the predementia stage of various dementing diseases of the brain, is a common neurological 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).

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 et al., 2009), especially when unexpected incidents occur. 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 mild cases and importantly in the very early stages, they may be imperceptible in one's daily routine yet still impact one's driving ability.

Neuropsychological measures pertain to cerebral disease, as well. They are the neurocognitive measures of neurological diseases affecting cognitive functions, and for that reason they are directly linked to driving performance. 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 Raed & Ponjaert-Kristoffersen, 2000, Mathias & Lucas, 2009). These tasks show considerable decline even with normal age and are associated with the probability of accident involvement (Clay et al., 2005, Lunsman et al., 2008).

In summary, various parameters may affect the driving performance of individuals with neurological diseases affecting cognitive functions, including demographic, medical, neurological and neuropsychological parameters. The aforementioned neurological diseases affecting cognitive functions and other related parameters are rather common in the general population, especially in older adults, and **may have an important effect on driving performance**, especially at unexpected incidents, which has not been investigated sufficiently.

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.

1.2. Objectives and scope

This thesis is an inter-disciplinary effort entering the scientific fields of traffic and safety behaviour of drivers on one hand and neurological disease affecting cognitive functions on the other.

The objective of the present inter-disciplinary PhD thesis is the analysis of traffic and safety behaviour of drivers with neurological diseases affecting cognitive functions. More specifically, the impact of certain brain pathologies on driving performance, driving errors, reaction time and accident probability is examined. The driving behaviour is examined in terms of both traffic and safety behaviour and the neurological diseases affecting cognitive functions concern Alzheimer's disease (AD), Parkinson's disease (PD), and Mild Cognitive Impairment (MCI), in their mild stages.

More analytically, the sub-objectives of this PhD thesis are the following:

» **Design and implementation** of a large driving simulator experiment
» **Development** of an original methodology for the assessment of the impact of drivers' neurological diseases affecting cognitive functions on their driving performance taking also into account their neuropsychological and demographic characteristics as well as the main road safety and traffic characteristics.
» **Quantification of the impact** of neurological diseases affecting cognitive functions directly on driving performance, driving errors, reaction time and accident probability
» **Comparative performance analysis** of drivers with different neurological diseases
» **Identification of the impact of distraction** on the performance of drivers with cerebral diseases

The PhD thesis aims to capture the interaction of neurological diseases affecting cognitive functions, other related parameters (i.e. demographic, medical, and neuropsychological) as well as road and traffic conditions, and driver distraction with respect to driving behaviour. The **combined effect of these key parameters** on driving performance, driving errors, reaction time and accident probability **reflects directly road safety** according to the conceptual framework (Figure 1.2).

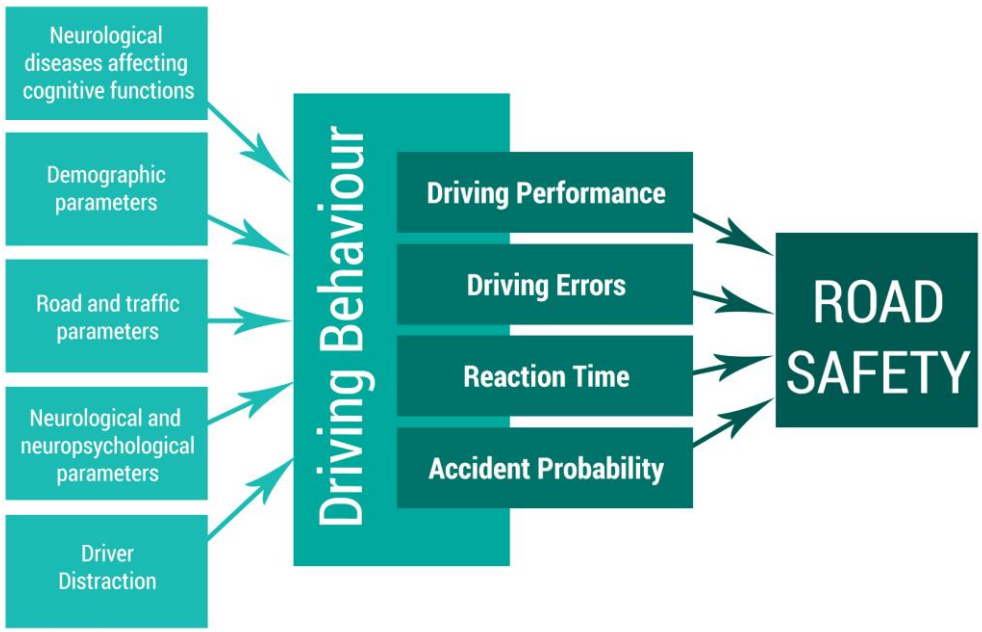


Figure 1.2. Conceptual framework of the PhD thesis

Critical neurological diseases affecting cognitive functions is derived from the literature review, which include both conditions observed in the general population as well as those pertaining to various vulnerable groups, e.g. the elderly, which collectively comprise a significant proportion of the general population. Neuropsychological parameters, which may be critical in everyday driving, are also derived. Driver performance in general is also affected by the road and traffic environment e.g. urban and rural areas, high or low traffic. The selection of parameters therefore concerns:

» **Neurological diseases affecting cognitive functions**
» **Demographic** parameters
» **Road and traffic conditions** parameters
» **Neurological and Neuropsychological** parameters
» **Driver distraction**

Given the interaction of several scientific areas in research of impaired driving due to neurological diseases affecting cognitive functions (transportation engineering, neurology and neuropsychology), this PhD thesis covers a field of research with an obvious and unique interdisciplinary nature, which has not been examined in the past. The analysis of the neurological diseases affecting cognitive functions and other demographic and neuropsychological characteristics in combination with the driving performance of the general population, is a very crucial domain and a scientific challenge at the same time. This PhD thesis' goals, despite their high frequency of appearance in the general population and especially in the elderly, haven't been adequately investigated, especially by applying driving simulator experiments.

1.3. Methodology steps

In order to achieve the objectives of this PhD dissertation, 4 discrete methodological steps were followed (Figure 1.3):

- **Extensive literature** (Chapter 2) covering several fields of the driving performance analysis of drivers with neurological diseases affecting cognitive functions examining in a comprehensive way driving behaviour and road safety, ways to assess driving behaviour, driving simulator characteristics as well as neurological diseases affecting cognitive functions (MCI, AD and PD) and how these cerebral diseases affect driving performance.
- **Methodological approach** (Chapter 3) based on review regarding simulator experiment, neurological and neuropsychological design principles, driving performance, cognitive and neurological state measures and statistical analysis methods.

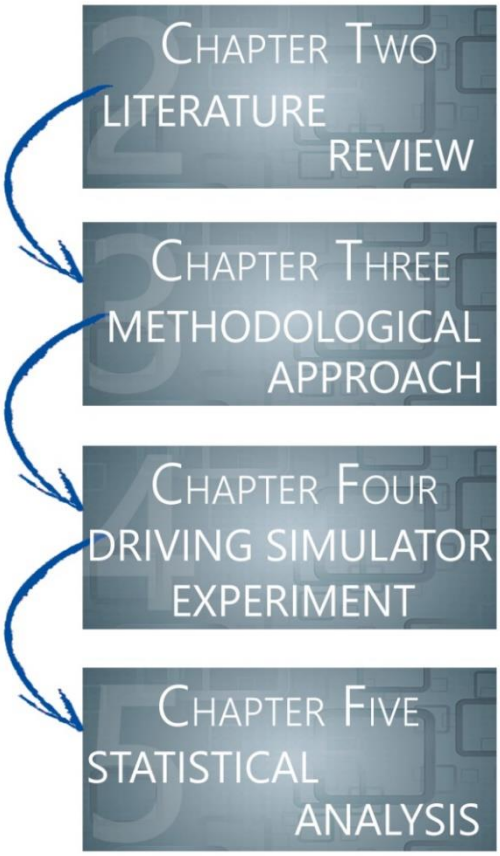


Figure 1.3. Methodology steps

- **Design and implementation** (Chapter 4) of a highly original large-scale driving simulator experiment. Based on the methodology review which was carried out and presented in the previous chapters, a large driving simulator experiment took place at the Department of Transportation Planning and Engineering of the School of Civil Engineering of the National Technical University of Athens aiming to assess driving performance of patients with neurological diseases affecting cognitive functions.
- **Development and application** (Chapter 5) of innovative statistical analysis methodology including five different types of analysis. The data collected from the driving simulator experiment, the neurological and neuropsychological assessments and the respective questionnaires, which configured the master database, are analyzed by means of a dedicated and innovative statistical analysis method. The five steps are: descriptive analysis, analysis of variance, regression modeling techniques, Principal Component Analysis and finally, Structural Equation Modeling techniques using latent variables.

1.4. Innovative scientific contribution and expected benefits

In the present PhD thesis, the performance of drivers with neurological diseases affecting cognitive functions is **explicitly considered for the first time** in the international literature. Because of the integration of the different scientific disciplines involved in impaired driving research (traffic engineering, neurology and neuropsychology), this PhD dissertation covers a research field with an obvious but not previously exploited multidisciplinary nature.

The analysis of the combined effect of neurological diseases affecting cognitive functions and other demographic 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 identification of specific impaired driving mechanisms for each condition examined, in combination with other potential normal or pathological parameters, is expected to provide an improved understanding and new insights regarding the causes of poor driving performance. Such results are expected not only to complement existing knowledge, but also to improve the existing methods of analysis and the tools used in the traffic engineering and neuropsychological research on the topic.

The methodological framework proposed in the present PhD thesis, based on the **combined assessment** of traffic, medical, neurological and neuropsychological parameters on driving performance can be extended to other related 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.

The results of the PhD dissertation **can be exploited in the development of recommendations and measures** for addressing all aspects of impaired driving due to neurological diseases affecting cognitive functions, 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 expected benefits from the present PhD thesis will be **both scientific and socioeconomic**. The scientific benefits concern the enhancement of existing knowledge on impaired driving mechanisms and driving performance at unexpected incidents, as well as the methods for designing and conducting simulator experiments. The socioeconomic benefits concern the improvement of road safety that will be achieved once impaired driving mechanisms due to neurological diseases affecting cognitive functions are better understood and explicitly tackled.

1.5. Structure

The PhD thesis is organized as follows (see also Figure 1.4):

Chapter 2 constitutes the main part of the **entire literature review** and consists of several parts. Starting with a review of driving behaviour parameters, an overview of human factors related to driver behaviour is presented as well as cognitive functions critical for safe driving. Then, as the present research is based on a large driving simulator experiment, information regarding the validity and fidelity of driving simulators are presented. Proceeding to the central part of the literature review, an exhaustive review on driving simulator studies on driving performance of patients with neurological diseases affecting cognitive functions takes place followed by a comparative analysis assessment of the existing driving simulator and on-road experiments, allowing for conclusions to be drawn with respect to methodological and statistical limitations of existing studies and setting the key research questions for the present PhD thesis.

Chapter 3 describes the **methodological approach** of the present research. In the beginning, the most common types of measures are recorded including lateral control, longitudinal control, reaction time, eye movement and workload measures. Then, the theoretical background for the selected statistical analysis is provided and finally a synopsis sets the key methodological research questions.

In **Chapter 4**, all steps of the **driving simulator experiment** are presented including the experimental design, driving scenarios, procedure of the experiment, behaviour and memory questionnaires, data base and processing as well as sample characteristics. More specifically, first the overview of the experiment is presented including information regarding the driving simulator, the inclusion criteria and the simulator sickness. Next, all different driving scenarios are analytically presented, the procedure of the

experiment, the different phases of the experiment are presented and special attempt is given to familiarize with the simulator. Finally, two questionnaires (Driving behaviour Questionnaire and Self-Assessment and Memory) are presented, details regarding the large data base and the processing are recorded while sample characteristics are provided.

Chapter 5 presents the **results of the modeling methodology** that has been developed in order to achieve the objectives set out in this PhD thesis. The methodology consists of several steps as followed below: In the first step, in order to analyze the large dataset, a descriptive analysis took place. Then, regression analysis, through generalized linear models, was developed in order to estimate the effect of neurological diseases affecting cognitive functions, driver, road and traffic risk factors on selected key driving performance parameters. In the third step, principal component analysis took place aiming to estimate the key driving simulator variables that underline driving performance, driving errors, neuropsychological state and neurological state. Finally, structural equation models were implemented in order to investigate all the critical risk factors that affect driving performance, driving errors, reaction time and accident probability.

In **Chapter 6**, **the conclusions** including a synthesis of the results take place answering all the research questions that have been raised in this PhD dissertation and setting out the scientific contributions of the present research. At last, some future steps for further research in the scientific field of driving behaviour and neurological diseases affecting cognitive functions are presented.

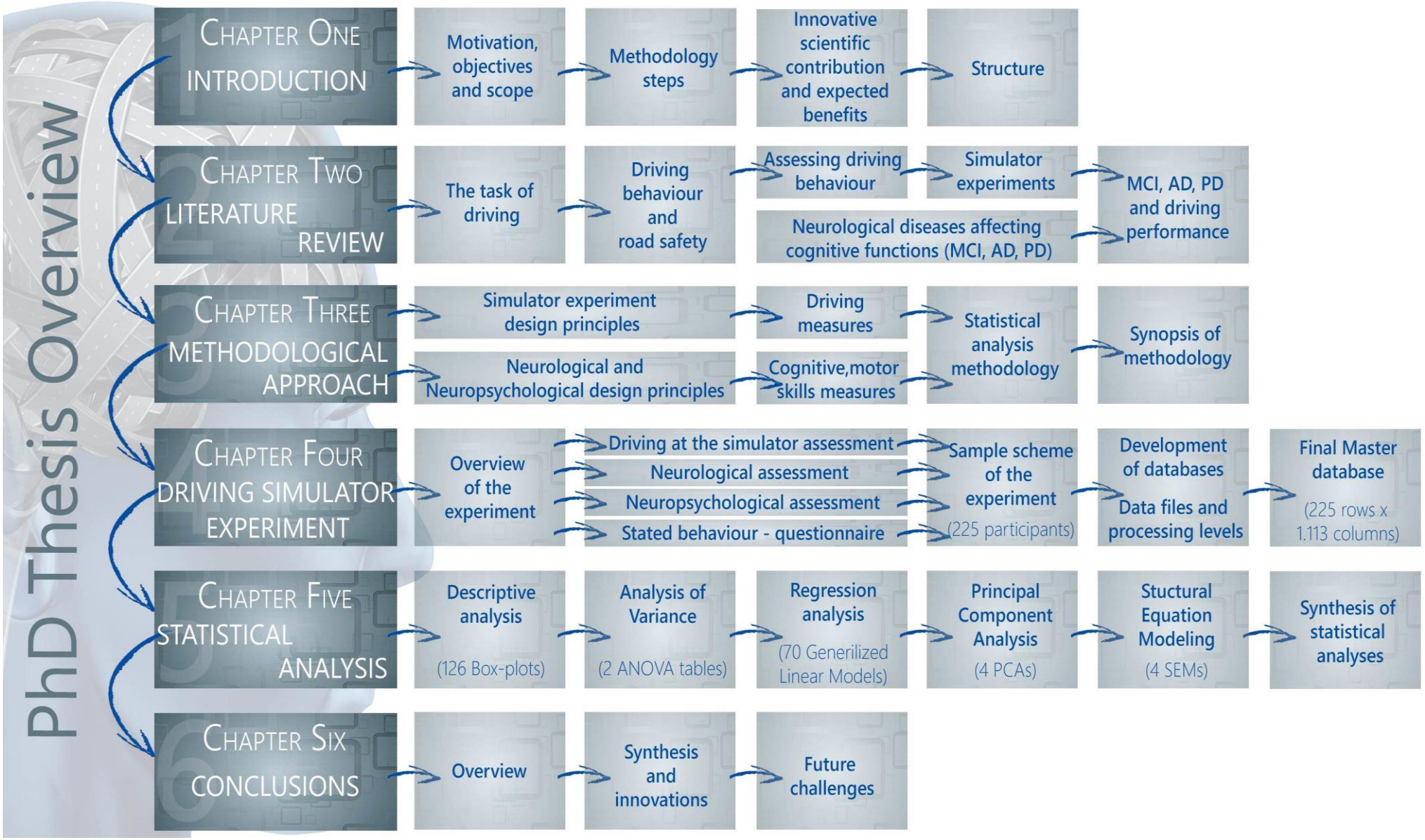


Figure 1.4. Structure of the PhD thesis

Chapter Two
Literature Review

2.1. Driving

2.1.1. Etymology of car driving and automobile

Driving most often refers to the **controlled operation and movement of a motorized vehicle**, such as a car, truck, or bus. The origin of the term driver, as recorded from the 15th century, refers to the occupation of driving working animals, especially pack horses or draft horses.

A car is a **wheeled, self-powered motor vehicle** used for transportation and a product of the automotive industry. Most definitions of the term specify that cars are designed to run primarily on roads, to have seating for one to eight people, to typically have four wheels with tyres, and to be constructed principally for the transport of people rather than goods (Fowler & Fowler, 1976).

The verb "***to drive***" in origin means "**to force to move, to impel by physical force**". It is first recorded of electric railway drivers in 1889 and of a motor-car driver in 1896. Early alternatives were motorneer (Century Dictionary, 1891), motor-man, motor-driver or motorist.

The word "**car**" is believed to originate from the Latin word carrus or carrum ("wheeled vehicle"), or the Middle English word carre (meaning cart, from Old North French). "Motor car" is attested from 1895, and is the usual formal name for cars in British English. The word "**automobile**" is a classical compound derived from the Ancient Greek word autós (αὐτός), meaning "self", and the Latin word mobilis, meaning "movable". It entered the English language from French, and was first adopted by the Automobile Club of Great Britain in 1897. Over time, the word "automobile" fell out of favour in Britain, and was replaced by "motor car".

2.1.2. Historical facts of car driving

The **first working steam-powered vehicle** was designed - and most likely built - by Ferdinand Verbiest, a Flemish member of a Jesuit mission in China around 1672. It was a 65-cm-long scale-model toy for the Chinese Emperor that was unable to carry a driver or a passenger (Setright, 2004). It is not known if Verbiest's model was ever built.

Although several other German engineers (including Gottlieb Daimler, Wilhelm Maybach, and Siegfried Marcus) were working on the problem at about the same time, **Karl Benz generally is acknowledged as the inventor of the modern car** (Stein, 1967). In 1879, Benz was granted a patent for his first engine, which had been designed in 1878. Many of his other inventions made the use of the internal combustion engine feasible for powering a vehicle. His first Motorwagen was built in 1885 in Mannheim, Germany. He was awarded the patent for its invention as of his application on 29 January 1886 (under the auspices of his major company, Benz & Cie., which was founded in 1883). Benz began promotion of the vehicle on 3 July 1886, and about 25 Benz vehicles were sold between 1888 and 1893, when his first four-wheeler was introduced along with a model intended for affordability. They also were powered with four-stroke engines of his own design. Emile Roger of France, already producing Benz engines under license, now added the Benz car to his line of products. Because France was more open to the early cars, initially more were built and sold in France through Roger than Benz sold in Germany. In August 1888 Bertha Benz, the wife of Karl Benz, undertook the first road trip by car, to prove the road-worthiness of her husband's invention.

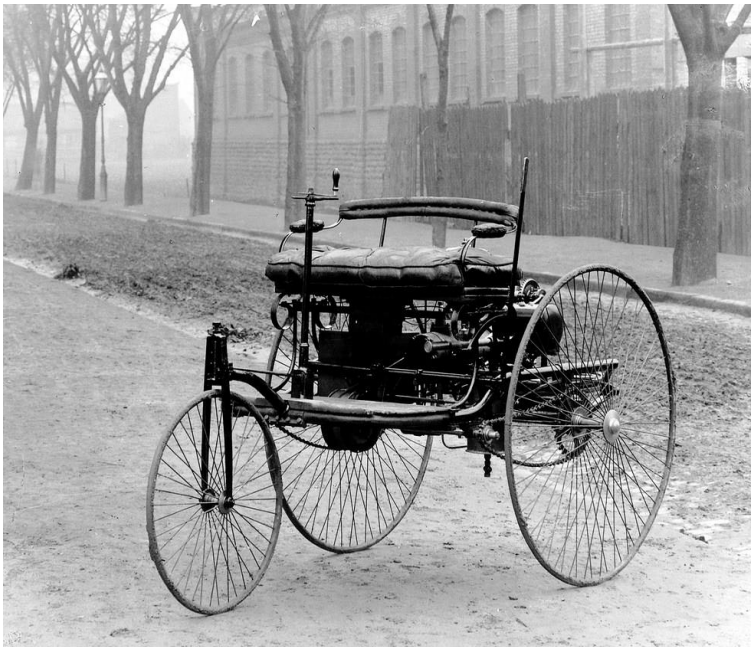


Figure 2.1. The original Benz Patent-Motorwagen, first built in 1885 and awarded the patent for the concept

Nowadays the car industry has enormously developed. It was estimated in 2010 that the number of cars had risen to **over 1 billion vehicles**, up from the 500 million of 1986 (Sousanis, 2011).

2.1.3. The task of driving

Driving in traffic is more than just knowing how to operate the mechanisms which control the vehicle; it requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses (Waller, 1980, Freund, 2005). The basic characteristics, a smooth driver should have are:

- **Concentration**
  - Concentration is to be able to keep your mind on the task of driving
- **Anticipation (defensive driving)**
  - Observing the driving environment for hazards
  - Reading into things that are happening around you, which in turn will lead you into defensive driving
  - Taking precautions before they happen in the interest of your well-being and other road users
- **Physical skills**
  - Starting the vehicle's engine with the starting system and setting the transmission to the correct gear
  - Depressing the pedals with one's feet to accelerate, slow, and stop the vehicle, and if the vehicle is equipped with a manual transmission, to modulate the clutch
  - Steering the vehicle's direction with the steering wheel
  - Operating other important ancillary devices such as the indicators, headlights, and windshield wipers
- **Mental skills**
  - Making good decisions based on factors such as road and traffic conditions, evasive maneuvering, skid control, steering and braking techniques, understanding vehicle dynamics, and right- and left-hand traffic
- **Memory and Perception**
  - Procedural memory, working memory, visuo-spatial perception
- **Attitude and Self-discipline**
  - Stay calm and tolerant in all possible circumstances
- **Knowledge**
  - Deep knowledge of the Traffic Code
  - Semantic knowledge

2.2. Driving Behaviour and Road Safety

The **driver's behaviour may include many aspects**, such as the perception of traffic conditions, decision-making, vehicle operation, using mobile phones and navigation systems, talking to other people in the vehicle, eating, drinking, applying cosmetics, looking around, etc. The vehicle operation includes longitudinal and lateral driving, which reflects the perception of the road, decision-making, and driver's intention and action, such as car following, lane change, lane keeping, acceleration and deceleration, etc. Longitudinal driving behaviour mainly focuses on vehicle movement along the driving direction, while lateral driving behaviour mainly focuses on vehicle movement perpendicular to the driving direction. These features represent the variation of vehicle states and the relationship with other vehicles when the driver operates on the accelerator/brake pedal, steering wheel, gear, and in-vehicle switches. The vehicle state can be quantified as position, speed, acceleration, and steering angle and rate (single vehicle trajectory), as well as distance headway, time headway, and time to collision (inter-vehicle relationship).

The driving traits, quality, and performance of the driver depend on physiology, psychology, knowledge, culture, traffic laws and regulations, driver's experience and temper, and brain health. The driver characteristics may also be classified by skills and styles, such as prudence (aggressive vs. prudent), stability (unstable vs. stable), conflict proneness (risk prone vs. risk avoidance), skillfulness (non-skillful vs. skillful), and self-discipline (law-abiding vs. violation frequent).

Road traffic safety refers to methods and measures for reducing the risk of a person using the road network for being killed or seriously injured. The users of a road include pedestrians, cyclists, motorists, their passengers, and passengers of on-road public transport, mainly buses and trams. Best-practice road safety strategies focus upon the prevention of serious injury and death crashes in spite of human fallibility (which is contrasted with the old road safety paradigm of simply reducing crashes assuming road user compliance with traffic regulations). Safe road design is now about providing a road environment which ensures vehicle speeds will be within the human tolerances for serious injury and death wherever conflict points exist (International Transport Forum, 2008).

Road accidents constitute a major social problem in modern societies, accounting for more than 1.2 million fatalities in 2013 worldwide (WHO, 2015) (Fig. 2.2), 25.000 in Europe and 879 in Greece (EL.STAT. 2014). Furthermore, human factors are the basic causes in 65-95% of road accidents (Sabey and Taylor, 1980; Salmon et al., 2011; Treat, 1980). The remaining factors include the road environment (road design, road signs, pavement, weather conditions etc.) and the vehicles (equipment and maintenance, damage etc.), as well as combinations of these three contributory factors.

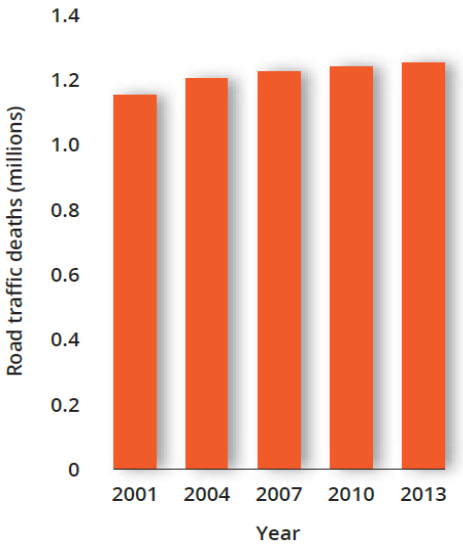


Figure 2.2. Number of road traffic deaths, worldwide, 2013

Every year more than 1 million people die on the roads all over the world, and another 20 to 50 million sustain nonfatal injuries as a result of road traffic accidents. These injuries and fatalities have an immeasurable impact on the families affected, whose lives are often changed irrevocably by these tragedies, and on the communities in which these people lived and worked (WHO, 2015).

Road accidents are estimated to be the eighth leading cause of fatalities globally, with an impact similar to that caused by many communicable diseases, such as malaria (Lazano et al., 2012) and the leading cause of fatalities for young people aged 15-29 years (WHO, 2015) (Fig. 2.3). Economically disadvantaged families are hardest hit by both direct medical costs and indirect costs such as lost wages that result from these injuries. At the national level, road traffic injuries result in considerable financial costs, particularly to developing economies. Indeed, road traffic injuries are estimated to cost low- and middle-income countries between 1-2 % of their gross national product, estimated at over US$ 100 billion a year (Jacobs, 2000).

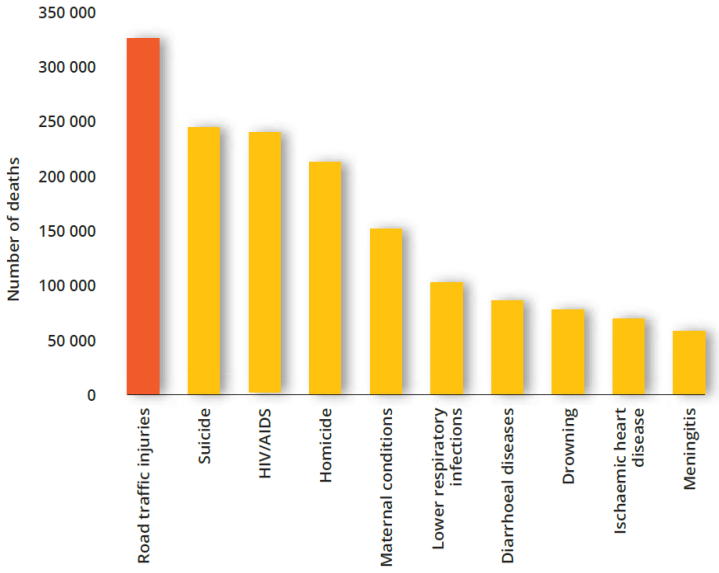


Figure 2.3. Top ten causes of death among people aged 15–29 years, 2012

Road accident fatalities have been steadily **increasing in many low- and middle income countries**, particularly where rapid motorization has not been accompanied sufficiently by improved road safety strategies. While better communication could, in theory, result in a reduced need for road travel, and thus lower the exposure to risk of road traffic injuries, in practice the combination of increased road transportation and better and continuous forms of communication may be detrimental to the global road safety picture (WHO, 2014).

Focusing on road accidents, **a number of factors have been identified** as affecting the likelihood of a road traffic injury, and limiting the exposure to these risk factors is critical to the success of efforts to reduce road traffic injuries. For example, there is now a large area of scientific research demonstrating the increased risk of road traffic fatalities and injuries resulting from human factors, such as excessive or inappropriate speed, drink–driving, non-use of seat-belts, child restraints or motorcycle helmets and driver distraction (Elvik, 2004; Pedden et al., 2004).

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 particularly in Greece is still unacceptable and illustrates the need for even greater efforts with respect to better driver behaviour and increased road safety (OECD, 2008). Golias et al., (1997), suggested that the necessary **recommendations for the improvement of the road safety level** should include formulating a national road safety policy, monitoring road safety both in aggregate and disaggregate levels, speeding up interventions for infrastructure improvement in both the interurban and urban road network, conducting information and education campaigns, retraining road users in safer traffic behaviour, and upgrading requirements for a driver's license.

Finally, several types of experiments on **assessing driving behaviour** exist, such as naturalistic driving experiments, driving simulator experiments, on road experiments, in-depth accident investigations and surveys on opinion and stated behaviour. Focusing on driving simulators, they allow for the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. Driving simulators, however, vary substantially in their characteristics, and this can affect their realism and the validity of the results obtained. Despite these limitations, driving simulators are an increasingly popular tool for measuring and analyzing driver distraction, and numerous studies have been conducted, particularly in the last decade (Regan et al., 2008).

2.2.1. Human factors in driving behaviour

Human factors research examines the way people interact with various aspects of the world and aims to make these interactions safer, healthier, and more efficient. This interdisciplinary field of research has a wide scope of application, spanning road safety, healthcare delivery, physical, cognitive, and technological systems. In the context of safety features and road safety, **human factors research aims to understand the driver's role in the safe operation of his or her vehicle**. Various factors contribute to how a person behaves in the driver's seat, including environmental, psychological, and vehicle design factors. The goal of human factors research is to expose these factors, determine the extent of their influence on driver performance, and modify road or vehicle design to reduce unsafe behaviour and improve driver performance. Vehicle safety features are part of a safe-driving system that includes human factors: the various ways that drivers interact with these features will help determine both how safe the driver is and how effective those safety features are.

The Traffic Injury Research Foundation's (TIRF) nation-wide 2012 survey revealed that some drivers admit that they would engage in unsafe driving practices like distracted driving and speeding if they knew that their vehicle was fully equipped with modern safety features. This is a clear example of human factors affecting the overall amount of safety benefit that these drivers can expect to see as a result of driving a vehicle with safety features. However, not all human factors are this obvious. A general lack of familiarity with how safety features work may have a subtle yet negative influence on a driver's ability to benefit from safety features.

Human factors are not necessarily limited to unsafe driving behaviour like excessive speeding and tailgating. Age, driving experience, attention level, and vehicle maintenance can all have an effect downstream on the performance of safety features. Drivers are an indispensable part of the road safety system, so factors that affect drivers accordingly affect road safety in general.

Examination of the operator plays a large role in transportation psychology. While many external factors influence traffic safety, internal factors are also significant. Some factors include:

» **Decision-making**
» **Demographics**
» **Distraction**

- **Detection Thresholds**
- **Drugs and alcohol**
- **Driving training and experience**
- **Familiarity with vehicle and environment**
- **Fatigue**
- **Inattention**
- **Perception-reaction time- response to the unexpected**
- **Risky behaviours**
- **Stress and panic**

According to Petridou & Moustaki (2000), human factors may include factors that reduce the driver's capability to meet traffic contingencies, in long or short term, or factors that modulate risk taking while driving (Table 2.1).

Table 2.1. Human factors affecting driver behaviour and safety (Petridou & Moustaki, 2000)

Reduce capability to meet traffic contingencies	
Long - Term	Inexperience Old age Disease and Disability Accident proneness Alcoholism and drug abuse
Short - Term	Drowsiness, fatigue Acute alcohol intoxication Short – term drug effects Binge eating Acute psychological stress Temporary distraction
Modulate risk taking while driving	
Long - Term	Overestimation of capabilities, 'macho' attitude Habitual speeding Habitual disregard of traffic regulations Indecent driving behaviour Non-use of seat belt or helmet Inappropriate sitting while driving Accident proneness Alcoholism
Short - Term	Moderate ethanol intake Psychotropic drugs Motor vehicle crime Suicidal behaviour Compulsive acts

Old age, disease and disability are among the key factors which may result in reduced capability to drive safely. Older drivers are more likely to have cognitive, motor and sensor-perceptual deficits that could affect their driving performance even in the absence of overt disease. The elderly driver, however, is often able to compensate for minor functional declines by adjusting driving behaviour. Nevertheless, several diseases and disabilities may reduce older driver's capability of driving.

2.2.2. Cognitive functions critical for safe driving

Driving is a complex task that requires possessing sufficient cognitive, visual and neurological state. The driver must have adequate motor strength, speed and coordination. Perhaps more importantly, **higher cognitive skills including concentration, attention, adequate visual perceptual skills, insight and memory** need to be present. Higher cortical functions required for driving include strategic and risk taking behavioural skills, which involve the ability to process multiple simultaneous environmental cues in order to make rapid, accurate and safe decisions. The task of driving requires the ability to receive sensory information, process the information, and to make proper, timely judgments and responses (Waller, 1980; Freund et al., 2005).

Cognitive functions related to driving may be categorized into the following six neuropsychological domains (Reger et al., 2004):

» **Mental status - general cognitive functions**
» **Attention - concentration**
» **Executive functions**
» **Language - verbal functioning**
» **Visuospatial skills and visual perception**
» **Memory**

Laberge (1997) made a distinction between three aspects of attention: selection, preparation and maintenance. Selection is a rapid process, which typically is used in search tasks to separate a target from distractors. Preparation is a slower process, which occurs when an individual recruits attention in order to concentrate on an upcoming stimulus without being distracted by irrelevant events. Maintenance of attention is the ability to allocate attention toward a stimulus source over a relatively long duration of time. Several researchers (Parasuraman & Nestor, 1991; Duchek et al., 1998) have argued that selective attention is most specific to driving deficits in older drivers, or in drivers

with some pathological condition (e.g. dementia). Identifying important information in the environment while ignoring irrelevant information may be important driving skills.

Drivers may compensate for declines in selective attention by driving more slowly, thereby allowing more time for information processing (Hakamies and Blomqvist, 1993). However, safe driving requires that a number of complex decisions are made while selecting attention between concurrent tasks, in a limited time frame.

The importance of visuo-spatial and visuoconstructive skills to driving has been highlighted in several studies (Johansson and Lundberg, 1997) Safe drivers must position the car accurately on the road and manoeuvre the vehicle correctly. Visuo-spatial skills are also important to judging distances, predicting the development of traffic situations and well perceive vehicle placement in space. Visuo-spatial deficits are commonly observed in older drivers, especially with early dementia, represented by a disturbance in formative activities such as assembling, building, and drawing, so that the individual is unable to assemble parts in order to form a whole (Benton, 1994).

Although attention and visuo-constructional skills represent a necessary foundation of driving ability, these competencies, similarly to all cognitive skills, require adequate supervision by the executive system of the brain (Royall, 2000). Executive abilities are thought to be important for dual task coordination, and necessary for car positioning, maintaining safe distances, driving on roundabouts, journey planning, estimating risk, for adapting behaviour such as adjusting speed to traffic conditions and for making judgements and taking quick decisions in face of unexpected incidents (Radford & Lincoln, 2004).

2.2.3. Driver distraction

Driver distraction constitutes a particular human factor of road accident causation. Driver distraction is generally defined as "a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver's awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes" (Regan et al., 2008). More specifically, driver distraction involves a secondary task, distracting driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004) and may include four different types: physical distraction, visual distraction, auditory distraction and cognitive distraction.

The use of different, and sometimes inconsistent, definitions of driver distraction can create a number of problems for researchers and road safety stakeholders. First, the lack of consistent definitions across studies can make the comparison of research findings difficult or even impossible, as even seemingly similar studies can be examining slightly different concepts and measuring different outcomes. Inconsistent definitions can also lead to different interpretations of road accident data and, ultimately, to different estimates of the role of distraction in accidents. These issues highlight the need to develop a common, generally accepted definition of driver distraction.

Driver distraction is part of the broader category of **driver inattention**. What distinguishes distracted driving from inattentive driving is the presence of a specific event or activity that triggers the distraction (Regan et al., 2005). Conversely with driver distraction, very few definitions of driver inattention exist in the literature, and those that do, like driver distraction, vary in meaning. Lee et al. (2008) for example, define driver inattention as "diminished attention to activities critical for safe driving in the absence of a competing activity". In this framework, Regan et al. (2005) proposed that: "Driver Inattention" means insufficient or no attention to activities critical for safe driving and "Driver distraction" is just one form of driver inattention, with the explicit characteristic of the presence of a competing activity.

There are four types of driver distraction: physical distraction, visual distraction, auditory distraction, and cognitive distraction. A distracting activity involves one, or more of these. The act of operating a hand-held cell phone for example, may involve all four types of distraction (Breen, 2009)

» **Physical distraction** when the driver has to use one or both hands to manipulate the telephone to dial a number, answer or end a call instead of concentrating on the physical tasks required by driving (Young et al., 2003).
» **Visual distraction** is caused by the amount of time that the drivers' eyes are on the cell phone and off the road or, while talking over the telephone, looking at the road but failing to see. The use of cell phones that display visual information (e.g. reading SMS) while driving will further distract drivers' visual attention away from the road (Dragutinovits and Twisk, 2005).
» **Auditory distraction** can occur when the driver is startled by the initial ringing of the telephone or by the conversation itself.
» **Cognitive distraction** involves lapses in attention and judgment. It occurs when two mental tasks are performed at the same time. Conversation competes with the

demands of driving. Listening, alone, can reduce activity in the part of the brain associated with driving by more than a third. The extent of the negative effects of cell phone use while driving depends on the complexity of both cell phone conversations and of driving situation. The more difficult and complex the conversation, the stronger its effects on driving performance. The more difficult the driving situation, the more impact the telephone conversation can be expected to make (SWOW, 2008).

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Driver distraction factors that occur **inside the vehicle** seem to have greater effect on driver behaviour and safety. Horberry et al. (2006) confirm that in-vehicle distraction sources have a more important effect on driver performance, compared to the increased complexity of the stimuli received from the road and traffic environment. Moreover, a couple of studies report that external distraction factors are less than 30% of the total distraction factors (Stutts et al., 2001; Kircher, 2007). Other studies specify that **external** distraction factors account for less than 10% of all distraction factors (Sagberg, 2001; MacEvoy et al., 2007).

It is noted that a recent exhaustive research conducted in the Great Britain, in which the effect of more than 70 road accident **contributory factors** was examined, driver distraction was found to be a contributory factor in only 3% of all accidents. Out of this 3%, in-vehicle distraction sources accounted for 2%, whereas external distraction sources accounted for only 1% of all accident contributory factors (Department for Transport, 2008).

Moreover, a study carried out by Patel et al. (2008) examined perceived qualitative characteristics of 14 driver distractions. Survey participants were asked to complete a questionnaire in which ranked a list of distractions according to certain criteria. Table 2.3 shows the **mean perceived risk** ratings of each of the 14 driver distractions. The highest perceived risk ratings were associated with the use of cell phones, followed by 'looking at a map or book' and 'grooming'. The lowest perceived risk ratings were associated with 'listening to music', 'talking to passengers' and 'looking at road signs'. It is noted that advertising signs and landscape have a non-negligible perceived risk level as external distraction sources.

Table 2.2. Perceived risk associated with driver distraction (Patel et al., 2008)

Driver Distraction Hazard	Risk rating	Lower limit	Upper limit
Listening to music	3.3	1.2	4.8
Talking to passengers	3.8	2.0	5.0
Looking for/at road signs	4.2	3.0	6.0
Satellite navigator use	4.6	3.0	6.0
Hands-free kit use	4.7	3.0	6.0
Looking at Landscape	5.2	3.0	7.0
Adjusting device	5.3	4.0	7.0
Smoking	5.3	3.0	7.0
Looking at advertising sign	5.7	4.0	8.0
Eating or drinking	6.3	5.3	8.0
Looking for object	7.4	6.0	9.0
Grooming/make-up	8.5	8.0	10.0
Looking at a map or book	8.5	8.0	10.0
Mobile phone use	**8.6**	8.0	10.0

More analytical results on the actual relative importance of different distraction factors was sought in the reports of the 100-Car naturalistic driving study carried out in the USA. Table 2.3 shows results on the odds ratio (i.e. increased risk) of engaging in various secondary distracting tasks over "just driving" (statistically significant results are in bold). A significant odds ratio indicates an important increase in risk associated with that activity.

Table 2.3. Odds ratio for secondary task (NHTSA, 2008)

Type of Secondary Task	Odds Ratio
Reaching for a moving object	8.82
Insect in vehicle	6.37
Reading	3.38
Applying makeup	3.13
Dialling hand-held device	2.79
Inserting/retrieving CD	2.25
Eating	1.57
Reaching for non-moving object	1.38
Talking/listening to a handle-held device	1.29
Drinking from open container	1.03
Other personal hygiene	0.70
Adjusting the radio	0.50
Passenger in adjacent seat	0.50
Passenger in rear seat	0.39
Child in rear seat	0.33

These results suggest that "reaching for a moving object" is associated with the highest risk, increased by more than eight times compared to just driving, followed by "reading' and 'applying make-up", increasing risk by more than 3 times. Subsequently, the use of **mobile phone** is associated with 2.8 times increased accident risk.

2.2.3.1. Compensatory behaviour

One fundamental question regarding the effect of distraction on driving performance is whether and **how drivers self-regulate their driving to compensate** for any decrease in attention to the driving task. Surprisingly, very little research has been conducted to specifically address this issue. Rather, research has focused on identifying the particular performance impairments associated with distraction activities (Haigney et al., 2000).

It is important to recognize, however, that not all changes in driving performance associated with non-driving tasks are indicative of driver impairment, and research suggests that drivers do engage in a range of conscious and unconscious compensatory behaviours in order to attempt to maintain an adequate level of safe driving (Poysti et al., 2005).

Compensatory or adaptive behaviour can occur at a number of levels ranging from the strategic (e.g., choosing not to use a cell phone while driving) to the operational level (e.g., reducing speed) (Alm and Nilsson, 1995; Lamble et al., 2002). At the highest level, drivers can choose to moderate their exposure to risk by choosing not to engage in a potentially distracting task while driving. Research has shown, for example, that older drivers' driving performance is impaired to a greater degree than younger drivers when using a cell phone and this results in compensatory behaviour at the highest level; many older drivers choose not use a cell phone while driving (Alm and Nilsson, 1995; Lamble et al., 2002).

At the operational level, several studies have shown that drivers attempt to reduce workload and moderate their exposure to risk while interacting with in-vehicle devices. They do this through a number of means: decreasing speed (Alm and Nilsson, 1990; Burns et al., 2002; Haigney et al., 2000; Rakauskas et al., 2004), increasing inter-vehicular distance (Jamson et al., 2004; Strayer and Drews, 2004; Strayer et al., 2003), changing the relative amount of attention given to the driving and non-driving tasks in response to changes in the road environment (Brookhuis et al., 1991), and accepting a temporary degradation in certain driving tasks (Brookhuis et al., 1991; Harbluk et al., 2002).

Several on-road and simulator studies have found that drivers tend to decrease their mean speed when engaging in a secondary task (Haigney, 2000; Rakauskas, 2004). The observed reductions in speed while engaging in a secondary task could be the result of drivers modifying their performance goals and accepting a sub-optimal level of driving performance, or the result of drivers simply allocating too much attention to the secondary task and insufficient attention to the primary driving task. Both of these explanations can have road safety implications, resulting from the driver either not allocating sufficient resources to the driving task and, hence, any potential hazards in the road environment, or because the driving performance standard that they are willing to accept may be below that needed for safe driving in certain situations.

An increase in following distance is another compensatory behaviour that has been displayed by drivers while they are interacting with in-vehicle devices (Strayer et al., 2003; Jamson et al., 2004; Yannis et al., 2010). Interestingly, although the drivers in all three studies attempted to compensate for their reduced attention to the roadway by adopting longer following distances, in many cases this increased headway was often inadequate to avoid collisions with other road users.

Another compensatory behaviour drivers have been found to engage in when interacting with in-vehicle devices is to change the amount of attention they allocate to the primary and secondary tasks at any given time in response to changes in the driving environment (Chiang et al., 2004; Brookhuis et al., 1991). It thus, appears that the amount of attention drivers are willing to allocate to the performance of a secondary task is situation dependent and may change across driving environments and task types.

2.3. Assessing driving behaviour

In this section, an extended literature review is carried out **regarding all available experiment types of assessing driving behaviour**. More specifically, benefits and limitations are presented regarding naturalistic driving experiments, driving simulator experiments, on road experiments, in-depth accident investigations and surveys on opinion and stated behaviour. In the end, a comparative assessment of experiments for the assessment driver behaviour is taking place.

2.3.1. On-road experiments and driving performance

In on-road experiments studies, an **instrumented vehicle is equipped with instrumentation to take recordings of a variety of aspects of driving** (Rizzo et al., 2002) (Fig. 2.4). These technologies include GPS, video-cameras, sensors, accelerometers, computers, and radar and video lane tracking systems. On-road experiments attempt to gain greater insights into the factors that contribute to road user accident risk and the associated accidents factors at specific conditions. These investigations are conducted by trained experts from multiple disciplines to collect as much useful information as possible, to be of maximum benefit in answering current research questions and any that may arise in the future (Wadley et al., 2009; Bowers et al., 2013; Okonkwo, 2009).

Figure 2.4. An instrumented vehicle used for on-road studies

On road driving evaluations are generally considered to be the gold standard method for determining driving fitness (Odenheimer et al., 1994; Di Stefano & McDonald, 2003) as a large degree of control over the variables that affect driving behaviour occurs. On-road testing, also provides the opportunity to examine driver competency, as drivers perform actual driving activities and includes aspects of driving that may not be easily replicable by other testing means (Ball & Ackerman, 2011).

On the other hand, on road studies can be criticized because they do not collect data over a longer time period and in response to selected interventions, as in more naturalistic settings as in naturalistic driving studies. Another methodological issue is that the studies utilizing instrumented test vehicles typically have at least one researcher present, at the very least, to give navigation directions. On other occasions a second

researcher is present to make other observations about the driver's behaviour. However, these types of studies do offer unique data collection opportunities with respect to the concurrent use of multiple methods and are of high cost (Ball and Ackerman, 2011).

2.3.2. Naturalistic driving experiments and driving performance

Naturalistic driving is a relatively new research method for the **observation of everyday driving behaviour of road users**. For this purpose, systems are installed in participants' own vehicles that register vehicle manoeuvres, driver behaviour (such as eye, head and hand manoeuvres) and external conditions (Fig. 2.5). In a Naturalistic Driving study, the participants drive the way they would normally do, in their own car and without specific instructions or interventions. This provides very interesting information about the relationship between driver, road, vehicle, weather and traffic conditions, not only under normal driving conditions, but also in the case of incidents or accidents (SWOW, 2010).

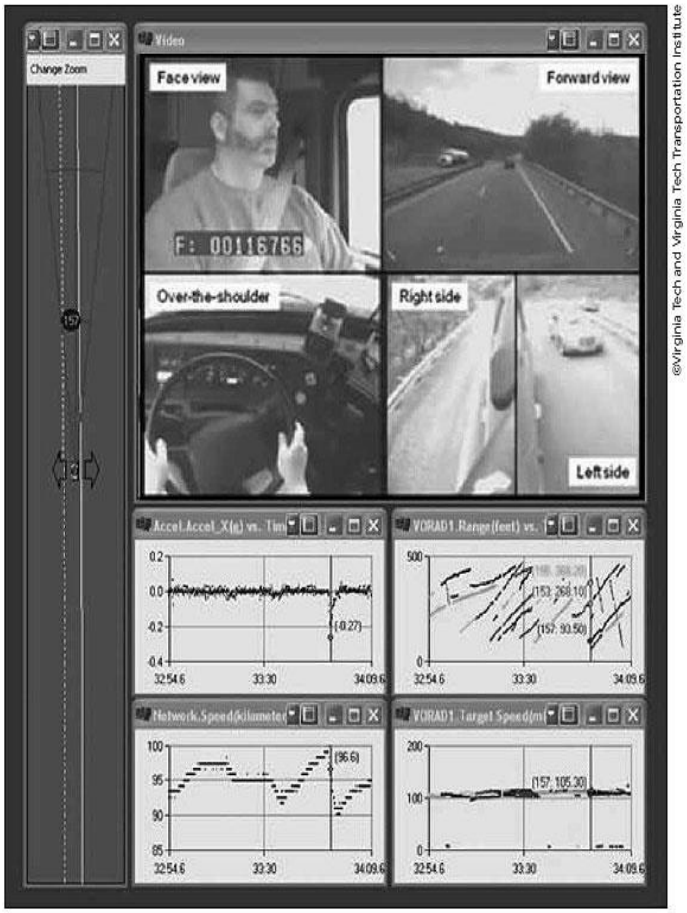


Figure 2.5. Naturalistic driving data collection (FHWA-HRT-12-040, 2012)

Naturalistic Driving Experiments offer much wider perspectives in understanding normal traffic behaviour in normal everyday traffic situations. Researchers study issues that cannot be investigated in a lab because participants feel as they are not involved in an experiment as there is no experimenter present, there are no experimental interventions or aims that participants can guess and act for. Furthermore, there is the possibility to observe conflicts, near crashes or even actual crashes in real time without potential biases of post-hoc reports. Moreover, a naturalistic study can contribute to clarifying the prevalence of fatigue and distraction amongst drivers and the related accident risk, to clarifying the interaction between road and traffic conditions and road user

behaviour, to understanding the interaction between car drivers and vulnerable road users in different circumstances, to specifying the relationship between driving style and vehicle emissions and fuel consumption, and many other aspects of traffic participation that are difficult to study by means of traditional research (Regan et al., 2012).

On the other hand, a first and important disadvantage of naturalistic studies is that, by definition, in a naturalistic study there is no experimental control of the various variables that potentially affect the behaviour of the road user. This means that naturalistic studies data results in correlation between particular variables and road user behaviour, but not in unambiguous causal relationships, while traffic incidents are very rare. Secondly, it is generally assumed that in a naturalistic study, drivers behave as they normally do, because after a while they forget that they participate in a study and that they are being observed all the time. There are indeed strong indications that this is what actually happens, but so far, strict scientific proof is lacking. A third related issue is that drivers in the study sample participate on a voluntary basis. Therefore, it cannot be ruled out that there is a self-selection bias and that the volunteers differ in relevant aspects from non-participants. Hence, the observed behaviour may not always be representative of the whole population. However, the direction and the approximate size of such a bias can be established and taken into account by using carefully designed background questionnaires (Van Schagen et al., 2011).

2.3.3. Driving simulator experiments and driving performance

Driving simulators allow for **the examination of a range of driving performance measures** in a controlled, relatively realistic and safe driving environment (Fig. 2.6). Driving simulators, however, vary substantially in their characteristics, and this can affect their realism and the validity of the results obtained.

Figure 2.6. Driving simulator

More specifically, driving simulators have a number of advantages over on-road studies. First they provide a safe environment for the examination of various issues using multiple-vehicle scenarios, where the driver can negotiate very demanding roadway situations. Second, greater experimental control can be applied in driving simulators compared with on-road studies, as they allow for the type and difficulty of driving tasks to be precisely specified and any potentially confounding variables, such as weather, to be eliminated or controlled for. Third, the cost of modifying the cockpit of a simulator to allow for the evaluation of new in-vehicle systems may be significantly less than modifying an actual vehicle. Finally, a large range of test conditions (e.g., night and day, different weather conditions, or road environments) can be implemented in the simulator with relative ease, and these conditions can include hazardous or risky driving situations that would be too difficult or dangerous to generate under real driving conditions (Papantoniou et al., 2013).

The use of driving simulators as research tools does, however, have a number of disadvantages (Blana & Golias, 2002). First, data collected from a driving simulator generally include the effects of learning to use the simulator and may also include the effects of being directly monitored by the experimenter. Second, driving simulators, particularly high-fidelity simulators, can be very expensive to install. Simulator discomfort / sickness is another problem encountered with simulators and is particularly pronounced in older drivers (Papantoniou et al., 2013).

2.3.4. In-depth accident investigation

In-depth accident investigations are **conducted by trained experts from multiple disciplines to collect as much useful information as possible** in order to describe the causes of accidents and injuries. The aim of these studies is to reveal detailed and factual information from an independent perspective on what happened in an accident by describing the accident process and determine appropriate countermeasures.

In depth accident investigations allow the factors contributing to an accident to be identified. In addition, research into injury prevention relies on in-depth data to identify injury outcomes in different impact scenarios, including vulnerable road users, and how the interaction between different vehicle types affects injury outcome. Data from in-depth accident investigations have also been utilized in the area of development as a tool to identify ideas for new products and to evaluate the expected effectiveness of new safety systems.

On the other hand the basic disadvantage regarding in-depth accident investigations is the insufficient reconstruction evidence which exist in each case investigated as well as the long period which is required for the final investigation results (Hill et al., 2012).

2.3.5. Surveys on opinion and stated behaviour

In stated behaviour surveys, **a reference questionnaire is built**, based on a list of selected topics and a representative sample of population is interviewed. The survey approach can employ a range of methods to answer the research questions such as postal questionnaires, face-to-face interviews, and telephone interviews.

They produce data based on real-world observations allowing investigating new situations, outside the current set of experiences. Furthermore, the breadth of coverage of many people or events means that it is more likely than some other approaches to obtain data based on a representative sample, and can therefore be generalizable to a population. Moreover, surveys can produce a large amount of data in a short time for a fairly low cost, making it easier to planning and delivering end results.

On the other hand, the nature of questions is often hypothetical and the actual behaviour is not observed, while the data that are produced are likely to lack details or depth on the topic being investigated (Kelley et al., 2003).

2.3.6. Experiments overview

From the above, it can be deduced that **each method** for assessing driver behaviour, in the general population and in particular in the elderly, **may have different advantages and limitations** (Table 2.4).

On-road studies, and their fully naturalistic versions, are considered to be more appropriate for the assessment of fitness to drive (Ball and Ackerman, 2011), however, simulators are also widely used, due to the safety and control over the experiment conditions, and despite their lower reliability. Questionnaire surveys are a very common tool for assessing various human factors of driving performance in the elderly (Vardaki & Karlaftis, 2011), yet they suffer from the known limitations of self-reported information.

Table 2.4. Comparative assessment of experiments

Experiment type	Method / tools	Advantages	Limitations
On road	Instrumented vehicle	Large degree of control over the variables, examination of driver competency	Data collection for a short period, in response to selected interventions, high cost
Naturalistic driving	Systems installed in participants' own vehicles	Understanding normal traffic, observation of conflicts	No experimental control of variables, traffic incidents are very rare, driver behaviour may not be representative,
Driving simulator experiments	Driving simulator	Safe environment, greater experimental control, large range of test conditions	learning effect, simulator sickness, very expensive
In-depth accident investigation	Trained experts investigate the causes of an actual accident	Identification of the factors contributing to an accident, research into injury prevention	Insufficient reconstruction evidence, long time period
Surveys on opinion and stated behaviour	Questionnaire	investigate new situations, large amount of data in a short time, low cost	Hypothetical questions, data lack details, self-reported data

Consequently, the selection of method for the assessment of driver performance should be carried out in accordance to the specific objectives or research questions of the assessment, the time-frame and the infrastructure or resources available etc.

All types of experiments should carefully follow some basic experimental design principles, allowing for reliable analysis of the data in order to provide appropriate answers to the research questions examined. Moreover, there are various other analysis challenges that need to be addressed when assessing driving ability, such as the selection of appropriate and relevant driving performance measures, the application of appropriate analysis techniques, and the reliability and validity of the analysis.

2.4. Driving simulator experiments

Driving simulators have been used to explore aspects of driving since 1960s. The main application areas of today driving simulators have been to investigate acceptability issues of innovative transport elements, to evaluate the safety concept (e.g. possible increase of accidents due to new road design, in-vehicle device), to the credibility and transferability of the simulator results to the real world as well as to the training of drivers.

Driving simulators have been used as research aids in a number of civil engineering, transport, psychology and ergonomics fields such as: innovative road design (e.g. testing the design of new tunnels, innovative highway design and road delineation, traffic calming); intelligent transport systems (e.g. new in-vehicle navigation systems, Head-Up-Displays, active pedals); impaired driver behaviour (driving behaviour affected by drugs, alcohol, severe brain damage, fatigue) and vehicle dynamics and layout (e.g. testing ABS, 4-wheel drive; vehicle interior design).

In this framework, in the beginning of the present chapter, advantages and limitations of driving simulators are recorded while the terms fidelity and validity are further investigated. Finally, the syndrome of simulator sickness is presented.

2.4.1. Advantages and limitations

A number of known advantages and disadvantages about driving simulators are the following (Regan et al., 2008).

Advantages:

» Has the capability to place drivers into crash likely situations without harming them, such as when they are using drugs, fatigued, engaging in police pursuits, during extreme weather, using new technologies, among other dangerous activities.
» Many confounding variables that occur in on-road driving can be controlled when driving simulation is used (e.g., weather, traffic, lighting, frequency of vulnerable road users, wind, potholes, proportion of vehicle types, irrational or unexpected behaviour of other drivers, and so forth).
» All of the sensory details of the real world are not used by drivers anyway. Perceptual information (Gibson, 1986) for driving is knowable and can be faithfully reproduced using simulators.

» Events or scenarios can be identically repeated for each participant.
» Simulators offer cost savings through flexible configurability so that a wide range of research question can be addressed (Jamson, 2001).
» Low-cost, low-fidelity simulators in the right hands can address a wide variety of interesting research questions.
» Driving simulation is compelling and elicits emotional reactions from drivers that are similar to those of actual driving.
» Simulators are good at assessing driver performance or what a driver can do (Evans, 2004).
» A structured driver training curricula can be set up and run for new drivers and for some skills, transfers to the open road (Pollatsek et al., 2006)

Limitations:

» Simulated crashes do not have the same consequences as a real crash and may affect subsequent behaviour. Crashes in a simulator may have an unknown psychological impact on participants.
» These confounding or interacting variables that occur in the real world also need to be understood and, since they cannot be fully recreated in simulators, are not necessarily amenable to testing (as yet). In other words, understanding driver behaviour is in the interacting details.
» The real world can never be perfectly reproduced (for now). The important combinations of real-world information and feedback that are important to driving are not completely known.
» Each exposure of trial affects responses to subsequent exposures.
» High-end simulators, such as NADs, require considerable hardware and software development to address a limited number of research questions.
» Low-cost simulators can be imprecise and inflexible and therefore do not address all needs.
» Drivers do not believe in the authenticity of the simulation at a fundamental level and responses are based on this perception.
» Simulators are not able to address questions of driver behaviour, which is what a driver does do in their own vehicle (Evans, 2004).
» The extent that the driver training transfers to on-road skills is not known nor is the relative cost-effectiveness of such programs (Jamson, 2001).

2.4.2. Fidelity

Fidelity refers to **the level of realism inherent in the virtual world**. The closer a simulator approximates real-world driving, in terms of the design and layout of the controls, the realism of the visual scene, and its physical response characteristics, the greater fidelity it is reported to have (Godley, Triggs & Fildes, 2002; Triggs, 1996). Numerous dimensions of fidelity have been proposed, many of which relate to the simulator's technical or physical characteristics, but these characteristics may not necessarily correspond to the degree to which the simulator replicates the driving experience.

Rehmann et al. (1995), proposed that there are **four interrelated dimensions** of simulator fidelity:

» **Equipment fidelity** refers to the degree to which the simulator replicates the appearance and feel of the real – world system, in terms of the layout of the vehicle cockpit and the size, shape, color, and position of the vehicle / system controls.
» **Environmental fidelity** concerns the extent to which the simulator replicates motion and visual cues, and other sensory information from the real – world environment.
» **Objective fidelity** refers to the degree to which a simulator replicates its real world counterpart in terms of dynamic cue timing and synchronization (e.g., timing of the visual cues matching steering inputs).
» **Perceptual or psychological fidelity**, is concerned with the degree to which the driver perceives the simulation to be a believable reproduction of the real driving task, and the degree to which the driver's pattern of interaction with the driving environment and system controls corresponds to real – world driving.

The level and type of fidelity required by a simulator depends on the type of research being conducted. It has been suggested that higher fidelity levels are required for research where the results of the simulation are used to draw conclusions about real-world driving performance, as when assessing whether interaction with an in-vehicle device distracts drivers (Triggs, 1996).

In terms of the specific aspects of simulator fidelity that are most important for distraction research, little research exists that can be used to guide this decision. However, knowledge regarding what driving performance measures are affected by distraction can provide some useful insights into what aspects of simulator fidelity might

be important. For example, distraction, particularly visual distraction, has been shown to affect drivers' ability to maintain lateral position (Engstrom et al., 2005; Greenberg et al., 2003). In turn, a lack of motion and visual cues has been shown to affect the precision of lateral position control to a greater extent in simulators than actual vehicles, because the absence of visual and kinesthetic feedback leads to a decreased ability to select appropriate steering corrections (Reed and Green, 1999; Blaauwm 1982). Thus, it appears that environmental fidelity, and the precise replication of motion and visual cues in particular, is important for the accurate measurement of the effects of distraction on lateral control. Distraction has also been shown to affect drivers' visual scanning patterns and their ability to detect events occurring in the periphery (Engstrom, et al., and Ostlund, 2005; Recarte and Nunes, 2003), suggesting that a display screen with a wide field of view is important to be able to capture the effects of distraction on the detection of objects or events occurring in the driver's peripheral field of view. A simulator's fidelity can thus affect how sensitive it is to the effects of distraction.

The **location of the in-vehicle system under evaluation**, relative to the driver and the roadway, and the type and layout of its controls are also important. The location of the system in the simulated vehicle and its visual angle from the road should match precisely its placement in real vehicles because its distance from the forward view directly contributes to the degree of distraction it imposes on drivers. For example, a study on monitor location within the vehicle revealed that as the downward viewing angle of the display increased, the drivers' ability to detect that they were closing in on a lead vehicle decreased (Asoh, Kimura and Ito, 2000). In addition, the types of controls used and their layout should be consistent across the simulated and real systems. Discrepancies in the location and design of the in-vehicle system between simulated and real vehicles may lead drivers to interact with the system differently in the simulator and, thus, lead to driving performance being differentially affected across the simulated and real-world environments.

2.4.3. Validity

Simulator validity typically refers to **the degree to which behaviour in a simulator corresponds to behaviour in real-world environments under the same condition** (Kaptei et al., 1996; Blaauw, 1982). The best method for determining the validity of a simulator is to compare driving performance in the simulator to driving performance in real vehicles using the same driving tasks (Blaauw, 1982). A number of studies have examined driving simulator validity and have generally found good correlations

between simulated driving performance and driving performance on real roads (Kaptei et al., 1996; Engstrom et al., 2005).

There are two types of validity: **absolute validity and relative validity**. If the numerical values for certain tasks obtained from the simulator and actual vehicles are identical or near identical, absolute validity is said to have been achieved (Godley et al., 2002; Harms, 1992). Relative validity is achieved when driving tasks have a similar affect (e.g., similar magnitude and direction of change) on driving performance in both the simulator and real vehicles (Harms, 1992). Although limited, research has generally found that simulators demonstrate good relative behavioural validity for many driving performance measures, although absolute validity has rarely been demonstrated (Godley et al., 2002; Reed and Green, 1999; Blaauw, 1982; Harms, 1992; Carsten et al., 1997; McLane and Wierwille, 1975)

2.4.4. Simulator sickness

Simulator sickness has been a source of concern from the earliest days of simulator development and application (Reason, 1978; Casali and Frank, 1988). Not every individual experiences simulator sickness to the same extent, even in identical situations. Reason's (1978) neural mismatch model of sensory conflict theory states that susceptibility is a product of an individual's overall experience with motion sickness.

Like motion sickness, simulator sickness has been described as **a syndrome because of the breadth of its symptoms, including headache, sweating, dry mouth, drowsiness, disorientation, vertigo, nausea, dizziness, and vomiting** (Kennedy et al., 1993; Cobb et al., 1999). Cobb et al. (1999) have also documented a negative effect on psychomotor control, believed to be the product of simulator sickness. Moreover, user characteristics such as age, experience, gender, illness, mental rotation ability, and postural instability play key roles in determining whether a participant will become sick.

Older adults tend to be more susceptible to simulator sickness than younger participants (Roenker et al., 2003). Additionally, simulator sickness may vary by exposure time; Cobb et al. (1999), have suggested that simulator sickness symptoms steadily increase for up to one hour during exposure to a virtual environment before returning to nominal levels 15 min later. During this adaptation period, however, some subjects may become too ill to continue and thus never reach the 1-h mark.

Finally, changes in scene content may affect the likelihood and severity of simulator sickness (Jones et al., 2004). While some researchers view simulator sickness as a type of motion sickness which occurs in a simulated environment, there are several reasons to treat motion sickness and simulator sickness as related but separate maladies. To begin with, motion sickness appears to occur in a larger portion of the population and tends to be more severe than simulator sickness. Additionally, a key indicator of motion sickness, drowsiness, does not necessarily indicate simulator sickness (Kennedy et al., 1993). Furthermore, eye movement disturbances are more common in simulator sickness.

2.5. Neurological diseases affecting cognitive functions

The brain is the body's control center. It's part of the nervous system, which also includes the spinal cord and a large network of nerves and neurons. Together, the nervous system controls everything (Figure 2.7) from the five senses to the muscles throughout the body.

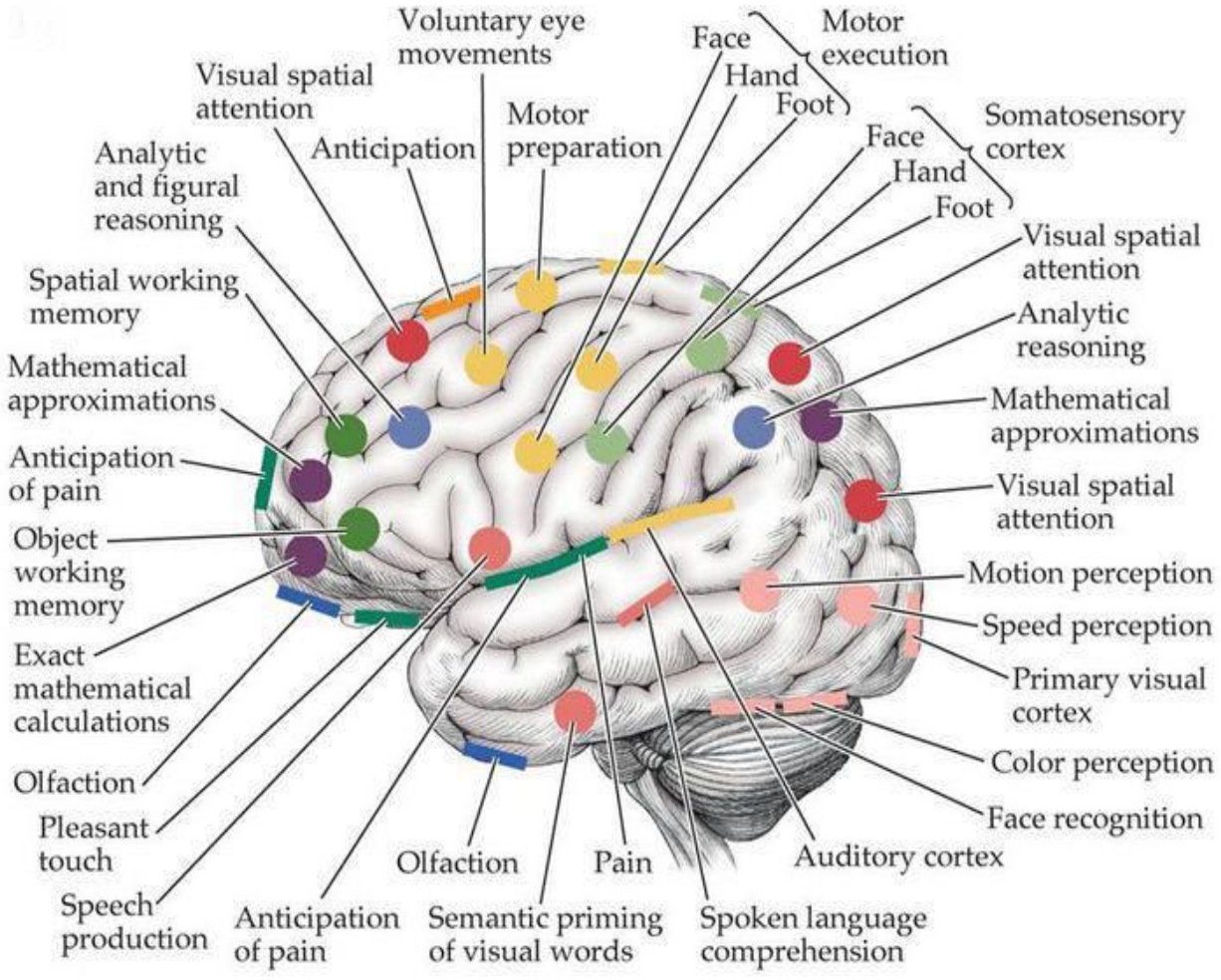


Figure 2.8. An oversimplified approach of localization of brain functions (Biological psychology, 2004)

Cognition is "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses." It encompasses processes such as knowledge, attention, memory and working memory, judgment and evaluation, reasoning and "computation", problem solving and decision making, comprehension and production of language, etc. Human cognition is conscious and unconscious, concrete or abstract, as well as intuitive (like knowledge of a language) and conceptual (like a model of a language). Cognitive processes use existing knowledge and generate new knowledge.

The **processes are analyzed from different perspectives within different contexts**, notably in the fields of linguistics, anesthesia, neurology, psychiatry, psychology, education, philosophy, anthropology, biology, systemics, logic, and computer science. These and other different approaches to the analysis of cognition are synthesized in the developing field of cognitive science, a progressively autonomous academic discipline. Within psychology and philosophy, the concept of cognition is closely related to abstract concepts such as mind and intelligence. It encompasses the mental functions, mental processes (thoughts), and states of intelligent entities (humans, collaborative groups, human organizations, highly autonomous machines, and artificial intelligences) (Blomberg, 2011).

Thus, **the term's usage varies across disciplines**; for example, in psychology and cognitive science, "cognition" usually refers to an information processing view of an individual's mental/psychological functions. It is also used in a branch of social psychology called social cognition to explain attitudes, attribution, and group dynamics (Sternberg & Sternberg, 2009). In cognitive psychology and cognitive engineering, cognition is typically assumed to be information processing in a participant's or operator's mind or brain (Blomberg, 2011).

When the brain is damaged, it can affect many different aspects of cognition, including memory, sensation, language, perception, attention, executive functions and even the whole personality of a person. Brain disorders include any conditions or disabilities that affect the brain. This includes those conditions that are caused by illness, genetics, or traumatic injury. This is a broad category of disorders, which vary greatly in symptoms and severity.

Cognitive disorders are a category of mental health disorders that primarily affect learning, memory, perception, and problem solving, and include amnesia, dementia, and

delirium. Causes vary between the different types of disorders but most include damage to the memory networks of the brain (Guerrero, 2008; Torpy, 2008). Treatments depend on how the disorder is caused (trauma, degenerative disease etc.). Medication is the most common treatments; however, for some types of disorders such as certain types of amnesia, treatments can suppress the symptoms but there is currently no cure like in case of Alzheimer's disease (Torpy, 2008; Torpy, 2010).

Overall, there are more than **350 neurological diseases and disorders**, out of which approximately **35 are the most known to affect cognitive functions**. Within the framework of this PhD dissertation, the neurological disorders affecting cognitive functions that were chosen to be examined are: **Mild Cognitive Impairment (MCI), Alzheimer's disease (AD), and Parkinson's disease (PD)**. The reason was that these three neurological diseases affecting cognitive functions have preoccupied the international literature the most and are considered to be the most widespread in the modern societies regarding the fields of neurology and neuropsychology.

2.5.1. Mild Cognitive Impairment (MCI)

Petersen et al., (1995) has described the concept of **Mild Cognitive Impairment (MCI) as a cognitive state that lies between normal aging and dementia**. Persons with MCI exhibit cognitive decline beyond what is expected to be normal for age, but they are overall functioning well and do not meet criteria for dementia. This condition has been studied intensively for over 30 years. The term MCI was first employed in 1988 and subsequently has been linked with a lot of possible etiologies and several terms (Reisberg et al., 2008). A typical MCI patient is one who has a memory impairment beyond what is felt to be normal for age, but is relatively intact in other cognitive domains. Accordingly, the criteria proposed for MCI by Petersen et al. (2001) refer to:

» Memory complaint, corroborated by an informant
» Objective memory impairment
» Normal general cognitive function
» Normal activities of daily living
» Absence of dementia

Because the concept of MCI has been derived from clinical settings, MCI definitions are continually being revised. Therefore, at present we can distinguish the following clinical subtypes for the MCI concept, according to Petersen (2004):

» Amnestic MCI

» Multiple domain (with a memory deficit) MCI
» Multiple domain (without a memory deficit) MCI
» Single nonmemory domain (i.e. with executive functioning deficits) MCI

Along with multiple definitions, different etiologies have been proposed for MCI. More specifically, MCI can evolve as a result of a neurodegenerative process, such as Alzheimer's disease (AD); most of the subjects with memory loss will progress to AD at a rate of 10%-15% per year (Petersen et al., 2001). Another possible cause for the appearance of MCI is vascular dementia, secondary to small vessel disease (Petersen et al., 2001). The two MCI subtypes induced from this medical condition are the multiple domain MCI and the single domain MCI (nonmemory domain, i.e. with executive functioning deficits). Other etiologies or causes reported for the MCI condition are brain trauma and metabolic disturbance (Petersen, 2004; Winblad et al., 2004). In amnestic MCI executive and visuospatial functions are affected even in a lesser degree (Economou et al., 2007).

2.5.2. Alzheimer's disease (AD)

Alzheimer's dementia (AD) is increasingly being recognized as one of the most important medical and social problems in older people in industrialized and non-industrialized nations (Yiannopoulou & Papageorgiou, 2013) and **accounts for 60% to 70% of cases of dementia** (Burns, 2009; WHO, 2015).

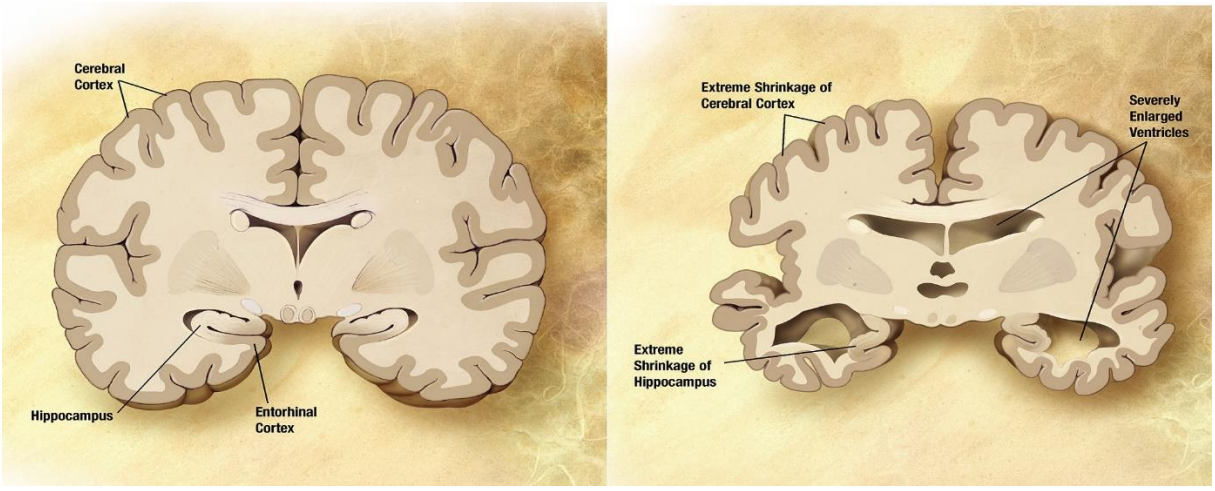


Figure 2.9. Comparison of a normal aged brain (left) and the brain of a person with Alzheimer's (right)

It is a chronic neurodegenerative disease that usually starts slowly and gets worse over time (Burns, 2009; WHO, 2015). The most common early symptom is difficulty in

remembering recent events (episodic memory loss) (Burns, 2009). As the disease advances, symptoms can include problems with language, disorientation (including easily getting lost), depression, loss of motivation, not managing self-care, and behavioural issues (Burns, 2009; WHO, 2015). As a person's condition declines, they often withdraw from family and society (Burns, 2009). Gradually, bodily functions are lost, ultimately leading to death. Although the speed of progression can vary, the average life expectancy following diagnosis is eight to ten years (Querfurth & LaFerla, 2010; Todd et al., 2013).

The cause of Alzheimer's disease is poorly understood (Burns, 2009). About 70% of the risk is believed to be genetic with many genes usually involved (Ballard et al., 2011). Other risk factors include a history of head injuries, depression, or hypertension (Burns, 2009) and several vascular risk factors. The disease process is associated with plaques and tangles in the brain (Ballard et al., 2011). A probable diagnosis is based on the history of the illness and cognitive testing with medical imaging and blood tests to rule out other possible causes. Initial symptoms are often mistaken for normal aging (Burns, 2009). Examination of brain tissue is needed for a definite diagnosis (Ballard et al., 2011). Mental and physical exercise, and avoiding obesity may decrease the risk of AD (Ballard et al., 2011).

No treatments stop or reverse its progression, though some may temporarily improve symptoms (Yiannopoulou & Papageorgiou, 2013; WHO, 2015). Affected people increasingly rely on others for assistance, often placing a burden on the caregiver; the pressures can include social, psychological, physical, and economic elements (Thompson et al., 2007). Exercise programs are beneficial with respect to activities of daily living and can potentially improve outcomes (Forbes et al., 2013). Treatment of behavioural problems or psychosis due to dementia with antipsychotics is common but not usually recommended due to there often being little benefit and an increased risk of early death (NICE, 2014).

In 2015, there were approximately **48 million people worldwide with AD** (WHO, 2015). It most often begins in people over 65 years of age, although 4% to 5% of cases are early-onset Alzheimer's which begin before this (Mendez, 2012). It affects about 6% of people 65 years and older (Burns, 2009). In 2010, dementia resulted in about 486,000 deaths (Lozano et al., 2012).

2.5.3. Parkinson's disease (PD)

Parkinson's disease (PD) is a degenerative disease of central nervous system that have an impact mainly on motor function. Symptoms of PD may vary from person to person and include: tremor, slowness of movement (bradykinesia), rigidity, flexed posture, shuffling gait or postural instability, impaired posture and balance, loss of automatic movements. Later, thinking and behavioural problems may arise, with dementia commonly occurring in the advanced stages of the disease, and depression being the most common psychiatric symptom. Other symptoms include sensory, sleep, and emotional problems. The main motor symptoms are collectively called "parkinsonism", or a "parkinsonian syndrome". The main pathological finding in PD is the death of cells that secrete dopamine in the pars compacta region of the **substantia nigra**[2] (Figure 2.10) (Fritsch et al., 2012; Gazewood et al., 2013).

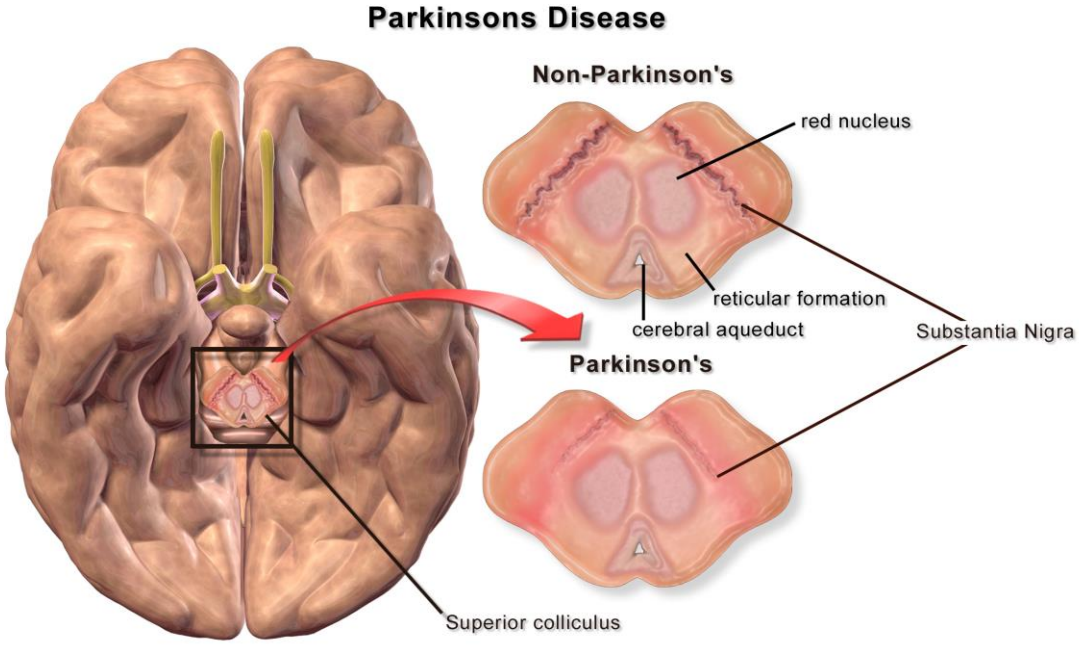


Figure 2.10. Comparison between a normal aged brain's substantia nigra and the respective of a person with PD

Levodopa (L-Dopa), an amino acid precursor of dopamine, and a number of dopamine agonists, are at present the basic therapy for the motor symptoms of PD. Moreover, cognitive decline may be apparent to patients with PD. Attentional difficulties, executive dysfunction, impairment of visuospatial abilities and decline in episodic memory are considered to be the most frequently reported deficits (Dubois & Pillon, 1996). In 2013 PD was present in **53 million people and resulted in about 103,000 deaths globally**

[2] A brain structure located in the mesencephalon (midbrain) that plays an important role in reward, addiction, and movement

(GBD, 2013). Parkinson's disease is more common in older people, with most cases occurring after the age of 50.

2.6. Neurological diseases affecting cognitive functions and driving performance

Driving performance can be affected by a wide variety of medical conditions, such as dementia (Ott & Daiello, 2010). MCI constitutes a medical condition that, as previously noted, mildly affects cognitive functions. In a similar manner, according to the most recent literature, MCI patients may experience an increased level of driving difficulties in comparison to their healthy counterparts without, however, being characterized as unsafe drivers (Fritteli et al., 2009; Kawano, et al., 2012; Olsen et al., 2014). So far, the literature investigating driving performance in the MCI population is relatively sparse (O' Connor et al, 2010).

Researchers suggest that individuals with AD are more than three times more likely to get involved in a car accident than age-matched drivers without primary degenerative dementia (Massie & Campbell, 1993; Tuokko et al., 1995). However, it is generally accepted that the accident probability in patients with dementia rises above acceptable rates beyond the third year of the disease (Drachman et al., 1993). Moreover, severity of cognitive and functional impairment has been correlated with worse driving performance as measured by the Clinical Dementia Rating (CDR) (Dubinsky et al, 2001).

In their review, Man-Son-Hing et al. (2007) indicated that, in comparison to healthy controls, AD patients have an impaired driving ability when tested with on-road driving experiments and driving simulator assessments. On the other hand, there are some studies which argue that not all patients with AD are unable to drive, especially in the earlier-mild stages of the disease (Carr et al., 2000; Perkinson et al., 2005). Due to the variance in the progression of symptoms in AD, most neurologists, neuropsychologists or transportation practitioners are faced with the critical question in everyday practice regarding the proper time for dissuading patients from driving, as ability to drive is an important factor of daily life that is of critical importance for preserving mobility, independence and self-confidence in the elderly (Gardezi et al., 2006; Johnson et al., 2013).

Several studies have investigated the driving capacity of patients with PD 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 cognitive functions and motor functioning, studies investigating fitness to drive in patients with PD have used a large variety of measures for predicting driving capacity. 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). Dubinsky et al., 1991 conducted a retrospective study that included patients with PD and found PD patients to have increased accident probability, which indicates that the association between the level of motor functioning in patients with PD and car accident engagement is an area that warrants further investigation.

The **significance of administrating neuropsychological tests** in order to evaluate the driving performance of those in the early stages of dementia and those who are cognitively intact concerns the international literature. The Mini Mental State Examination (MMSE) is considered to be the most commonly used index for the evaluation of general cognitive ability and a lot of studies suggest a consistent relationship between driving performance and MMSE (Brown et al., 2004; Lesikar et al., 2002; Uc et al., 2005). Useful Field of View (UFOV) is a computerized test examining visual attention and more specifically processing speed, divided attention, and selective attention.

A lot of studies examined and confirmed the predictive validity of UFOV regarding driving performance (Brown et al., 2005; De Raedt et al., 2001; Owsley et al., 1991; Paccalin et al., 2005; Uc et al., 2004; Whelihan et al, 2005). The Driving Scenes Test of the Neuropsychological Assessment Battery (Stern et al., 2003; Brown et al., 2005) was developed as a measurement of visuospatial attention skills considered to be important in driving ability. Finally, tests that appear to be efficient predictors of driving performance evaluating executive functions are: Porteus Maze Test (Grace et al., 2005; Ott et al., 2003), Trail Making Test - Trails A and B (Dawson et al., 2009; Ott et al., 2008; Paccalin et al., 2005; Reger et al., 2004; Szlyk et al., 2002) and Clock Drowning Test (De Raedt et al., 2001; Freund et al., 2002; Ott et al., 2000).

In the following chapters, an exhaustive literature review regarding the driving performance of drivers with the three examined neurological diseases affecting cognitive functions (MCI, AD and PD) is presented.

2.6.1. Drivers with MCI

2.6.1.1. Driving performance of drivers with MCI

In this chapter**, eight studies that examine the driving performance of patients with MCI** (4 through on-road assessment and 4 through driving simulator experiment) are presented and the critical parameters assessing the driving performance of this group of patients are extracted. In Table 2.3, all following studies and their basic results are presented.

Snellgrove, (2005) evaluated the driving behaviour of patients with MCI through an on-road driving experiment. Results indicated that 50% of patients with MCI failed the driving test because of a series of driving errors: left and right turn errors, general driving errors and late braking related to poor planning and observation skills, difficulty to control the vehicle's speed, poor car positioning in the lane, pedal confusion and lack of defensive driving.

More driving errors were made also by MCI participants in another study (Bowers et al. 2013).The authors examined the highway and non-highway driving skills of 11 patients with MCI. Results suggested that 8 MCI patients were rated as "at risk" committing driving errors such as, highway, observation, planning, speed control and indication errors.

Wadley et al. (2009) investigated the driving performance of 46 adults with MCI and 59 cognitively intact older adults using an on road driving experiment. All participants went through a neurological and neuropsychological examination and a visual screening. The on-road assessment was carried out using a standardized route with clear weather conditions, with a duration of 45 minutes, under the supervision of a certified driving rehabilitation specialist blind to the participants' group status. Participants' driving behaviour was rated on a 5 point Likert scale and included several driving indexes, such as lateral position, gap judgment, turning, maintaining proper speed, stopping distance, signaling, obeying traffic signs, pre-turn and post-turn position, headway, steer steadiness, pre-crossing and post-crossing position and proper scanning of driving space. The results indicated significant differences between the MCI and the control group regarding lateral position and left-hand turns.

Frittelli et al. (2009) investigated the driving performance of 20 patients with mild AD, 20 patients with MCI and 20 controls, of similar demographic characteristics, using a driving simulator experiment[3]. All participants were administered the Stanford Sleepiness Scale, the MMSE and a simple visual reaction time test. The driving simulation task included a two-lane urban road about 6km long with good visibility conditions, and a variety of events. Results indicated significant performance differences between AD patients, MCI participants and normal controls in mean time to collision and number of off-road events. The authors concluded that mild AD significantly affects driving behaviour, whereas MCI has a limited impact on driving skills, and proposed that studies should target the investigation of accident risk.

A study that indicated no statistically significant differences between MCI drivers and healthy controls is that of Devlin et al. (2012). They investigated the brake patterns of older drivers with MCI when approaching junctions, as compared to their age-matched healthy counterparts, through a portable driving simulator. Fourteen drivers with MCI and 14 healthy controls with similar demographics and self-reported collisions experienced in the past 2 years, participated in the study. Researchers designed a brief driving scenario incorporating a number of intersections and monitored driver foot movements. All participants went through cognitive, vision and physical assessments. Screening included the administration of the MMSE, the Rapid Pace Walk test (see Appendix for definition), the Trail Making Test-part B (TMT-B), a reaction time task and a test for visual acuity. Overall, driving performance of MCI patients was worse than that of cognitively intact individuals but there was no statistically significant difference in any of the driving indexes, or in any of the neuropsychological and motor measures between the two groups.

Kawano et al. (2012) focused on identifying the specific cognitive characteristics of MCI patients that may predict safe driving performance. They designed a case control study and compared the driving performance of 12 patients with MCI, 26 elderly controls, and 19 young healthy adults using a simulated driving test. The driving evaluation task included a road tracking task, a car-following task, and a harsh braking task. The MCI group performed significantly worse than the normal older adults on the car-following task and significantly worse than the normal young adults on the car-following task and the road-tracking tasks. The authors suggested that differences in driving performance between MCI drivers and their age-matched counterparts may be due to poor flexibility

[3] This study could be considered in the next section as well, because AD patients were also examined

and impaired visual attention, warranting the close supervision of the MCI driving population.

Griffith et al. (2013) indicated that drivers with amnestic MCI made more driving errors than cognitively intact individuals, in an on-road task. Driving variables that were examined included crossing intersections, merging, turning at junctions, exiting the interstate, changing lanes, driving on straight stretches and taking turns. The authors indicated difficulties in lateral position of patients with MCI, suggesting a link between the MCI and difficulties in positioning the vehicle in the lane. These visuospatial deficits by MCI patients are explained by the findings of Economou et al., (2007).

Finally, in a study conducted by our research team (Pavlou et al., 2015a) we investigated the driving behaviour of drivers with neurological diseases affecting cognitive functions through a driving simulator experiment. More specifically, the objective of this research was the analysis of the driving performance of drivers with (AD) and (MCI)[4], on the basis of a driving simulator experiment, in which healthy "control" drivers and drivers with neurological diseases affecting cognitive functions drove in different driving scenarios, following a thorough neurological and neuropsychological assessment. The driving scenarios included driving in rural and urban areas in low and high traffic volumes. The driving performance of drivers impaired by the examined pathologies (AD and MCI) was compared to that of healthy controls by means of Repeated Measures General Linear Modeling techniques. In this paper, a sample of 75 participants (38 healthy controls, 14 AD patients and 23 MCI patients was analyzed and various driving performance measures were investigated, including speed, lateral position, steering angle, headway, reaction time at unexpected events etc., some in terms of their mean values and some in both their mean values and their variability. The results suggested that patients with AD and MCI performed significantly worse than the cognitively intact individuals, and there were common driving patterns for both neurological diseases. More specifically, drivers with the above cerebral diseases had significantly lower speeds, kept larger headways compared to healthy drivers, appeared to have difficulties in positioning the vehicle on the lane, and had longer reaction times.

[4] This study could be considered in the next section as well, because AD patients were also examined

2.6.1.2. Self-assessment of driving status of patients with MCI

Examination of self-assessment of driving performance in patients with MCI also has divergent results. According to some researchers, drivers with MCI seem to maintain a good level of self-awareness as regards driving ability (Okonkwo, 2009), although self-awareness of deficits in MCI patients is controversial (paper accepted for publication, Fragkiadaki et al., 2016). Drivers with MCI reduce their driving frequency at a faster rate that cognitively intact individuals and they avoid difficult driving situation in a similar patterns as patients diagnosed with dementia (O' Connor 2010; 2013, Keay et al., 2009).

On the contrary, a study by Meng et al. (2013) reported that, although cognitively impaired individuals (mean score MMSE: 25) are self-aware of their cognitive difficulties, they do not report the same as regards their driving abilities while cognitively intact older drivers in the particular study seemed to perceive changes in driving ability and reported driving-related discomfort. However, in the particular study no comparison to objective measures of driving performance was reported.

A recent qualitative study (Johnson et al., 2013) investigated the views of seven MCI individuals regarding decision making on driving cessation. Maintaining agency emerged as the key issue considering the analysis of the results. That is, MCI participants valued driving to preserve their autonomy, independence, control and - for the male participants only - masculine identity. Moreover, participants reported that, although, they would respect and consent to their general practitioner's advice to stop driving, they would have preferred to decide to stop driving themselves or to self-regulate their driving (i.e., slower driving, avoiding peak hours). The authors suggested that involving elderly individuals with MCI in the decision about driving cessation, would lead to enhanced quality of life in this population, and highlighted the symbolic importance of driving to male drivers.

In a recent study by Vardaki et al., (2016) a number of variables (age, memory assessment and self-report of driving avoidance and global driving ability) were utilized in order to predict probable diagnosis of MCI. From the aforementioned variables, only the self-report of global driving ability was statistically significant in predicting diagnosis of MCI.

2.6.1.3. Prediction of driving behaviour of patients with MCI

Bowers et al., 2013, assessed the highway and non-highway driving skills of 11 individuals with MCI. Eight were rated as being at risk committing highway, observation, planning, speed control and indication errors. The best four-test combination, identifying high risk drivers with 95% specificity and 80% sensitivity (.91 area under the curve (AUC)) included the Mini Mental State Examination (MMSE), Useful Field of View-subtest 2, visual acuity and contrast sensitivity. The best single predictor with an AUC of .84 was the UFOV-subtest 2. The authors concluded that it is imperative to establish test batteries, both sensitive and specific, with high predictive power of at risk drivers.

In a study conducted by our research team (Beratis et al., 2015- submitted) we explored the impact of depressive symptomatology in the MCI population. We examined 24 individuals with MCI and 16 cognitively intact individuals. For the assessment of depressive symptomatology we used the Patient Health Questionnaire (PHQ-9) along with a simulator driving assessment and a battery of neuropsychological tests. Our results indicated that the presence of depressive symptoms may be correlated with a number of driving variables in MCI patients that included longitudinal parameters, namely average speed, average headway distance and headway distance variation as well as lateral parameters, such as lateral position variation and average wheel position. What is more, significant associations were also present with measures directly linked with the possibility of a road accident, such as actual number of crashes, hits of side bars and number of speed limit violations. Similar associations between depressive symptoms and driving performance were not found in the analysis of the control group. Hence, this pattern of findings, at least in terms of effect size as indicated by the larger correlation coefficient values, appears to be specific for individuals with MCI.

2.6.1.4. Conclusions

In this review, the question of **driving competency in the MCI population was addressed**. Several studies were examined, including the assessment of driving ability through on-road testing, driving on a simulator and questionnaires. Regarding the driving performance of drivers with MCI compared to that of healthy controls, as the review of driving simulator and on-road experiments indicated, a summarized Table (2.5) is presented below:

Table 2.5. Review regarding driving performance of patients with MCI

			Diagnosis				Sample Scheme			Type of assessments				Driving Performance Measures with Significant differences													
	Authors	year	MCI	AD	PD	Controls	sample size	age <55	age >55	on road	driving simulator	neurological /neuropsychological examination	questionnaire	driving errors	speed (+variability)	lateral position (+variability)	reaction time	accident risk	headway	left turns	time to collision	confusion or disorientation	seat-belt use	significant differences only in neuropsychological tests	overall worse driving performance	
1	*Wadley et al.*	2009	●	-	-	●	105 (46+59)	-	●	●	-	●	●			●				●					●	*MCI: 5/8*
2	*Snellgrove*	2005	●	-	-	-	115	-	●	●	-	●	-	●	●	●									●	
3	*Griffith et al.*	2013	●	-	-	●	49 (15+34)	-	●	●	-	●	●	●		●									●	
4	*Bowers*	2013	●	-	-	-	47	-	●	●	-	●	-	●	●										●	
5	*Devlin et al.*	2012	●	-	-	●	28 (14+14)	-	●	-	●	●	●	-	-	-	-		-	-	-				-	
6	*Kawano et al.*	2012	●	-	-	●	57 (12+45)	●	●	-	●	●	●				-		●						○	
7	*Fritteli et al.*	2009	●	●	-	●	60 (20+20 +20)	-	●	-	●	●	●	●			●				●				●	
8	*Pavlou et al.*	2015	●	●	-	●	75 (23+14 +38)	-	●	-	●	●	●		●	●	●		●						●	

However, these conclusions are to be considered with some caution; given the small number of existing studies and their methodological variability, it is not yet safe to draw final conclusions. It is thereby noted that on-road assessments, simulator studies and self-report questionnaires have different objectives, advantages and limitations.

In addition to these different methodological properties of the experimental procedures, the designs of the experiments show very considerable variability, in terms of the driving performance measures used (e.g. number of errors for the on-road assessments, speed and lateral position for the simulators, self-reported driving frequency in the questionnaires), the duration of the assessment, the confounding factors controlled for etc., making it difficult to compare the results. It has also been emphasized that there is notable variability in the neuropsychological tools used to complement the assessment - while the related selection criteria for forming the batteries are often unclear - , making it difficult to validate the association of each tool with driving ability.

Of those studies assessing driving competence through on road testing, it seems that MCI patients, although they experience subtle changes in their driving competence are still able to drive. However, a level of impairment compared to healthy controls is generally being reported meaning that they still constitute a population at risk that warrants close supervision.

In accordance to the relative heterogeneity of outcomes of the on-road assessment studies, authors investigating driving competency through simulators also resulted in ambiguous findings. One study showed a limited impact of MCI on driving ability (i.e. mean time to collision), one study investigating brake patterns found no significant differences between MCI and healthy controls, whilst the third study presented significant differences in driving performance in a car following and in road tracking tasks.

Although MCI people preserve their awareness regarding their driving ability they experience changes in their driving behaviour such as poor scanning and observation of traffic and road signals, confusion with pedals and lack of anticipatory or defensive driving, errors on left turns and poor lane control. Studies involving the self-assessment of MCI population with regards to their driving status highlighted the great importance that driving holds with regards to their dependence and reported decline in driving frequency driving difficulties, situational avoidance, avoidance of unfamiliar areas and high traffic roads.

In a study by Olsen et al (2014) the question whether patients with MCI are safe to drive was addressed under the presence of unclear driving guidelines and assessment methods for the particular group. As the authors suggest, current guidelines in the United Kingdom do not distinguish memory impairment in a continuum from mild deficits to the level of dementia, resulting in a rather hazy interpretation of the term "cognitive impairment". What is more, no driving assessment is strictly required when concerns arise and it depends on the clinician to refer the patient for further evaluation. The authors also draw significant concern of the psychological and social consequences of screening for cognitive impairments resulting on a diagnosis and on the possible necessity for implementing driving restrictions. In conclusion, the lack of unified guidelines and evaluation tools across countries and the avoidance of timely driving assessment due to the negative impact on the patients' quality of life deter proper diagnosis and treatment in individuals with cognitive deficits.

Overall, while most on-road studies have shown that MCI patients are fit to drive, studies on a simulator environment have demonstrated that individuals with MCI are deficient in a number of variables compared to their healthy counterparts. Detection of deficient MCI drivers is critical for road safety. Prediction of driving fitness seems to be possible by neuropsychological tests and/or neurological or psychiatric measures (Beratis et al., 2015 – submitted). However, prediction of specific errors is still lacking in the literature or scarce.

Papageorgiou et al., (2014) indicated that neurological and neuropsychological measures are useful predictors of driving performance indexes of individuals with MCI. Measures assessing balance and movement coordination, visuospatial memory, speed of attention and information processing speed made the most important contribution on predicting various indexes of driving performance in the MCI group.

It may be interesting to note that, in addition to the general consensus among existing studies on the effect of MCI on driving performance, some known driving patterns often adopted by the general elderly population, are also identifiable in the MCI population, such as the awareness of physical and often cognitive decline, the adoption of compensatory strategies (e.g. driving at lower speeds, avoiding complex driving conditions etc.). However, the degree to which these patterns and compensatory strategies may have a positive or negative effect on their eventual crash risk is a most challenging research question.

Consistent with previous reports regarding levels of cognitive functioning, MCI constitutes an intermediate stage between normal aging and dementia. With regards to driving competence, this statement reflects an issue that requires further investigation. It has been argued that an interaction between the progressing of the pathology and the impaired driving exists for these individuals, making it difficult, and most interesting for further investigation, to conclude whether the stage of the disease is a predictor of driving ability or vice-versa.

Due to the heterogeneity of the MCI population, in terms of etiology, symptoms and evolvement, the systematic monitoring of the MCI population is stressed in all studies. Future studies, preferably by applying longitudinal designs, could expand our insight in the nature and particularities of driving ability in patients with MCI.

2.6.2. Drivers with AD

2.6.2.1. AD and driving ability

The risk of motor vehicle crashes for cognitively impaired individuals was first reported in 1967 (Waller, 1967). In the following years, many researchers have demonstrated that persons with dementia in the moderate or severe stage are incapable of driving (Johansson & Lundberg, 1997) and have been reported as contributing to hazardous driving (Brown and Ott 2004; Ernst et al. 2010; Johansson and Lundberg, 1997; Dubinsky et al., 1992; Rizzo et al., 2001; Uc et al., 2005; Uc et al., 2006; Ott 2008; Ernst et al. 2010), posing a significant risk to individual and public road safety (Man-Song-Hing et al., 2007; Reger et al., 2004; Lincoln et al., 2009) with increased possibility of getting lost (Kaszniak, Nussbaum, & Allender, 1990; Eby et al., 2012; Uc et al., 2004) or even cause crashes as pedestrians (Gorrie et al., 2008).

Lucas et al., (1988), reported that 30% of patients diagnosed with dementia had been involved in a car accident since the initial report of their cognitive symptoms. Other researchers found that individuals with Alzheimer's disease are 2.5 to 4.7 times more likely to be involved in a car crash than age-matched drivers without primary degenerative dementia. Indeed, the risk for crashes in demented patients rises above control rates beyond the third year of the disease (Drachman & Swearer, 1993), and patients with a score on the Clinical Dementia Rating scale (CDR) (Morris, 1993) exceeding one point (corresponding to moderate stage dementia) have worse driving performance when compared to patients with a CDR=0.5 (corresponding to questionable dementia or MCI) (Duchec et al., 2003; Stein & Dubinsky, 2011). In fact, higher CDR scores have been associated with poorer driving in several studies (Dubinsky et al., 2000; Hughes et al., 1982).

A systematic review conducted by Man-Son-Hing et al. (2007), clearly demonstrates that patients with AD perform more poorly on driving ability tasks when compared to control groups, both in on-road and driving simulator evaluations, and are more likely to drive slowly or off-road, and to have difficulties when attempting left turns (Uc et al., 2005; Cox et al., 1998). However, the duration of the disease forms only a very tenuous relationship with driving ability (Friedland et al., 1988; Reuben, 1991) and not all patients are incapable of driving, especially in the earlier stages of the disease (Perkinson et al., 2005, Trobe et al., 1995; Carr et al., 2000; Brown & Ott 2004; Ernst et al.2010; Withaar et al. 2000). Patients with very mild to mild AD may still be safe drivers, especially when

substantial driving experience, available through procedural memory, helps an individual to compensate for impairments (Piersma et al., 2016). Anderson et al. (2007) found that memory impairment does not impair most aspects of the driving performance of experienced drivers, but may increase safety risk under conditions of distraction.

According to the American Academy of Neurology (Iverson et al., 2010) and the Alzheimer's Association, a diagnosis of dementia is not, in and of itself, a sufficient reason to withdraw driving privileges; instead, the withdrawal of driving privileges should be based on the individual's driving ability. Although there is general consensus among professional organizations for recommending cessation of driving to patients at the moderate and severe stage of the disease, proper guidelines for those at the early stages of the disease are debatable. Given this evidence, it is particularly important to determine the cognitive or functional factors most likely to contribute to driving impairment among those with AD, especially when taking into account that a vast majority of patients with AD are active drivers (Mauri et al., 2014).

2.6.2.2. Driving performance of drivers with AD

In this chapter, **thirteen studies that examine the driving performance of patients with AD** (5 through on-road assessment and 8 through driving simulator experiment) are presented and the critical parameters assessing the driving performance of this group of patients are extracted. In Table 2.4, all following studies and their basic results are presented.

Hunt et al. (1997) evaluated the reliability of a standardized road test and found that failure rate on the road test for the group of controls was 3%, for patients with very mild AD was 6 times higher, and for patients with mild AD was 14 times higher. They concluded that dementia adversely affects driving performance even in its mild stages, although some AD patients drive safely for some time after the start of the disease. A traffic-interactive, performance-based road test that examines cognitive behaviours, provides an accurate and reliable functional assessment of driving behaviour. Likewise, Fitten (1995) showed that individuals with mild AD perform significantly worse on an on-road assessment than control subjects, with the demented group driving at slower speeds and making more driving errors.

More driving errors were made also by AD participants in another study (Bieliauskas et al., 1998). They investigated the performance of 9 individuals with AD and 9 age-matched controls on neuropsychological testing on an on-the-road driving test. Patients with AD differed significantly from controls on all neuropsychological tests, measures of driving error and reaction times. Although certain general cognitive measures appeared to predict some driving errors for those with AD, neuropsychological tests showed relatively weak overall power in predicting measured driving errors, consistent with most of the literature.

Uc et al. (2004), aimed to assess navigation and safety errors during a route-following task in drivers with AD. Thirty-two subjects with probable AD of mild severity and 136 neurologically normal older adults were tested on a battery of visual and cognitive tests of abilities that are critical to safe automobile driving. Each driver also performed a route-finding task administered on the road in an instrumented vehicle. Main outcome variables were number of a) incorrect turns, b) times lost, and c) at-fault safety errors. The drivers with mild AD made significantly more incorrect turns, got lost more often, and made more at-fault safety errors than control subjects, although their basic vehicular control abilities were normal. The navigational and safety errors were predicted using scores on standardized tests sensitive to visual and cognitive decline in early AD. The authors concluded that drivers with AD made more errors than neurologically normal drivers on a route-following task that placed demands on driver memory, attention, and perception.

Ott et al. (2008) examined the driving impairment of patients with dementia, in order to focus on the driving abilities primarily impaired in this kind of cerebral disease. For that purpose, they examined 84 individuals with clinically diagnosed AD and 44 cognitively intact individuals of similar demographic characteristics. They assessed the participants over a period of 3 years during which they went through cognitive, neurologic, visual and physical evaluations, and the participants' family informants provided the experimenters with information regarding accident history and traffic violations history. All subjects also participated in an on-road driving evaluation two weeks after the medical assessment. The results indicated that, overall, individuals with AD had worse driving performance than the control group, they had more accidents and presented a more significant deterioration of their driving performance over the years. However, the level of driving impairment depends on the stage of the disease and the demographic characteristics.

Dawson et al. (2009) aimed to measure the association of cognition, visual perception, and motor function with driving safety in AD. For that purpose, 40 drivers with probable early AD and 115 elderly drivers without neurologic disease underwent a battery of cognitive, visual, and motor tests, and a driving simulator experiment. A composite cognitive score (COGSTAT) was calculated for each subject based on eight neuropsychological tests. Drivers with AD committed an average 10 more safety errors/drive compared to drivers without AD; the most common errors were lane violations.

Eby et al. (2012) compared the driving performance of drivers with mild dementia to that of healthy controls without any cerebral disorder, on an on-road experiment. The objective of this project was to use in-vehicle technology to describe a set of driving behaviours that may be common in individuals with early stage dementia and compare these behaviours to a group of drivers without cognitive impairment. Seventeen drivers with a diagnosis of early stage dementia, who had completed a comprehensive driving assessment and were cleared to drive, participated in the study. Participants had their vehicles instrumented with a suite of sensors and a data acquisition system, and drove 1-2 months as they would under normal circumstances. Data from the early stage dementia group were compared to similar data from an existing dataset of 26 older drivers without dementia. In general, the driving performance of the two groups was not significantly different. However, the group of mild AD was found to have lower driving speed, was more unlikely to use their seat-belt and had disorientation issues. More specifically, the early stage dementia group was found to have significantly restricted driving space relative to the comparison group. At the same time, the early stage AD group drove as safely as the comparison group. Few safety-related behavioural errors were found for either group. Wayfinding problems were rare among both groups, but the early stage dementia group was significantly more likely to get lost.

Cox et al. (1998) indicated that AD patients when operating a driving simulator are more likely to have difficulty comprehending and operating the vehicle, drove outside the road lines, drove at significantly slower speed than the permitted limit, hit the brakes with little pressure when it is necessary, had difficulties with left turns and had a worse driving performance overall.

Frittelli et al. (2009) compared 20 patients with mild AD and 20 patients with MCI (as clustered by the CDR scores) with a group without any cognitive decline on a driving simulation task. Participants with mild AD had worse performance on two simulated

driving indexes: a) mean time to collision and b) number of off-road events. Visual reaction times were worse in the mild AD group and had a marginal correlation with their performance on the simulator.

Rizzo et al. (2001) studied the response of 18 drivers with AD and 12 healthy controls of similar age to a vehicle incursion at an intersection in a high-fidelity simulator (Iowa Driving Simulator). The results indicated increased crashes for the AD group, inappropriate or too slow control responses, and inattention 5 sec preceding a crash event. Measures of lateral control and longitudinal vehicle control on the uneventful segments before the intersection varied within restricted ranges and did not differ significantly between the two groups. Interestingly, the authors suggest in their discussion that by manipulating task demands in a simulated environment, that is by increasing "exposure" of cognitively impaired drivers and posing sufficient challenge, it is possible to observe safety errors of different types and infer crash risk through these observations.

Uc et al. (2006) tested avoidance of rear-end collisions in 61 drivers with AD and 115 elderly controls, all holding valid driving licenses, using a high fidelity driving simulator. Indexes of driving performance used were the standard deviations of mean steering wheel position, mean speed change, mean number of large steering adjustments (>6) per minute. The response of the AD subjects in collision avoidance situations was less effective than that of the control group. Although the likelihood of rear-end collisions in AD drivers was not significantly higher, they were less quick to react and were more likely to respond in an unsafe manner, by suddenly slowing down or stopping before reaching the intersection. Drivers with AD had poorer vehicle control than cognitively intact drivers, based on significantly increased variability and a tendency for increased speed variability in baseline driving circumstances under low traffic conditions on an uneventful segment of two-lane highway. Poorer vehicle control at baseline predicted unsafe outcomes in the complex driving condition at the intersection, suggesting that basic driving performance measures in the driving simulator can predict outcomes in high risk situations.

Finally, Vaux et al. (2010) studied how the ability of participants with neurodegenerative disease (AD or PD)[5] to detect impending collisions differed from that of cognitively intact subjects of comparable age in a low-fidelity simulator (6 AD patients, 8 PD patients and 18 healthy controls). Performance on a battery of standardized neuropsychological

[5] This paper could be considered in the next section as well, because PD patients were also examined

tests suggested early cognitive decline in the AD and PD group. The dependent variables were the collision detection sensitivity, indicating the ability to detect collision, and independent variables were the number of obstacles and time to collision. The results suggest that drivers with AD and PD required additional time to detect impending collisions, which likely impairs their ability to avoid collision events measured by the current simulation task. Impairments on the collision detection tasks in the neurodegenerative disease group reflected a variety of combined disturbances of visual-sensory processing, motion processing, attention, visuospatial skills and executive functions, as implied by the association between poor collision sensitivity and poor performance on tests of cognition and visual attention.

2.6.2.3. Neuropsychological contributions to driving assessment in AD

The predictive validity of neuropsychological tests for estimating the driving ability of patients with dementia and thus making recommendations about their driving status would be expected to correlate with their performance on on-road evaluations. However, within dementia samples, most neuropsychological tests correlated poorly with on-road test variables, with the exception of tests of visuospatial perception and attention–concentration (Reger et al., 2004).

As studies regarding the assessment of driving ability in older individuals and patients with AD accumulate, a growing body of research underscores the importance of administering neuropsychological tests to estimate the driving ability of both healthy adults and those in the early stages of cognitive decline. However, studies investigating the relationship between performance on neuropsychological tests and fitness to drive have yielded ambiguous results. This ambiguity underscores the importance of developing appropriate cognitive screening batteries in order to achieve a valid and reliable prediction of driving competence in patients with AD who may be at risk to drive (Hunt et al., 1993).

For example, Trobe et al. (1996) examined scores on neuropsychological tests as predictors of adverse driving events. They reviewed the crash and violation rates of 143 licensed drivers with Alzheimer's disease and 715 licensed drivers as control subjects. The results showed that neuropsychological performance could not predict future crashes or violations. However, other studies examining the same question have concluded that there is a correlation between driving ability and neuropsychological

variables, especially those measuring attention and executive skills (Uc et al., 2005; Elkin-Frankston et al., 2007).

The MMSE is the most commonly used measure for the evaluation of general cognitive ability among the elderly. A number of prospective and review studies have examined performance on the MMSE in relation to driving abilities, with variable results. Although the inconsistency of the MMSE as a predictor of driving ability has been shown in a number of studies (Uc et al., 2005; Fitten et al., 1995; Adler & Kuskowski, 2003; Paccalin et al., 2005), other studies suggest a consistent relationship between the two (Brown & Ott, 2004; Fox et al., 1997; Lesikar et al., 2002).

Attention, particularly visual attention, was one of the first functions identified in the literature as an important cognitive factor in relation to driving. Deficits in attention are present even in the early stages of AD, when individuals are more likely still to be driving. Selective attention, the ability to focus on a specific stimulus among others occurring simultaneously, is more specific to driving deficits than other components of attention, such as divided and sustained attention (Duchek et al., 1997; Parasuraman &Nestor, 1991). More specifically, selective attention refers to the ability to identify the important information in the environment, while ignoring the irrelevant, and presumably is critical for driving skills (Duchek et al., 1998).

The development of visual attention tests, administered via computers, has yielded greater consistency in findings than more traditional neuropsychological tests. The Useful Field of View (UFOV) is a computerized test examining the visual area available in a single glance, without head or eye movements and may also serve as a measure of the ability to detect, identify and localize a target among distracting stimuli. It was developed by Ball et al., (1993) and appears to be a valid predictor of driving ability. Using logistic regression models, Sims et al. (1998) found that a 40% reduction in UFOV was correlated with increased crash involvement. Moreover, Owsley et al. (1991) have suggested that statistical models incorporating the UFOV and the Dementia Rating Scale (DRS) have been useful in predicting the frequency of accidents in groups of older drivers. Thus, it appears that measures of selective attention are good predictors of driving in the elderly population, especially those with Alzheimer's disease. Additionally, based on the findings from these computerized visual attention tasks, the Driving Scenes Test of the Neuropsychological Assessment Battery (Stern & White, 2003) was developed as a measurement of visuospatial attention skills considered to be important in driving ability. Brown et al (2005) suggested that the aforementioned

neuropsychological test appears to have good ecological validity for real-world driving ability in normal and very mildly demented older adults.

Tasks measuring **executive functions** have also been reported to correlate with on-road tests of driving ability (Uc et al., 2005; Ott et al., 2003; Reger et al., 2004; Brown & Ott, 2004; Szlyk et al., 2002; Whelihan et al., 2005). More specifically, the Porteus Maze test, the Trail Making Test, particularly Part B and the Clock Drowning Test appear to be effective predictors of driving ability. Etienne and her collaborators (2013) studied mental flexibility in patients with early AD and how this function may affect driving performance. They found that AD patients had a significant worse performance in mental flexibility test than the control group and this deficit was linked to the deficit they showed in the driving simulator flexibility tests.

Episodic memory is one of the first functions to show decline in Alzheimer's disease, although it has not been considered a primary factor in driving ability. Yet Szlyk et al. (2002) found that Logical Memory (Immediate Recall condition) of the Wechsler Memory Scale-Revised (WMS-R), a measure of anterograde episodic verbal memory, had a significant relationship with several driving measures, such as lane boundary violations. Similarly, Uc and colleagues (2004) found that the Rey Auditory Verbal Learning Test recall condition could serve as a predictor of incorrect turns, number of times lost, and at-fault safety errors. Anderson (2007) found a positive association between neuropsychological tests (Rey Auditory, Verbal Learning Test (AVLT) and Complex Figure Test Recall (CFTR) with prospective crash rate.

As seen so far, a number of studies have examined a variety of neuropsychological tests as predictors of driving ability but not all tests have yielded conclusive results. For example, Hunt et al. (1993) in a study of on-road driving performance concluded that several neuropsychological measures (WMS-R Logical Memory, Benton Visual Retention Test (BVRT), Trail Making Test - Trails A, Boston Naming Test, Wechsler Adult Intelligence Scale - R (WAIS-R), Digit Symbol correlated with driving performance. Although Verbal Fluency was not related to driving performance in this study, it was associated with driving performance using a driving simulator in another study. By contrast, Fox et al., (1997) did not find any relationship between the neuropsychological measures employed (Visual Form Discrimination Test, Judgment of Line Orientation Test, Trail Making Test - Trails Trails A and B, BVRT, and WAIS-R subtests) and an on-road driving evaluation.

A meta-analysis by Reger et al. (2004), revealed a significant relationship between neuropsychological functioning and driving ability, as measured by on-road tests and off-road tests. Visuospatial perception may play a critical role in accurately positioning the car on the road and operating it, in judging distances and in predicting the development of traffic situations; thus, visuospatial tests may be particularly helpful in evaluating driving ability and in identifying unsafe drivers. Impairments of visuospatial abilities is often a primary symptom in early Alzheimer's disease and other dementias, especially under more complicated task demands. Reaction time has also been found to be impaired significantly in patients with Alzheimer's disease on an on-road driving evaluation. In the study of Dawson et al. (2009), those neuropsychological tests that reliably predicted fitness to drive in individuals with Alzheimer's disease were measures of working memory (BVRT), visuoconstructional skills (Complex Figure Test-Copy), motor function (Functional Reach), and visual search and visual motor speed (Trail Making Test-Part A).

Szlyk and colleagues (2002) examined the relationship between a neuropsychological test battery and driving simulation performance. Their battery was formed based on a survey answered by 125 neuropsychologists inquiring about the kinds of neuropsychological tests in use for driving ability screening. According to the results of the survey, a battery of nine cognitive tests was developed: the Seashore Rhythm Test, Logical Memory from the WMS-R (Immediate and Delayed Recall conditions), Visual Reproduction from WMS-R (Immediate and Delayed Recall conditions), Trail Making Test (Parts A and B), Digit Span, Digit Symbol, Block Design, Visual Form Discrimination and the Zoo Map Test. A group of patients with suspected dementia participated in a driving simulation task in which they had significantly more lane boundary crossings and slower driving speed than control participants. Number of lane boundary crossings was correlated with the greatest number of neuropsychological test variables and poorer cognitive performance overall. More specifically, Trails A and B and immediate recall on Logical Memory (WMS-R), correlated with the largest number of driving measures.

2.6.2.4. Conclusions

In this review, the question of **driving competency in the AD population was addressed**. Several studies have shown impaired in driving in on-road, as well as simulation experiments, among patients with AD. However, as subgroups of these patients have been found to be capable of driving, an accurate prediction of fitness to

drive is crucial for patients with AD. Regarding the driving performance of drivers with AD compared to that of healthy controls, as the review of driving simulator and on-road experiments indicated, a summarized Table (2.6) is presented below:

Table 2.6. Review regarding driving performance of patients with AD

			Diagnosis				**Sample Scheme**			**Type of assessments**				**Driving Performance Measures with Significant differences**												
	Authors	year	MCI	AD	PD	Controls	sample size	age <55	age >55	on road	driving simulator	neurological /neuropsychological examination	questionnaire	driving errors	speed (+variability)	lateral position (+variability)	reaction time	accident risk	headway	left turns	time to collision	confusion or disorientation	seat-belt use	**overall worse driving performance**	
1	*Fritteli et al.*	2009	●	●	-	●	60 (20+20+20)	-	●	-	●	●	●	●			●				●			●*	***AD: 12/13***
2	*Pavlou et al.*	2015	●	●	-	●	75 (23+14+38)	-	●	-	●	●	●		●	●	●		●					●	
3	*Hunt et al.*	1997	-	●	-	●	123 (65+58)	-	●	●	-	●	-	●										●	
4	*Fitten*	1995	-	●	-	●	69 (27+42)	●	●	●	-	●	-	●										●	
5	*Bieliauskas et al.*	1998	-	●	-	●	18 (9+9)	-	●	●	-	●	-	●			●							●	
6	*Uc et al.*	2004	-	●	-	●	168 (32+134)	-	●	-	●	●	-	●						●		●		●	
7	*Ott et al.*	2008	-	●	-	●	128 (84+44)	-	●	●	-	●	●					●						●	
8	*Dawson et al.*	2009	-	●	-	●	165 (40+115)	-	●	-	●	●	●	●										●	
9	*Eby et al.*	2012	-	●	-	●	43 (17+26)	-	●	●	-	●	●		●							●	●	-	
10	*Cox et al.*	1998	-	●	-	●	50 (29+21)	-	●	-	●	●	●	●	●					●		●		●	
11	*Rizzo et al.*	2001	-	●	-	●	30 (18+12)	-	●	-	●	●	-				●	●						●	
12	*Uc et al.*	2006	-	●	-	●	176 (61+115)	-	●	-	●	●	-		●	●	●	●			●			●	
13	*Vaux et al.*	2010	-	●	●	●	32 (6+8+18)	-	●	-	●	●	-								●			●	

More specifically, several studies have clearly demonstrated that driving performance declines considerably in individuals with AD and several on-road and simulator studies indicated worse driving performance for AD group compared to healthy controls in several driving measures. However, the research findings are less conclusive when it comes to the early stages of the disease, such as MCI or mild dementia. In these cases, there is variability in the type of cognitive functions impaired, as well as in the degree of impairment, and the degree to which these impairments are associated with driving abilities. Further research should therefore focus on this group of early stage AD

patients. In particular, longitudinal studies would be required in order to monitor the progression of the disease with respect to driving performance; in this framework, it may be worth investigating whether a decline in driving performance is a predictor of progression of the AD, or vice versa.

The awareness of these individuals in terms of the effect of the disease on their driving ability may also be a key aspect of further research. It has been demonstrated that early AD patients may attempt to compensate for their reduced driving skills by limiting the number and length of own driving trips, by avoiding demanding driving situations (e.g. nighttime, adverse weather, unfamiliar road network etc.) and by driving at reduced speeds. However, it is possible that their reduced exposure and the avoidance of certain situations may further compromise their driving performance. Moreover, the driving at reduced speed may, under certain conditions, have positive or negative effect on the traffic safety of these drivers.

Research priorities in the field should further address the association of on-road and simulator evaluations in terms of driving ability of individuals with dementia. Both experimental approaches have different advantages and limitations, and researchers are challenged to tradeoff between safety and control over the experimental conditions, with unfamiliar or unrealistic conditions. Most importantly, the optimal driving performance measures need to be identified, given that each method uses different measures (e.g. number of errors are the typical measures for on-road assessments, while speed, lateral control and reaction time are the most common measures of driving performance in simulator studies).

The neuropsychological literature suggests that performance on tests measuring selective attention, visuospatial abilities, and, to a lesser extent, executive functioning and memory, may predict the ability to drive safely in dementia. It is worth mentioning that attention, visuospatial skills and executive functions have been noted as the most critical functions for safe driving in several studies, as they appear to affect important driving tasks, such as journey planning, wayfinding, positioning and maneuvering the vehicle (e.g. left-turns), judging distances and predicting the development of driving situations, estimating risk and adapting speed etc. These findings make sense intuitively.

As Brown and Ott (2004) suggest, the ability to properly process visual information and to organize and monitor multiple stimuli at once are critical components of driving.

However, due to the moderate relationships of the neuropsychological tests with driving measures and individual variability, relying only on these tests for making recommendations regarding future driving restrictions for patients with dementia may be inadequate. In addition, although individual neuropsychological tests have shown a certain degree of relationship with driving measures, no single neuropsychological variable can consistently and reliably predict driving behaviour. Rather, different neuropsychological measures may be related to different aspects of driving behaviour. Ideally, neuropsychological tests should be used in combination with other measures, such as findings from a neurological assessment and the administration of actual or simulated road tests, to make driving recommendations.

2.6.3. Drivers with PD

2.6.3.1. PD and driving ability

A retrospective study published in the early 90s that included 150 PD patients and 100 controls found that **PD patients with more severe motor impairment** as assessed by the Hoehn & Yahr (H&Y) scale experience an increased risk for car accidents (Dubinsky et al., 1991). In particular during the 3-year period prior to the conduction of the study, PD patients with H&Y stages 2 & 3 were involved in more motor vehicle accidents (MVAs) when compared either to patients with H&Y stage 1 or to normal controls. Also, epidemiological information from Germany suggests that 15% of the 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). Notably, the presence of sleeping disturbances while driving appeared to significantly increase the risk for car accidents in the specific clinical group. Limitations of the aforementioned study are the lack of a control group as well as the low participation rate that could induce selection bias, thus masking the actual frequency of car accidents in patients with PD.

However, findings from a recent prospective cohort study did not reveal differences in crash risk between patients with PD and controls even after adjusting for age, education, gender, and miles driven per week at baseline (Uc et al., 2011). Nonetheless, the specific study revealed significantly greater rates of driving cessation in drivers with PD as compared to those of the control group. Hence, a possible reason for not detecting an increase crass risk in patients with PD could be explained by the decision of those individuals that were more impaired to stop driving before their actual engagement in a car accident. Increased rates of driving cessation in patients with PD were also found

in a retrospective study that took place in France (Lafont, Laumon, Helmer, Dartigues, & Fabrigoule, 2008). Moreover, the specific study also showed absence of a significant association between PD and car crashes. However, a noticeable limitation of this work is the self-reported nature of the information about the number of crashes. In addition, the small number of cases with PD in the analyzed sample could reduce in a critical way the power of study.

Future longitudinal studies by studying large cohorts of drivers with PD could add to our knowledge about the presence or not of an increased crash risk in drivers with PD as well as about the parameters that play a role on the levels of driving cessation in the specific clinical group. Notably, in a recent study it was found that only subjective feelings of a decline in driving performance and not objective measures of cognitive functioning and simulated driving performance played a role on the driving cessation of patients with PD (Stolwyk et al., 2015).

2.6.3.2. Indicative predictors of driving capacity of drivers with PD

Considerable effort has been directed toward the identification of **neuropsychological measures that can serve as predictors of fitness to drive in individuals with PD**. An indicative neuropsychological test that has been identified in several studies as predictor of driving skills in patients with PD is the Trail Making Test (TMT), especially part B of the specific test (Amick, Grace, & Ott, 2007; Classen et al., 2009; Grace et al., 2005). Abilities such as visual search, motor speed, and spatial skills are examined in both parts of the test (Crowe, 1998; Gaudino, Geisler, & Squires, 1995). In addition part B assesses aspects of executive control, such as mental flexibility and task shifting (Beratis, Rabavilas, Kyprianou, Papadimitriou, & Papageorgiou, 2013; Kortte, Horner, & Windham, 2002; Olivera-Souza et al., 2000). In the study of Amick et al. (Amick et al., 2007) a significant association was found between a greater number of driving errors and a poorer performance on the parts A and parts B of the TMT in drivers with PD that underwent an on-road driving evaluation. Similarly, drivers with PD that were characterized as unsafe according to their on-road driving performance had important difficulties on the part B of the TMT (Grace et al., 2005). Along the same vein, the study of Classen et al. (Classen et al., 2009) found in patients with PD that the part B of the TMT was significantly associated with the overall driving performance and the number of driving errors during an on-road assessment.

One more neuropsychological test that previous research has associated with driving skills of individuals with PD is the Useful Field of View (UFV) (Classen et al., 2009; Classen et al., 2011; Uc, Rizzo, Johnson, et al., 2009). The UFV is a computerized test that assesses various aspects of visual perception and attention, namely central vision and processing speed, divided attention, and selective attention (Ball & Owsley, 1993). In the study of Classen et al. (Classen et al., 2009) a strong correlation between UFOV risk index and the divided attention subtest with both the global rating score and the number of errors made during an on-road driving test was observed in patients with PD. In the same group of patients the correlations with other cognitive tests ranged from weak to moderate. A more recent study by the same research group also revealed the capacity of UFV to serve as a central predictor of driving fitness in patients with PD (Classen et al., 2011). Participants underwent an on-road driving evaluation and a number of visual, cognitive, and motor tests. In PD patients the divided attention subtest of the UFV showed the highest correlation with the pass/fail driving outcome and the number of maneuver errors.

The identification of UFV as a strong predictor of driving ability in patients with PD indicates the central involvement of impaired visual perception and visual attention in the driving difficulties commonly observed in the specific clinical group. Nonetheless, UFV is a computerized test that could be sensitive to various subject variables. Also, when using tests like the UFV, it is important to take under consideration the influence of primary aspects of visual functioning that could be impaired because of the neuropathology of PD. This is especially the case for contrast sensitivity (CS) that appears to commonly deteriorate in cases of PD because of the use of dopamine as neurotransmitter by cells within the retina (Bodis-Wollner & Tzelepi, 1998; Harnois & Di Paolo, 1990; Parkinson, 1989).Therefore, a good recommendation when using the UFV or other similar tasks related to visual attention is to include in the same analysis CS measures, in order to study the unique contribution of each predictor after controlling for their shared variance.

Another test that research findings support its capacity to serve as predictor of driving fitness in individuals with PD is the Rey-Osterreith Complex Figure (ROCF) (Amick et al., 2007; Grace et al., 2005; Uc, Rizzo, Johnson, et al., 2009). Notably, the aforementioned studies found associations between the ROCF test and driving performance during on-road testing procedures. This classical neuropsychological test assesses multiple cognitive domains, such as visual perception, visual spatial organization, motor functioning, executive skills, and non-verbal memory (Strauss, Sherman, Spreen, &

Spreen, 2006). As in the case of the TMT, the ROCF puts a substantial load on multiple cognitive domains that are required in order to achieve adequate driving functioning.

2.6.3.2. Driving performance of drivers with PD

In this chapter, **ten studies that examine the driving performance of patients with PD** (7 through on-road assessment and 3 through driving simulator experiment) are presented are presented and the critical parameters assessing the driving performance of this group of patients are extracted. In Table 2.5, all following studies and their basic results are presented.

Heikkilä et al. (1998) evaluated the driving ability of 20 patients with PD and 20 age-matched and sex-matched healthy controls by a structured on-road driving test. All participants were also assessed by the test package of the Austrian Road Safety Board (see Appendix for definition). Patients with PD showed significantly worse driving performance than control subjects in all neuropsychological tests. The number of driving errors correlated with performance on tests of all the cognitive domains investigated by the test package in both groups (except for the visual memory test). Slowness of visual processing, errors in perception, and slowness in recalling visual material, explained 62% of the variance in driving errors in the group of PD.

Grace et al. (2005) evaluated 18 patients with PD and 21 healthy elderly controls with a standardized on-road driving test and a battery of neuropsychological tests that measure visuospatial skills, psychomotor speed, memory, and executive functioning. Based on their performance on the road test, the patients were classified as either safe (n=11) or unsafe drivers (n=7). Unsafe drivers with PD differed significantly from safe drivers with PD on the delayed recall condition of the Hopkins Verbal Learning Test-Revised (see Appendix for definition), on the Rey-Osterrieth Complex Figure (see Appendix for definition) (ROCF), on TMT-B. Also, the severity of the disease, as determined by the Hoehn and Yahr scale (see Appendix for definition), was significantly linked to unsafe driving in PD patients.

Uc et al., (2006) aimed to assess the ability for visual search and recognition of roadside targets and safety errors during a landmark and traffic sign identification task in drivers with PD. Seventy-nine drivers with PD and 151 neurologically normal older adults went through a battery of visual, cognitive, and motor tests. The drivers were asked to report sightings of specific landmarks and traffic signs along a four-lane commercial strip

during an experimental drive in an instrumented vehicle. The PD drivers identified significantly fewer landmarks and traffic signs, and they committed more safety errors than control subjects, even after adjusting for baseline errors. The cognitive and visual deficits associated with PD resulted in impaired visual search while driving, and the increased cognitive load during this task worsened their driving safety. The strongest predictor for safety errors was the difference between the two conditions of the TMT that is considered to be a measure of executive functioning that controls for the influence of psychomotor speed and visual search.

Singh et al. (2007) aimed to explore the driving problems associated with PD and to ascertain whether any clinical features or tests predict driver safety. The driving ability of 154 individuals with PD referred to a driving assessment center was determined by a combination of clinical tests, reaction times on a test rig and an in car driving test. The majority of cases were able to continue driving although 46 individuals required an automatic transmission and 10 others needed car modifications. Ability to drive was predicted by the severity of physical disease, age, presence of other associated medical conditions, particularly dementia, duration of disease, brake reaction, time on a test rig and score on a driving test. Overall, most individuals with PD were safe to drive, although many benefited from car modifications or from using an automatic transmission.

Lee and al. (2007) explored the validity of driving simulator technology in assessing drivers with PD. Fifty PD patients and 150 healthy controls of similar demographics participated in the study. The criteria for assessing the simulator and on-road tests were combined by principal component analysis (PCA), while an overall simulated driving index and a road assessment index were developed for the PD group and the control group. The indices were significantly different in the experimental and control groups. In the simulated driving test, the drivers with PD performed significantly less safely than the controls. Participants with PD tended to drive slower 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.

Uc et al. (2009) studied the driving performance of 84 patients with PD and 182 elderly controls. Participants went through an on-road drive test with an instrumented vehicle and were subjected to visual, motor, and cognitive tests similar to those used in their previous studies (Uc et al., 2006a; Uc et al., 2006b). The findings indicated that in addition to age and global cognitive function, decline in visual attention (UFOV), motion

perception, far visual acuity, constructional skills (CFT-copy), and visual memory (CFT-recall) predicted total driving errors. There was no significant association with motor dysfunction. However, although driving errors were more frequent in the drivers with PD, approximately 25% of them had error counts similar to the median errors of the control drivers.

Classen et al. (2011) used screening tests administered by a certified driving rehabilitation specialist and by PD specialty neurologists to develop a model to predict on-road outcomes for patients with PD. The authors administered a battery of screening tests to 41 patients with PD and 41 age-matched control participants before on-road testing. They used statistical models to predict actual on-road performance. The PD group had a higher failure rate, indicating more on-road errors. For the PD participants, the UFOV Subtest 2 and Rapid Pace Walk were responsible for most of the variance in the on-road test. The model accurately categorized pass-fail outcomes for 81% of PD patients. Clinical screening batteries may be predictive of driving performance in PD. The identification of UFOV in individuals with PD as a strong predictor of on-road driving ability indicates the central involvement of impaired visual perception and visual attention in the declined driving ability of PD patients.

Ranchet et al. (2013) aimed to determine the role of cognitive impairments in specific executive functions on driving performance of patients with PD. For this purpose, 19 patients with mild to moderate PD and 21 healthy controls matched for age, education, and driving experience were tested using a neuropsychological battery assessing global cognitive abilities, updating, flexibility, and inhibition. Participants also underwent a 45-minute road test in which they were scored by a driving instructor and a second experimenter. To separate "at-risk" drivers from safe drivers, a composite driving indicator was calculated from the Test Ride for Investigating Practical Fitness to Drive score, the penalty score from the observation grid, and the number of safety interventions made by the driving instructor. The authors found out that 8 out of 40 participants (all PD patients) were rated as "at risk".

Finally, a study carried out by our research team (Pavlou et al., 2015b) aimed in investigating the driving performance of drivers with PD in a driving simulator experiment, in which healthy participants and PD patients drove in different driving scenarios. Sixty-two participants participated, 21 PD patients and 41 demographically matched control drivers. The driving scenarios included driving in rural area in low and high traffic volumes and driving on a motorway. The driving performance of PD was

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. Various driving performance measures were examined, including speed, lateral position, steering angle, headway distance, 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 was examined: maneuvers through work-zone segments in motorway. The results showed that PD patients performed significantly worse than the control group. More specifically, they drove at significantly lower speeds and with larger headway compared to healthy drivers, had higher reaction times, were more likely to have an accident in the work-zone segment of the motorway, had difficulties in positioning the vehicle in the lane and had difficulties in dealing with demanding tasks.

2.6.3.4. Comparison of cognitive and motor measures

In studies that have applied multivariate models, **cognitive measures appear to be stronger predictors than motor indexes of driving fitness in patients with PD**. For example, the study of Uc et al. (Uc, Rizzo, Johnson, et al., 2009) found that certain cognitive measures, such visual attention, constructional skills and visual memory could predict total driving errors, whereas this was not the case for motor dysfunction. Also, no significant associations between measures of motor function (UPDRS-motor, Tapping speed, Walking Speed) and driving errors were observed in another study of the same research group. On the contrary, the reduced driving performance of patients with PD was linked to the functioning of various cognitive domains (Uc et al., 2007). Driving simulator research has also revealed a similar pattern of results. Executive-related measures and measures of information processing speed were associated with the majority of the driving measures, while a limited number of significant correlations between the driving measures and motor symptoms of the disease, as measured by the motor-UPDRS were observed (Stolwyk, Charlton, et al., 2006).

A study that utilized a univariate statistical approach showed significant associations between driving fitness and specific items of the motor component of the Unified Parkinson Disease Rating Scale (UPDRS-motor) scale, namely postural stability, facial expression and neck rigidity (Grace et al., 2005). Also, the severity of the disease, as determined by the Hoehn and Yahr scale, was significantly linked to unsafe driving in PD patients. Nonetheless, the findings of the specific work are limited because of the absence of a multivariate model that would have the capacity to assess the unique

contribution of each predictor. According to simulator data, motor measures and not only cognitive variables could have a central role as predictors of driving fitness under low visibility conditions that require sufficient response speed in order to avoid a crash (Uc, Rizzo, Anderson, et al., 2009). Prospective research could add to the existing knowledge by studying the role of cognitive and motor measures and their interaction under various demanding driving conditions. Finally, a parameter that may explain why motor measures do no generally show a strong connection with driving performance in patients with PD could be the positive association that exists between motor dysfunction and driving cessation in the specific clinical group (Crizzle, Myers, & Almeida, 2012).

2.6.3.5. Conclusions

However, as subgroups of these patients have been found to be capable of driving, an accurate prediction of fitness to drive is crucial for patients with PD. Regarding the driving performance of drivers with PD compared to that of healthy controls, as the review of driving simulator and on-road experiments indicated, a summarized Table (2.7) is presented below:

Table 2.7. Review regarding driving performance of patients with PD

			Diagnosis				**Sample Scheme**			**Type of assessments**				**Driving Performance Measures with Significant differences**											
	Authors	year	MCI	AD	PD	Controls	sample size	age <55	age >55	on road	driving simulator	neurological /neuropsychological examination	questionnaire	driving errors	speed (+variability)	lateral position (+variability)	reaction time	accident risk	headway	left turns	time to collision	significant differences only in neuropsychological tests		**overall worse driving performance**	
1	*Vaux et al.*	2010	-	●	●	●	32 (6+8+18)	-	●	-	●	●	-								●			●	***PD: 8/10***
2	*Ranchet et al.*	2013	-	-	●	●	40 (19+21)	-	●	●	-	●	●		●	●		●	●					●	
3	*Heikkila et al.*	1998	-	-	●	●	40 (20+20)	-	●	●	-	●	●	●										●	
4	*Grace et al.*	2005	-	-	●	●	39 (18+21)	-	●	●	-	●	●									●		-	
5	*Uc et al.*	2006	-	-	●	●	230 (79+151)	-	●	●	-	●	●	●								●		●	
6	*Uc et al.*	2009	-	-	●	●	168 (84+182)	-	●	●	-	●	●	●										●	
7	*Singh et al.*	2007	-	-	●	-	154	-	●	●	-	●	●											○	
8	*Lee et al.*	2007	-	-	●	●	200 (50+150)	-	●	●	●	●	●	●	●	●		●						●	
9	*Classen et al.*	2011	-	-	●	●	82 (41+41)	-	●	●	-	●	●	●										●	
10	*Pavlou et al.*	2015	-	-	●	●	62 (21+41)	-	●	-	●	●	●	●	●	●	●	●	●					●	

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. Notably, measures that engage executive, attentional and visuospatial resources show strong associations with driving fitness in individuals with PD. These three domains have been found to be crucial for safe driving in numerous studies (Adler, Rottunda, & Dysken, 2005; Asimakopulos et al., 2012; Mathias & Lucas, 2009), as they affect primary driving tasks such as journey planning and route choice / way-finding, positioning and maneuvering the vehicle (e.g. left-turns, merging etc.), judging distances and predicting the development of driving situations, estimating risk and adapting driving behaviour (e.g. speed).

Moreover, pronounced difficulties in indexes of driving performance seem to appear in drivers with PD under demanding driving conditions that involve increased cognitive load (e.g. dual-tasking, distraction, way-finding etc.). However, care should be taken the dual tasking or distraction conditions that are applied to require a similar amount of resources from all drivers independently of whether they belong to a clinical or the control group in order to compare their driving performance under balanced conditions.

The current knowledge about the driving performance of patients with PD is based both on on-road and simulator studies, two different methodological approaches with different advantages and limitations. For example, an important advantage of driving simulator experiments is that they provide the opportunity to test the driving performance of patients with PD under demanding driving conditions, whose assessment is very difficult or even unethical during on-road driving evaluations. Moreover, driving simulator procedures provide a detailed analysis of driving behaviour that increases our insight about the underlying reasons that lead to driving errors or even to crashes. However, a limitation of driving simulator testing compared to on-road testing is that its validity has not been established yet in samples that include older individuals with an underlying neurological disorder.

Prospective studies by combining information from on-road evaluations and simulator designs could reach to more solid conclusions about the role and the effect size of various predictors on driving performance measures. Also, an objective of future research should be the development of a wider array of cutoff scores with the use of larger and more representative samples of patients with PD. This kind of information can facilitate decisions about the restriction or total loss of driving privileges.

For improving our insight, the use of multiple measures that assess various domains appears to be essential, because this approach permits the extraction of the unique effect of each predictor as well as the estimation of its relative importance. Moreover, the combination of cognitive measures with brain imaging data could refine the methods currently used for assessing the driving ability of patients with PD (Weathers, Kotagal, Bohnen, & Chou, 2014).

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 conducting the statistical procedures 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 as well as during the time of 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, hallucinations).

Based on the findings of the previous studies it appears that various cognitive 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 in isolation, because this practice could lead to imprecise decisions that can have dangerous consequences (Beratis et al., 2015).

Future studies by expanding the existing bounds of knowledge can further our theoretical and practical insight about the link that exists between cognitive dysfunction due to PD and driving fitness under various driving conditions and environments.

2.6.4. Drivers with MCI, AD and PD and distraction

Driver distraction constitutes a particular human factor of road accident causation. Driver distraction is generally defined as "a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver's awareness, decision making ability and/or

performance, leading to an increased risk of corrective actions, near-crashes, or crashes" (Regan et al., 2011).

More specifically, driver distraction involves a secondary task, distracting driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004) and may include four different types: physical distraction, visual distraction, auditory distraction and cognitive distraction.

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Driver distraction factors that occur inside the vehicle seem to have greater effect on driver behaviour and safety. Horberry et al., (2006) confirm that in-vehicle distraction sources have a more important effect on driver performance, compared to the increased complexity of the stimuli received from the road and traffic environment. Moreover, certain studies report that external distraction factors are less than 30% of the total distraction factors (Stutts et al., 2001; Kircher, 2007). Other studies specify that external distraction factors account for less than 10% of all distraction factors (Sagberg, 2001; MacEvoy et al., 2007).

According to accumulating evidence, one of the most important in-vehicle distractors appears to be the use of mobile phone (Burns et al., 2002; Dragutinovits et al., 2005; McEvoy et al., 2005; Sagberg 2001). Patel et al., (2008) by assessing 14 common types of driver distraction, concluded that the highest perceived risk appeared in the case of mobile phone use, whereas "conversing to passengers" was considered as one of the distractors with the lowest perceived risk. Also, the greater distraction load of the mobile phone use, as compared to the conversation with passengers, was documented by NHTSA (2008). In particular, the use of mobile phone was associated with more than 3 times increased accident risk compared to "conversing with a passenger".

Previous research has examined the influence of driver demographics like age and gender on driving performance under driving conditions with distraction. A greater negative impact on the reaction time of older drivers compared to young drivers that used a mobile phone was reported by Caird et al., (2008). Along the same vein, a driving simulator experiment conducted by Nilsson and Alm (1991) showed that elderly drivers' reaction time to an unexpected event was significantly larger than that of young drivers when distracted by a mobile phone conversation.

Within the group of older drivers, measures of cognitive functioning appear to moderate the link between distraction and driving performance (Cuenen et al., 2015). However, to the best of our knowledge previous research **has not focused on the role of distraction on the driving behaviour of patients with MCI, AD or PD**, three common neurological conditions with a high prevalence in the group of older drivers.

2.7. Synthesis of review findings

The objective of the present PhD thesis is the analysis of the effect of neurological diseases affecting cognitive functions on driver behaviour and road safety. Within this framework, **an exhaustive literature review was carried out and presented in this chapter** examining in a comprehensive way driving behaviour and road safety, ways to assess driving behaviour, driving simulator characteristics as well as neurological diseases affecting cognitive functions (MCI, AD and PD) and how these cerebral diseases affect driving performance (Figure 2.11).

Figure 2.11. Chapter 2 outline

The main part of this review included the review of several studies, which allowed the drawing of conclusions about the driving deficits of drivers suffering from cerebral diseases, such as MCI, AD and PD and the critical parameters assessing the driving performance of these group of patients were extracted. From all these complementary reviews several specific conclusions are extracted and presented here-in.

Regarding driving behaviour of patients with MCI:

» The conclusions are **to be considered with some caution**; given the small number of existing studies and their methodological variability, it is not yet safe to draw final conclusions.
» The designs of the experiments show **very considerable variability**, making it difficult to compare the results.
» Of those studies assessing driving competence through on road testing, it seems that **MCI patients**, although they experience certain changes in their driving competence **they are still able to drive**.

» However, **a level of impairment compared to healthy controls is generally being reported** meaning that they still constitute a population at risk that warrants close supervision.
» Although MCI people preserve their **awareness regarding their driving ability** they experience changes in their driving behaviour such as poor scanning and observation of traffic and road signals, confusion with pedals and lack of anticipatory or defensive driving, errors on left turns and poor lane control.
» Studies involving the self-assessment of MCI population with regards to their driving status highlighted **the great importance that driving holds with regards to their dependence** and reported decline in driving frequency driving difficulties, situational avoidance, avoidance of unfamiliar areas and high traffic roads.
» Studies on a simulator environment have demonstrated that **individuals with MCI are deficient** in a number of variables compared to their healthy counterparts.
» **Detection of deficient MCI drivers** is critical for road safety.
» Prediction of driving fitness seems to be possible by **neuropsychological tests and/or neurological or psychiatric measures**. However, prediction of specific errors is still lacking in the literature or scarce.
» Some known **driving patterns often adopted** by the general elderly population, are also identifiable in the MCI population, such as the awareness of physical and often cognitive decline, the adoption of compensatory strategies.
» MCI constitutes an **intermediate stage** between normal aging and dementia. With regards to driving competence, this statement reflects an issue that requires further investigation.
» Previous research has not focused on **the role of distraction** on the driving behaviour of patients with MCI.
» Future studies, preferably by **applying longitudinal designs**, could expand our insight in the nature and particularities of driving ability in patients with MCI.

Regarding driving behaviour of patients with AD:

» **Driving performance declines considerably** in individuals with moderate or severe dementia.
» Longitudinal studies would be required in order to monitor the **progression of the disease with respect to driving performance;** in this framework, it may be worth investigating whether a decline in driving performance is a predictor of progression of the AD, or vice versa.
» The awareness of these individuals in terms of the effect of the disease on their driving ability may also be **a key aspect of further research**.

» Early **AD patients may attempt to compensate for their reduced driving skills** by limiting the number and length of own driving trips, by avoiding demanding driving situations (e.g. nighttime, adverse weather, unfamiliar road network etc.) and by driving at reduced speeds.
» However, it is possible that **their reduced exposure and the avoidance of certain situations** may further compromise their driving performance. Moreover, the driving at reduced speed may, under certain conditions, have positive or negative effect on the traffic safety of these drivers.
» Research priorities in the field should **further address the association** of on-road and simulator evaluations in terms of driving ability of individuals with dementia.
» **The optimal driving performance measures** need to be identified, given that each method uses different measures (e.g. number of errors are the typical measures for on-road assessments, while speed, lateral control and reaction time are the most common measures of driving performance in simulator studies).
» The neuropsychological literature suggests that performance on tests measuring selective attention, visuospatial abilities, and, to a lesser extent, executive functioning and memory, **may predict the ability to drive safely in dementia**.
» Ideally, **neuropsychological tests** should be used in combination with other measures, such as findings from a neurological assessment and the administration of actual or simulated road tests, to make driving recommendations.
» Previous research has not focused **on the role of distraction** on the driving behaviour of patients with AD.

Regarding driving behaviour of patients with PD:
» Previous research indicate that **driving capacity in patients with PD is mainly compromised** due to cognitive deficits that accompany this clinical condition.
» Moreover, **pronounced difficulties in indexes** of driving performance seem to appear in drivers with PD under demanding driving conditions that involve increased cognitive load (e.g. dual-tasking, distraction, way-finding etc.).
» However, **care should be taken the dual tasking** or distraction conditions that are applied to require a similar amount of resources from all drivers independently of whether they belong to a clinical or the control group in order to compare their driving performance under balanced conditions.
» The **current knowledge about the driving performance of patients with PD** is based both on on-road and simulator studies, two different methodological approaches with different advantages and limitations.

» Moreover, driving simulator procedures **provide a detailed analysis of driving behaviour** that increases our insight about the underlying reasons that lead to driving errors or even to crashes.
» Prospective studies by **combining information from on-road evaluations and simulator designs** could reach to more solid conclusions about the role and the effect size of various predictors on driving performance measures.
» For **improving our insight**, the use of multiple measures that assess various domains appears to be essential, because this approach 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 conducting the statistical procedures 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 as well as during the time of the neurological/neuropsychological assessment.
» Various cognitive 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 in isolation, because this practice could lead to imprecise decisions that can have dangerous consequences.
» Future studies by **expanding the existing bounds of knowledge** can further our theoretical and practical insight about the link that exists between cognitive dysfunction due to PD and driving fitness under various driving conditions and environments.

Overall, the driving behaviour and safety characteristics of patients with neurological diseases affecting cognition, haven't been examined, in-depth, so far by the international literature, and thus there is a gap that this PhD thesis is going to fill in, mathematically by innovative statistical techniques.

Table 2.8 presents the studies and the driving measures in which drivers with cerebral diseases have significant differences with the healthy controls, in a summary format.

Table 2.8. Overview of the literature review

			Diagnosis				Sample Scheme			Type of assessments				Driving Performance Measures with Significant differences												
	Authors	year	MCI	AD	PD	Controls	sample size	age <55	age >55	on road	driving simulator	neurological /neuropsychological	questionnaire	driving errors	speed (+variability)	lateral position (+variability)	reaction time	accident risk	headway	left turns	time to collision	confusion or disorientation	seat-belt use	significant differences only in neuropsychological tests	overall worse driving performance	
1	*Wadley et al.*	2009	●	-	-	●	105 (46+59)	-	●	●	-	●	●			●				●					●	
2	*Snellgrove*	2005	●	-	-	-	115	-	●	●	-	●	-	●	●	●									●	
3	*Griffith et al.*	2013	●	-	-	●	49 (15+34)	-	●	●	-	●	●	●		●									●	
4	*Bowers*	2013	●	-	-	-	47	-	●	●	-	●	-	●	●										●	
5	*Devlin et al.*	2012	●	-	-	●	28 (14+14)	-	●	-	●	●	●	-	-	-	-		-	-	-				-	
6	*Kawano et al.*	2012	●	-	-	●	57 (12+45)	●	●	-	●	●	●				-		●						○	*MCI: 5/8*
7	*Fritteli et al.*	2009	●	●	-	●	60	-	●	-	●	●	●	●			●				●				●*	
8	*Pavlou et al.*	2015	●	●	-	●	75	-	●	-	●	●	●		●	●	●		●						●	
9	*Hunt et al.*	1997	-	●	-	●	123 (65+58)	-	●	●	-	●	-	●											●	
10	*Fitten*	1995	-	●	-	●	69 (27+42)	●	●	●	-	●	-	●											●	
11	*Bieliauskas et al.*	1998	-	●	-	●	18 (9+9)	-	●	●	-	●	-	●			●								●	
12	*Uc et al.*	2004	-	●	-	●	168	-	●	-	●	●	-	●						●		●			●	
13	*Ott et al.*	2008	-	●	-	●	128 (84+44)	-	●	●	-	●	●					●							●	
14	*Dawson et al.*	2009	-	●	-	●	165	-	●	-	●	●	●	●											●	
15	*Eby et al.*	2012	-	●	-	●	43 (17+26)	-	●	●	-	●	●		●							●	●		-	*AD: 12/13*
16	*Cox et al.*	1998	-	●	-	●	50 (29+21)	-	●	-	●	●	●	●	●					●		●			●	
17	*Rizzo et al.*	2001	-	●	-	●	30 (18+12)	-	●	-	●	●	-				●	●							●	
18	*Uc et al.*	2006	-	●	-	●	176	-	●	-	●	●	-		●	●	●	●			●				●	
19	*Vaux et al.*	2010	-	●	●	●	32 (6+8+18)	-	●	-	●	●	-								●				●	
20	*Ranchet et al.*	2013	-	-	●	●	40 (19+21)	-	●	●	-	●	●		●	●		●	●						●	
21	*Heikkila et al.*	1998	-	-	●	●	40 (20+20)	-	●	●	-	●	●	●											●	
22	*Grace et al.*	2005	-	-	●	●	39 (18+21)	-	●	●	-	●	●											●	-	*PD: 8/10*
23	*Uc et al.*	2006	-	-	●	●	230	-	●	●	-	●	●	●										●	●	
24	*Uc et al.*	2009	-	-	●	●	168	-	●	●	-	●	●	●											●	
25	*Singh et al.*	2007	-	-	●	-	154	-	●	●	-	●	●				○								○	
26	*Lee et al.*	2007	-	-	●	●	200	-	●	●	●	●	●	●	●	●		●							●	
27	*Classen et al.*	2011	-	-	●	●	82 (41+41)	-	●	●	-	●	●	●											●	
28	*Pavlou et al.*	2015	-	-	●	●	62 (21+41)	-	●	-	●	●	●	●	●	●	●	●	●						●	
*only for the AD group		Total	8	13	10					17	12			16	9	8	6	6	4	3	3	3	1	2		

Chapter Three
Methodological Approach

This chapter includes the methodological approach of the present PhD thesis. Firstly, an **innovative methodological approach** is a central component of this research. For this purpose, an extended literature review (presented in chapter 2) took place in order to investigate the key driving performance measures and the statistical analyses implemented in the scientific field of driving performance of drivers with neurological diseases affecting cognitive functions. Based on this literature review, the **critical driving performance measures** are selected and **a unique statistical methodology** is developed for the investigation of the effect of cerebral disorders on driving performance, driving errors, reaction time and accident probability.

In the beginning of this chapter, driving performance measures examined in driving simulator experiments are presented and analyzed including lateral control, longitudinal control, reaction time, gap acceptance, eye movement and workload measures. Furthermore, a list of the most common driving simulator dependent variables is cited. Next, based on the literature review presented in chapter 2, regarding statistical methods implemented in driver performance experiments, an innovative statistical methodology analysis is developed which consists of the following phases. The first phase concerns the development of regression models regarding key performance parameters of the database. Such models are often used in driver behaviour analysis in order to estimate the effect of cerebral diseases on specific driving performance parameters and indirectly on driving behaviour and road safety. The second phase of the analysis methodology, is the central component of the PhD thesis as for the first time latent analysis is implemented on driver behaviour research regarding patients with neurological diseases affecting cognitive functions. The aim of this attempt is to estimate directly the effect of driver, road and traffic environment characteristics both on driving performance, driving errors, reaction time and accident probability. In order to achieve this target, latent models analysis is implemented including Principal Component Analysis and Structural Equation Models (SEMs). Within this framework, the theoretical background of all steps of the selected statistical analyses are presented in this chapter. Finally, a synopsis of the overall methodology is presented.

3.1. "Driving at the simulator" experimental design principles

There is a variety of ways that an experiment can be designed. For example, subjects can all be tested under each of the treatment conditions or a different group of subjects can be used for each treatment. An experiment might have just one independent variable or it might have several. This section describes basic experimental designs and their advantages and disadvantages.

3.1.1. Within or between-subjects designs

Within-subjects factors refer to the variables of interest that are measured for all subjects, i.e. the variables pertaining to the experiment conditions. On the other hand, between-subjects factors refers to the variables that apply only to some subjects. In the driving simulator experiment these are typically subject variables, such as demographic variables and participant type where part of the subjects are tested for some of the experiment conditions, while the rest of the subjects are tested for the remaining experiment conditions. In several cases, a mixture of both types of design will be involved, given that there are variables which are by nature between-subject (e.g. gender, as a participant can be either male or female) while others can be within-subject (e.g. driving with distraction or without distraction - a condition that can be tested for all subjects). A mixed factorial design includes both within-subjects and between-subjects factors.

An advantage of within-subjects designs is that individual differences in subjects' overall levels of performance are controlled. This is important because subjects invariably will differ greatly from one another. In an experiment on problem solving, some subjects will be better than others regardless of the condition they are in. Similarly, in a study of blood pressure some subjects will have higher blood pressure than others regardless of the condition. Within-subjects designs control these individual differences by comparing the scores of a subject in one condition to the scores of the same subject in other conditions. In this sense each subject serves as his or her own control. This typically gives within-subjects designs considerably more power than between-subjects designs. That is, this makes within-subjects designs more able to detect an effect of the independent variable than are between-subjects designs.

Within-subjects designs are often called "repeated-measures" designs since repeated measurements are taken for each subject. Similarly, a within-subject variable can be called a repeated-measures factor.

3.1.2. Full factorial or fractional factorial design

Each experiment is based on a combination of conditions, resulting from the combinations of levels of the variables of interest. The complete combination of all levels of the variables of interest results in a full factorial design. In several cases, however, a fractional factorial design may be opted for, by eliminating some of the combinations of levels of the variables examined, on the basis of appropriate criteria (McLean and Anderson, 1984), especially when the number of variables is high, resulting to an unmanageable full factorial design. More specifically, a fractional factorial design is most often based on a full factorial design of some key variables of interest, complemented with selected combinations of these variables with other variables of interest (Montgomery, 2000).

3.1.3. Methodological gaps of driving simulator designs

Furthermore, the review of the literature referring to experiments using a driving simulator reveals that there is a number of recurrent threats to validity when conducting driving simulator experiments in particular, namely (Caird & Horrey, 2011):

» **Failure to adequately screen participants**: Vision or health problems of certain individuals may contribute to experimental error that masks or distorts effects. It's crucial to use appropriate tests to screen drivers;
» **Generalization issues**: Tasks, population samples and environments are not similar to whom or what you wish to generalize. It is crucial to qualify results according to generalizability limitations. Researchers should include similar tasks, samples and environments to desired generalizations;
» **Drop out due to simulator sickness**: Properties of the simulator or activities in the simulator cause participants to become sick. A possible solution is to reduce maneuvers that require a sweeping motion such as left or right turns;
» **Non randomization of participants, treatments or events**: Treatments, participants or events are not randomly assigned to levels of the independent variable. Events are predictably located within drivers. The solution is simple: Randomize;

» **Range or carry-over effects**: Multiple treatments are experienced by the same participant. The order of treatment and experience causes asymmetric effects. It's crucial to use between-subjects designs for different treatment levels.

All these possible threats need to be taken into account in the design of the present simulator experiment.

3.2. Dependent measures for simulator studies on older drivers

A **variety of different dependent measures are used to assess driver performance** and the choice of variables is in part dictated by the research question. Investigators should be wary of ceiling and floor effects when testing different age groups no matter what dependent measure they choose. Pilot testing can help ensure that the task is neither too easy nor too difficult to reveal age differences.

This chapter reviews a range of assessment measures that have been used in order to assess the impact of cerebral disorders on driving performance including lateral control, longitudinal control, reaction time, eye movement and workload measures. Finally, a list of the most common driving simulator dependent variables is cited and some general remarks are provided.

3.2.1. Longitudinal control measures

A range of longitudinal control measures can be examined in driver behaviour and human factors research. Two of the most common are speed and headway (Figure 3.1)

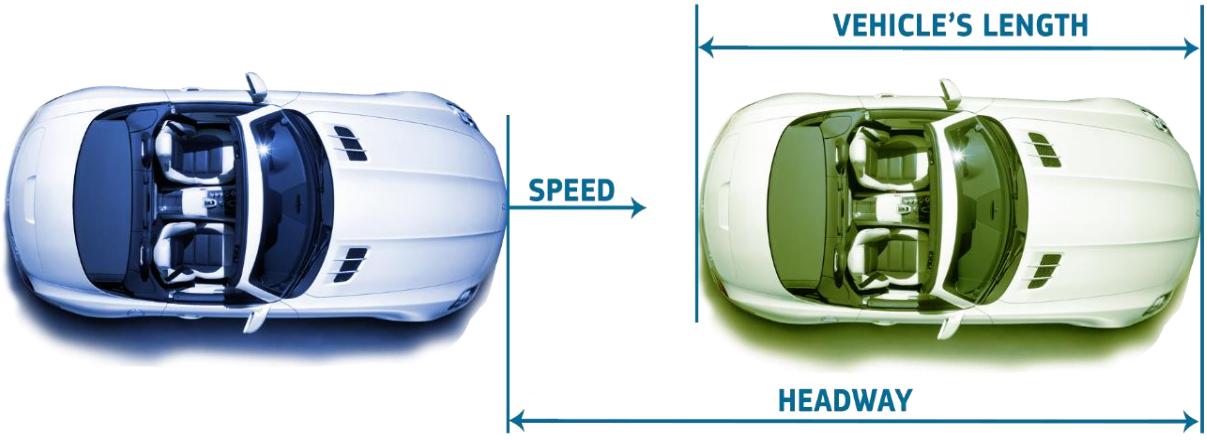


Figure 3.1. Speed and headway icon

which are further analyzed below. Overall, **longitudinal measures assess how well drivers achieve or maintain a certain target speed** (Trick & Caird, 2011). However, it is pertinent to take into consideration that compared to younger drivers, older drivers take longer to accelerate to the posted speed limit (Strayer & Drews, 2004) and brake over longer distances (Caird et al., 2007). There is evidence that older drivers try to stop with more precision, compared to younger drivers and, in general, they are more inclined to value accuracy over speed. It is important to consider this possibility when designing instructions and, if possible, it may be beneficial to try to assess whether participants are putting differential emphasis on speed or accuracy.

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. Speed maintenance is an essential driving skill and it can be related to tactical decisions (Michon, 1989). For older drivers, the most common pattern is to adopt slower speeds to increase available reaction time (Chu, 1994). Older drivers and especially drivers with cerebral diseases may use this strategy in order to exert some control over their circumstances and compensate for age-related and cerebral-related increases in reaction time. When age comparisons are made, driving speeds are typically more variable within a given drive in samples of older drivers. In general, driving speeds are about three to five kilometers per hour slower in older drivers, but this may change depending on the posted speed limit of a roadway (Milloy & Caird, 2011).

Because fewer perceptual cues to depth are available in a simulator, drivers may have difficulty calibrating their speed, a problem which may be exacerbated by reductions in image contrast (Horswill & Plooy, 2008). Also, older drivers have a smaller pupil diameter (limiting the amount of light reaching the retina) and reduced contrast sensitivity. Scialfa, Adams and Giovanetto (1991) argue that older drivers are generally less sensitive to how fast they are traveling, but this effect has not been replicated in a simulator to this point. Nonetheless, given that depth cues are less available in the simulator and given that these cues may be even less effective for older drivers than young, before testing begins it is essential to provide participants with opportunities to learn how to calibrate their speed appropriately in the simulator. In particular, it is vital to have a warm-up period where drivers are encouraged to repeatedly check the speedometer and then the roadway. Because participants may lose track of how fast they are going when they become preoccupied with other things, during this warm-up period it is a good idea to provide occasional verbal prompts to remind drivers to monitor their speed.

Another measure of longitudinal control is headway. Headway can be defined in terms of the **distance to a lead vehicle or the time-to-contact**. The distribution of headways for a given driver may reflect following preferences and the need to respond to surrounding traffic. Older drivers or drivers with cerebral diseases who maintain a greater headway may have others pull into their headway gap (Trick & Caird, 2011). Certain drivers attempt to block others from pulling into a gap ahead, though at this point, there has never been a scenario designed to assess this behaviour. Furthermore, there are no simulations that measure how drivers accommodate to other drivers changing lanes, though it seems very plausible that such a scenario would reveal age differences. Research on this topic is a logical extension of automated vehicle algorithms (Kearney & Grechkin, 2011) but it has not been the focus of study.

3.2.2. Lateral control measures

Lateral control measures assess **how well drivers maintain vehicle position** within a lane (Figure 3.2).

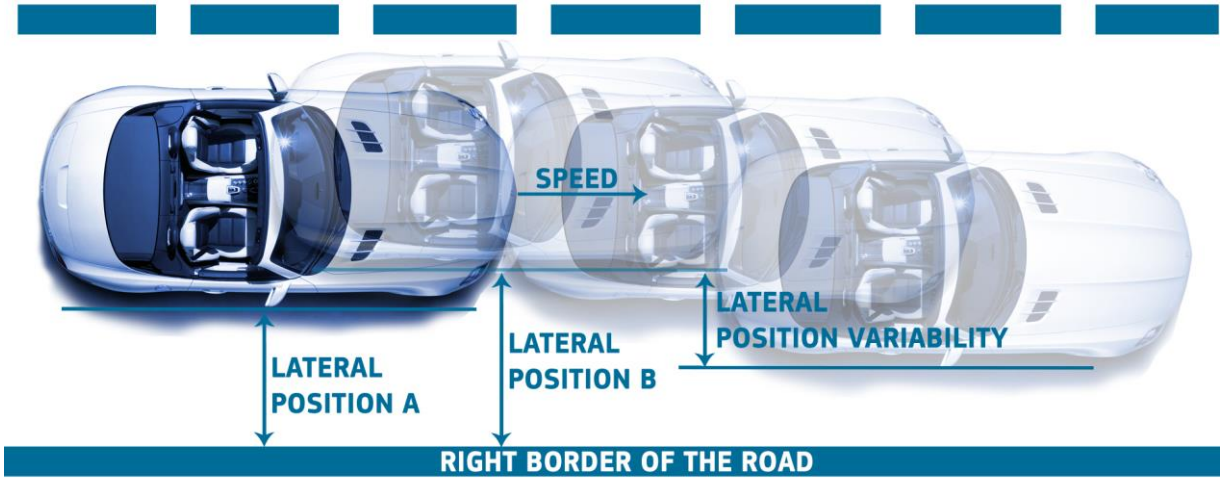


Figure 3.2. Lateral position and lateral position variability icon

These include standard deviation of lane position, lane excursions, and deviations within a lane to increase clearance of other vehicles and road users (for example, moving left to avoid a cyclist). Lateral control measures can be sensitive to eyes off the road from distractions, perceptual-motor declines, and some cognitive declines (Trick & Caird, 2011). However, lateral control measures are also affected by the handling characteristics of the driving simulator, and the simulator vehicle may differ markedly from the one that the participant normally drives. Older drivers may have more problems adapting to these differences in handling, and this may be especially problematic when frequent right and left turns are required. Consequently, it is vital that

older participants be given adequate practice so that they can get used to how the simulator vehicle handles.

3.2.3. Reaction time measures

An obvious way to measure differences in driving performance is to look for age-differences in collisions, but collisions are relatively rare and, as a result, perception response times are often measured (Trick & Caird, 2011). There are **a variety of different reaction time measures**, and different issues emerge depending on the event that gives rise to the response. For example, one common scenario requires drivers to respond to lead-vehicle braking (Strayer & Drews, 2004). Complications emerge when this scenario is used with older drivers. Because older drivers often adopt larger following distances than younger drivers, they may avoid a collision even though they take longer to brake in response to lead-vehicle braking (Milloy & Caird, 2011). Another way to measure performance on this task is to assess minimum headway: how close the driver comes to a lead vehicle when it brakes (Caird, Chisholm, & Lockhart, 2008).

There are also studies that **measure reaction times to sudden hazards that emerge from the periphery**: pedestrians, cyclists, or vehicles that travel into the path of the driver (Trick & Caird, 2011). Response times can be measured in different ways: if a pedestrian walks into the roadway, detection time could be defined as the time from the appearance until the eyes of the driver land on the pedestrian (i.e., fixation) followed by an adequate avoidance of the pedestrian. More commonly, perception response time (PRT) is defined as the time from first appearance of the hazard until the driver places his or her foot on the brake. Perception and response time can be further fractionated. Perception time is the time from appearance of the hazard until the driver removes his or her foot from the accelerator and response time is the length of time from leaving the brake until placing it on the brake (Olson & Farber, 2003). PRT is used to determine whether drivers can respond adequately to traffic control devices, signs, and road geometry, and it is an essential component of many design assumptions (Staplin et al., 1998). Accident reconstructionists use PRT to determine if a driver responded with due care and attention when a crash has occurred. Estimated PRT falling outside of certain distributions are used to infer proportional blame (Olson & Farber, 2003).

A variety of other reaction time measures require drivers to respond to the appearance of a probe stimulus, for example, the sudden illumination of a light-emitting diode within the vehicle (Lamble, Kauranen, Laakso, & Summala, 1999). In this type of study,

participants are required to do two things at once: drive (the primary task) and respond to the probe (the secondary task). The assumption is that attention is shared between tasks. If there are more attentional resources to be shared, or if the driving task demands fewer resources for a given individual, then response to the secondary task should be more efficient. Thus, these probe response time tasks are an index of the amount of "spare" attention available for secondary tasks. A number of reviews have addressed a range of common response time measures (Green, 2000; Summala, 2000). Older drivers typically take longer to respond to these stimuli (Olson & Sivak, 1986). This may indicate that they have less "spare" attention, but it may also show that older drivers are more cautious and place a greater emphasis on driving than carrying out secondary tasks.

3.2.4. Eye movement measures

It has become **increasingly common to use eye movement systems in driving simulator studies**, but there are a number of pragmatic considerations that make it difficult to measure eye movements when testing older drivers (Trick & Caird, 2011). First, the eye tracking or her glasses. Our experience is that about three-quarters of older drivers can be calibrated, but this is dependent on the system that is used and the acquisition of calibration expertise by research assistants (Caird et al., 2011). Reflections of the infrared beam from eyeglass lenses and frames may interfere with obtaining a reliable corneal reflection; loss of eye movement data can result.

In general, head-mounted systems (Figure 3.3) may restrict head movements because of the cordsa that exit the mounting band on the back of the head. Restriction of head movements due to age-related loss of range of motion may be confused with this imposed restriction. This is a problem in studies that measure head movements, such as those investigating eye-head relationships when participants perform lane change maneuvers. Sorting out the various baseline

Figure 3.3. Head-mounted device tracks the eye movements

restrictions imposed by head-mounted systems would require a separate study. Dash-mounted eye movement systems also have limitations in calibration and reliability over the course of an experiment. For instance, detecting the position of the eye and gaze relative to the environment may be difficult because many older drivers wear corrective lenses. Loss of data and unbalanced cells must be properly analyzed (Tabachnick & Fidell, 2006).

A large number of different eye movement measures can be collected. Often they require time-consuming data reduction and extraction. (Caird et al., 2011; Pollatsek et al., 2011). Given the difficulties inherent in collecting eye movement data from older drivers and the amount of work necessary in extracting the results, it is especially important for researchers to think carefully before including eye movement measures in their study.

What will knowing the total fixation duration or the total length of time extracting information from a location necessarily tell you about an older driver, a disease, a roadway modification or technology? Are there proxies of eye movements that can provide insight into the same question without incurring the same time costs? For example, when testing the impact of using a new in-vehicle interface, it may be as effective to measure time to task completion (time to use the interface) or an aspect of driving performance (Trick & Caird, 2011).

Variations on fixation frequency and duration are common. Definitions of these measures can be found in Green (2007). Older drivers typically look at an object longer and more frequently to extract the same information from it as younger drivers (Ho et al., 2001). In addition, older drivers look at a sign later (when they are in closer proximity) given restrictions to legibility - an effect that may be even more pronounced when testing is conducted in a driving simulator (Kline & Dewar, 2004; Caird et al., 2011).

3.2.5. Workload measures

There is still no universally accepted definition for mental workload. One proposed definition is: "**Mental workload is a hypothetical construct** that describes the extent to which the cognitive resources required to perform a task have been actively engaged by the operator" (Gopher, 1986). Another definition of mental workload proposed by Verwey (2000) is that "mental workload is related to the amount of attention required for making decisions." Just defining the concept of workload is not enough; there must

also be a way to measure it. Since there is not even an accepted definition of workload, it is not surprising that there is not a single way to measure it either. There are three main classifications for measurement of workload: physiological, subjective, and performance-based measures (Miller, 2001).

3.2.5.1. Subjective measurement

Subjective measurement of levels of workload is based on the **use of rankings or scales to measure the amount of workload** a person is feeling. Subjective workload measures are devoted primarily to the intermittent question-answer type response to varying levels of workload. The two main types of scales used to measure subjective workload are unidimensional and multidimensional scales (Miller, 2001).

Unidimensional rating scales are considered the simplest to use because there are no complicated analysis techniques. The unidimensional scale has only one dimension. Generally, the unidimensional scale is more sensitive than the multidimensional scale (De Waard, 1996). The multidimensional workload scale is considered to be a more complex and more time consuming form of measurement, and has from three to six dimensions. The multidimensional scale is generally more diagnostic (De Waard, 1996).

Several simple subjective mental workload scales have been developed to measure an individuals' perceived workload. Some of the main scales used in the driving domain include NASA-task Load Index (TLX), Rating Scale Mental Effort (RSME), Situation Awareness Global Assessment Technique, Driving Activity Load Index (DALI) (Miller, 2001).

3.2.5.2. Physiological measurement

Physiological measurement of workload is a factually based concept that relies on evidence **that increased mental demands lead to increased physical response from the body** (Moray, 1979). Physiological workload measures are devoted primarily to continuous measurement of the physical responses of the body. Most research focuses on five physiological areas to measure workload: cardiac activity, respiratory activity, eye activity, speech measures, and brain activity. Cardiac activity is measured through heart rate, heart rate variability, and blood pressure. Respiratory activity measures the amount of air a person is breathing in and the number of breaths in a given amount of time. Eye measures mainly include horizontal eye movements, eye blink rate, and interval of

closure, but there are several other less accepted measures. Speech measures take pitch, rate, loudness, jitter, and shimmer into account when determining workload. To measure brain activity, either the electroencephalograph (EEG) (Figure 3.4) or electro-oculogram (EOG) are usually used (Miller, 2001).

Figure 3.4. Measuring Driver's Mental Workload using electroencephalograph

3.2.5.3. Performance measurement

"Performance may be roughly defined as the effectiveness in accomplishing a particular task" (Paas & Vanmerrienboer, 1993). The two main ways to measure workload by means of performance are primary and secondary measures. The basis for using primary and secondary tasks to measure workload is based on the assumption that people have limited resources (Yeh & Wickens, 1988). Derrick (1988) explains how the "tasks that demand the same resource structure will reveal performance decrements when time-shared and further decrements when the difficulty of one or both is manipulated." This means that workload can be estimated by measuring the decrease in performance by either the primary or secondary tasks. The primary task measure is a more direct way to measure workload than the secondary task measure, but both are used and at least moderately accepted.

3.2.6. Summary of driving performance measures

It is considered as of major significance, a handy dependent variable list for driving simulation. Investigators should have a good idea about the scope of variables that can be collected and interpreted. A number of common questions arise about which dependent variable can be measured and how to interpret each relative to past use. The selection of dependent variables occurs based on prior use, simulation capability, researcher expertise, practical and applied generalities, and theoretical considerations. More succinctly, the choice of dependent variables is made based on the questions being asked. Table 3.1 lists common, but not necessarily agreed upon, groupings of dependent variables.

Table 3.1. Common driving simulation dependent variables (Regan et al., 2008)

Variable Classification	Variable
Longitudinal Control	Speed
	Speed Variability
	Time of Distance Headway
Lateral Control	Lateral Position
	Lateral Position variability (SDLP)
	Lane exceedances (LANEX)
	Time to Lane Crossing (TLC)
	Reversal Rate (RR)
	Standard deviation of steering wheel angle
	Steering wheel reversal rate
Reaction time	Perception Response Time (PRT)
	Brake Response Time (BRT)
	Time to Collision (TTC)
	Number of collisions
Eye Movements	Glance
	Eyes-off-road-time
	Fixation
	Percent Dwell Time (PDT)
Workload, Subjective	NASA-task Load Index (TLX)
	Rating Scale Mental Effort (RSME)
	Situation Awareness Global Assessment Technique
	Driving Activity Load Index (DALI)
Workload, Physiological	Heart Rate (HR)
	HR Variability
	Respiration
	Electroencephalography (EEG)
	Skin Conductance
Crash	Crash
Other Measures	Entropy
	Safety Margins
	Navigation
	Other higher-order or aggregate measures

3.3. Neurological/neuropsychological assessment design principles

A full **neurological assessment is essential in order to assess the neurological state** of the participants in a driving simulator experiment, especially including patients with neurological diseases affecting cognitive functions. The basic protocol of the medical and neurological examination should include full assessment of motor and sensory systems and cranial and peripheral nerves. During the medical interview a clinical assessment of higher cortical functions (memory, language, attention, executive

functions, and perception) as well as behavioural and emotional state should be conducted. All patients should have a comprehensive laboratory evaluation including blood tests, biochemistry, neuroimaging (Cerebral MRI or CT scan) and Electroencephalography (as needed). Taking into consideration that the design of the neurological battery of tests is beyond the scope of this PhD dissertation, the Clinical Neurological Assessment should include the completion of basic scales which correspond to the domains that are presented in Table 3.2.

Table 3.2. Neurological Assessment Battery

Domain	Tests
Memory, orientation in time/space, judgment and problem solving, community affairs, home activities	*Clinical Dementia Rating Scale (CDR)*
Differentiation of the commonest dementia types	*Hachinski Ischemic Scale*
Motor system	*Unified Parkinson's Disease Rating Scale-motor (UPDRS-Motor),* *Hoehn & Yahr Scale (H&Y)*
Behaviour in relation to brain diseases	*Neuropsychological Inventory (NPI)* *Frontal Behaviour Inventory (FBI)*
Daily activities	*Instrumental Activities of Daily Living (IADL),* *Functional Activities Questionnaire (FAQ),* *Informant Questionnaire on Cognitive Decline in Elderly (IQ-CODE)*
Emotional state	*Geriatric Depression Scale (GDS), PHQ-9*
Sleep behaviour	*Parkinson's Disease Sleeping Scale-2 (PDSS-2),* *Athens Insomnia Scale (AIS),* *Epworth Sleepiness Scale*
Motor abilities: Gait-balance-speed	*Rapid Paced Walk*
Motor abilities: Visual field, Ability to perceive objects in field of view, Time of reaction.	*Head and Trunk rotation task (modified)*
Motor abilities: Balance, movement coordination, mistakes and time of execution	*Alternate foot tapping (modified),* *Tandem Walking at 2 meter distance*

A full **neuropsychological assessment is essential in order to assess the cognitive status** of the participants in a driving simulator experiment, especially including patients with neurological diseases affecting cognitive functions. The selection of the cognitive tests is in accordance with one of the main goals of the neuropsychological design. That is, to verify in specific which cognitive characteristics of individuals with MCI, AD and PD contribute to safer driving performance and which do not. In line with this perspective, and taking into consideration that the design of the neurological battery of tests is beyond the scope of this PhD dissertation, neuropsychological assessment in our

protocol is conducted by an extended battery of tests that measure a broad range of cognitive abilities (Table 3.3).

Table 3.3. Neuropsychological Assessment Battery

Cognitive Domain	**Tests**
Global Cognitive Status	*Mini Mental State Examination, Montreal Cognitive Assessment test*
Verbal Memory and Learning	*The Hopkins Verbal Learning Test - Revised*
Verbal Working Memory	*Letter Number Sequencing task - Wechsler Adult Intelligence Scale-IV*
Visual Scanning and Spatial Memory and Learning	*The Brief Visuospatial Memory Test-Revised* *Driving Scenes Test - Neuropsychological Assessment Battery*
Visuospatial Perception	*Line Orientation Test - Repeatable Battery of Neuropsychological Screening, Clock Drawing Test*
Visuospatial Working Memory	*Spatial Span Task - Wechsler Memory Scale* *Driving Scenes Test - Neuropsychological Assessment Battery*
Constructional ability	*Clock Drawing Test*
Attention/Information Processing Speed/Perception	*Trail Making Test - part A, Comprehensive Trail Making Test, Symbol Digit Modalities Test, Useful Field of View, Witkin's - Embedded* Figures *Test*
Selective and Divided Attention	*Useful Field of View* *Driving Scenes Test-Neuropsychological Assessment Battery*
Executive Functions	*Frontal Assessment Battery, Trail Making Test-part B, Spatial Addition Task - Wechsler Memory Scale, Clock Drawing Test*
Psychomotor vigilance	*Psychomotor Vigilance Test*

3.4. Statistical analysis methodology

To achieve the objectives set out in this PhD dissertation, **an innovative analysis methodology has been developed** exploiting a set of existing and advanced statistical mathematical models. For the development of this innovative analysis methodology all statistical modelling limitations and needs were taken into account, as derived from the extended literature review presented in the preview chapter.

More specifically, in the majority of the examined studies the main statistical analysis is repeated measures ANOVA. This is probably explained by the fact that in most driving simulator experiments, participants are asked to drive more than one time, apart from the practice drive. Consequently, some other studies perform only descriptive statistics tests aiming to gain general information regarding different performance measures, while in only a few researches linear regression models are implemented.

On the other hand, a very interesting finding from this literature review is that none of the examined researches used latent variables and SEM analysis. This type of analysis is used to deal with several difficult modeling challenges, including cases in which some variables of interest are unobservable or latent and are measured using one or more exogenous variables.

The innovative analysis methodology developed consists of the following steps:

» In the first step, descriptive statistics are used to describe the basic features of the data as they provide simple summaries about the sample and the measures. Together with simple graphics analysis, they form the basis of virtually quantitative analysis of data.

» The second step concerns a preliminary analysis of variance (ANOVA) and then the development of regression models with regard to key performance parameters.

» In the next step, Principal Component Analysis (PCA) is implemented in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data. This type of analysis is designed to deal with several difficult modeling challenges, including cases in which some variables of interest are unobservable or latent and are measured using one or more exogenous variables.

» In the final step, the central part of the statistical analysis of the present PhD dissertation is taking place including the implementation of structural equation models (SEM) for the first time in the scientific field of driving behaviour of drivers with neurological diseases affecting cognitive functions. Within the framework of latent analysis, four Structural Equation Models are implemented aiming to investigate the quantification of the impact of driver, road and traffic characteristics directly on driving performance, driving errors, reaction time and accident probability.

The theoretical background of the described methodology is presented at the following sections.

3.4.1. Descriptive analysis

The large dataset exploited in the present research makes the descriptive analysis of a large number of variables essential. Within this framework, box plots (also known as a box-and-whisker charts) is a convenient way to show groups of numerical data, such as minimum and maximum values, upper and lower quartiles, median values, outlying and extreme values (Figure 3.5).

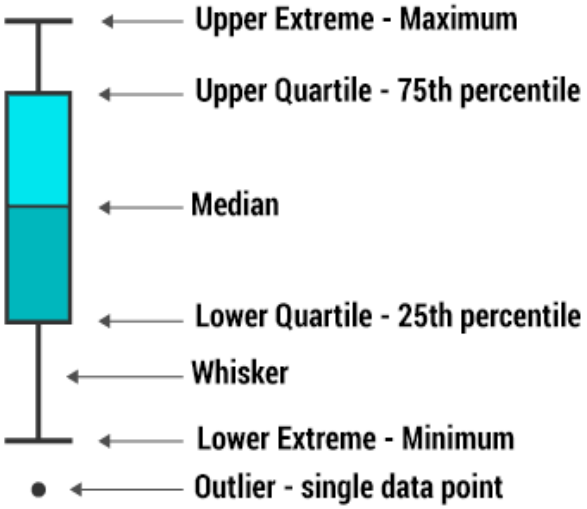


Figure 3.5. Box-and-Whisker chart explanation

The spacing between the different parts of the box plot indicates the degree of dispersion (spread) and skewness in the data and identifies outliers. More specifically, regarding box plots, the line in the middle of the boxes is the median. The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile. The top of the box represents the 75th percentile. Twenty-five percent of cases have values above the 75th percentile. This means that 50% of the cases lie within the box.

3.4.2. Analysis of variance

Analysis of variance (ANOVA) is a **particular form of statistical hypothesis testing heavily used in the analysis of experimental data**. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis. A statistically significant result, when a probability (p-value) is less than a threshold (significance level), justifies the rejection of the null hypothesis, but only if the a priori probability of the null hypothesis is not high.

In the typical application of ANOVA, the null hypothesis is that all groups are simply random samples of the same population. For example, when studying the effect of different treatments on similar samples of patients, the null hypothesis would be that all treatments have the same effect (perhaps none). Rejecting the null hypothesis would imply that different treatments result in altered effects.

By construction, hypothesis testing limits the rate of Type I errors (false positives) to a significance level. Experimenters also wish to limit Type II errors (false negatives). The rate of Type II errors depends largely on sample size (the rate will increase for small numbers of samples), significance level (when the standard of proof is high, the chances of overlooking a discovery are also high) and effect size (a smaller effect size is more prone to Type II error).

The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error.

There are several types of ANOVA. Many statisticians base ANOVA on the design of the experiment, especially on the protocol that specifies the random assignment of treatments to subjects; the protocol's description of the assignment mechanism should include a specification of the structure of the treatments and of any blocking. It is also common to apply ANOVA to observational data using an appropriate statistical model.

Some popular designs use the following types of ANOVA:

» **One-way ANOVA** is used to test for differences among two or more independent groups (means). Typically, however, the one-way ANOVA is used to test for differences among at least three groups, since the two-group case can be covered by a t-test. When there are only two means to compare, the t-test and the ANOVA F-test are equivalent; the relation between ANOVA and t is given by $F = t^2$.

» **Factorial ANOVA** is used when the experimenter wants to study the interaction effects among the treatments.

» **Repeated measures ANOVA** is used when the same subjects are used for each treatment (e.g., in a longitudinal study).

» **Multivariate analysis of variance (MANOVA)** is used when there is more than one response variable.

3.4.3. Regression analysis

Linear regression is one of the **most widely studied and applied statistical and econometric techniques**, for numerous reasons. First, linear regression is suitable for modeling a wide variety of relationships between variables. In addition, the assumptions of linear regression models are often suitably satisfied in many practical applications. Furthermore, regression model outputs are relatively easy to interpret and communicate to others, numerical estimation of regression models is relatively easy, and software for estimating models is readily available in numerous "non-specialty" software packages. Linear regression can also be overused or misused. In some cases the assumptions are not strictly met, and suitable alternatives are not known, understood, or applied (Washington et al., 2011).

It should not be surprising that linear regression serves as an excellent starting point for illustrating statistical model estimation procedures. Although it is a flexible and useful tool, applying linear regression when other methods are more suitable should be avoided. This chapter illustrates the estimation of linear regression models, explains when linear regression models are appropriate by setting several assumptions and deals with generalized linear models (GLMs).

3.4.3.1 Assumptions of linear regression models

Linear regression is used to model a **linear relationship between a continuous dependent variable** and one or more independent variables. Most regression applications seek to identify a set of explanatory variables that are thought to covary with the dependent variable. In general, explanatory or "casual" models are based on data obtained from well-controlled experiments, predictive models are based on data obtained from observational studies, and quality control models are based on data obtained from a process or system being controlled. Whether explanatory variable cause or are merely associated with changes in the dependent variable depends on numerous factors and cannot be determined on the basis of statistical modeling alone (Washington et al., 2011).

There are numerous assumptions (or requirements) of the linear regression model. When any of the requirements are not met remedial actions should be taken, and in some cases, alternative modeling approaches adopted. The following are the assumptions of the linear regression models (Washington et al., 2011).

» Continuous dependent variable Y
» Linear-in-parameters relationship between X and Y
» Observations independently and randomly sampled
» Uncertain relationship between variables
» Disturbance term independent of X and expected value zero
» Disturbance terms not auto-correlated
» Regressors and disturbances uncorrelated

3.4.2.2 Generalized linear models

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 (Washington et al., 2011).

Generalized linear models were formulated as a way of unifying various other statistical models, including linear regression, logistic regression and Poisson regression (Hastie and Tibshirani, 1990). Hastie and Tibshirani (1990) proposed an iteratively reweighted least squares method for maximum likelihood estimation of the model parameters. Maximum-likelihood estimation remains popular and is the default method on many statistical computing packages. Other approaches, including Bayesian approaches and least squares fits to variance stabilized responses, have been developed.

A key point in the development of GLM was the generalization of the normal distribution (on which the linear regression model relies) to the exponential family of distributions. This idea was developed by Fisher (1934). Consider a single random variable y whose probability (mass) function (if it is discrete) or probability density function (if it is continuous) depends on a single parameter θ. The distribution belongs to the exponential family if it can be written in the form (Eq. (3.1)):

$$f(y;\theta) = s(y)t(\theta)e^{a(y)b(\theta)} \tag{3.1}$$

Where a, b, s, and t are known functions.
The symmetry between y and θ becomes more evident if Eq. (3.1) is rewritten as Eq. (3.2):

$$f(y;\theta) = \exp[a(y)b(\theta) + c(\theta) + d(y)] \quad (3.2)$$

Where s(y) = exp[d(y)] and t(θ) = exp[c(θ)].

If a(y) =y then the distribution is said to be in the canonical form. Furthermore, any additional parameters (besides the parameter of interest θ) are regarded as nuisance parameters forming parts of the functions a, b, c, and d, and they are treated as though they were known. Many well-known distributions belong to the exponential family, including - for example - the Poisson, normal, and binomial distributions. On the other hand, examples of well-known and widely used distributions that cannot be expressed in this form are the student's t-distribution and the uniform distribution (Washington et al., 2011).

3.4.4. Principal Component Analysis

In many analyses, **the initial steps attempt to uncover structure in data** that can then be used to formulate and specify statistical models. These situations arise predominately in observational settings - when the analyst does not have control over many of the measured variables, or when the study is exploratory and there are not well-articulated theories regarding the structure in the data. There are several approaches to uncovering data structure. Principal Component Analysis (PCA) is widely used as an exploratory method for revealing structure in data.

PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. The resulting vectors are an uncorrelated orthogonal basis set. The principal components are orthogonal because they are the eigenvectors of the covariance matrix, which is symmetric. PCA is sensitive to the relative scaling of the original variables.

PCA is mostly used as a tool in exploratory data analysis and for making predictive models. PCA can be done by eigenvalue decomposition of a data covariance (or

correlation) matrix or singular value decomposition of a data matrix, usually after mean centering (and normalizing or using Z-scores) the data matrix for each attribute (Abdi & Williams, 2010). The results of a PCA are usually discussed in terms of component scores, sometimes called factor scores (the transformed variable values corresponding to a particular data point), and loadings (the weight by which each standardized original variable should be multiplied to get the component score) (Shaw, 2003).

PCA can be thought of as fitting an n-dimensional ellipsoid to the data, where each axis of the ellipsoid represents a principal component. If some axis of the ellipse is small, then the variance along that axis is also small, and by omitting that axis and its corresponding principal component from our representation of the dataset, we lose only a commensurately small amount of information.

PCA is mathematically defined (Jolliffe, 2003) as an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by some projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on.

PCA begins by noting that *n* observations, each with *P* variables or measurements upon them, is expressed in an $_{11}$ *x P* matrix **X** (Washington et al., 2011):

$$\boldsymbol{X}_{nxP} = \begin{bmatrix} x_{11} & \cdots & x_{1P} \\ \vdots & \ddots & \vdots \\ x_{n1} & \dots & x_{nP} \end{bmatrix} \quad (3.3)$$

PCA is not a statistical model, and there is no distinction between dependent and independent variables. If the PCA is useful, there are $K < n$ principal components, with the first principal component:

$$\boldsymbol{Z_1 = a_{11}x_1 + a_{12}x_2 + \dots + a_{1p}x_p} \quad (3.4)$$

which maximizes the variability across individuals, subject to the constraint

$$\boldsymbol{a_{11}^2 + a_{12}^2 + \dots + a_{1p}^2 = 1} \quad (3.5)$$

Thus, *VAR* $[Z_1]$ is maximized given the constraint in Eq. 3.5, with the constraint imposed simply because the solution is indeterminate otherwise because one could simply increase one or more of the a_{ij} values to increase the variance. A second principal

component Z_2 is then sought that maximizes the variability across individuals subject to the constraints that $a_{11}^2+a_{12}^2+\ldots+a_{1p}^2=1$ and $COR\ [Z_1,Z_2]=0$. In keeping, a third principal component is added subject to the same constraint on the a_{ij} values, with the additional constraint that $COR\ [Z_1,Z_2,Z_3]=0$. Additional principal components are added up to *P*, the number of variables in the original dataset.

The eigenvalues of the sample variance-covariance matrix **X** are the variances of the principal components. The corresponding eigenvector provides the coefficients to satisfy Eq.3.5. The symmetric *P x P* sample variance-covariance matrix is given as:

$$\boldsymbol{S}^2[\boldsymbol{X}]=\begin{bmatrix} s^2(x_1) & s(x_1,x_2) & \cdots & s(x_1,x_P) \\ s(x_2,x_1) & s^2(x_2) & \cdots & s(x_2,x_P) \\ \vdots & \vdots & \ddots & \vdots \\ s(x_P,x_1) & s(x_P,x_2) & \cdots & s^2(x_P) \end{bmatrix} \tag{3.6}$$

The diagonal elements of this matrix represent the estimated variances of random variables 1 through *P,* while the off-diagonal elements represent the estimated covariances between variables.

The sum of the eigenvalues λ_P of the sample variance-covariance matrix is equal to the sum of the diagonal elements in $S^2[X]$, or the sum of the variances of the *P* variables in matrix *X*, that is:

$$\boldsymbol{\lambda_1+\lambda_2+\ldots+\lambda_P=VAR(x_1)+\ VAR(x_2)+\ldots+\ VAR(x_P)} \tag{3.7}$$

Because the sum of the diagonal elements represents the total sample variance and the sum of the eigenvalues is equal to the trace of $S^2[X]$, then the variance in the principal components accounts for all of the variation in the original data. There are *P* eigenvalues, and the proportion of total variance explained by the j^{th} principal component is given by:

$$\boldsymbol{VAR_j}=\frac{\boldsymbol{\lambda_j}}{\boldsymbol{\lambda_1+\lambda_2+\cdots+\lambda_P}}\ ,\ \ \boldsymbol{j=1,2,\ldots P} \tag{3.8}$$

With the basic statistical mechanics in place, the basic steps in PCA are (Manly, 1986):

» **Standardize** all observed variables in the X matrix
» **Calculate** the variance-covariance matrix, which is the correlation matrix after standardization

» **Determine** the eigenvalues and corresponding eigenvectors of the correlation matrix
» **Discard** any components that account for a relatively small proportion of the variation in the data.

3.4.5. Structural equation models (SEMs)

Structural equation models represent **a natural extension of a measurement model, and a mature statistical modelling framework**. The SEM is a tool developed largely by clinical sociologists and psychologists. It is designed to deal with several difficult modelling challenges, including cases in which some variables of interest to a researcher are unobservable or latent and are measured using one or more exogenous variables, endogeneity among variables, and complex underlying social phenomena (Washington et al., 2011).

When measurement errors in independent variables are incorporated into a regression equation (via a poorly measured variable), the variances of the measurement errors in the repressors are transmitted to the model error, thereby inflating the model error variance. The estimated model variance is thus larger than if no measurement errors are present. This outcome would have deleterious effects on standard errors of coefficient estimates, and goodness-of-fit (GOF) criteria, including the standard F- ratio and R-squared measures. If parameters are estimated using ordinary least squares then parameter estimates are biased and are a function of the measurement error variances. The SEM framework resolves potential problems by explicitly incorporating measurement errors into the modelling framework. In addition, the SEM model can accommodate a latent variable as a dependent variable, something that cannot be done in the traditional regression analysis.

Major applications of SEM include:

» **Causal modeling**, or path analysis, which hypothesizes causal relationships among variables and tests the causal models with a linear equation system. Causal models can involve either manifest variables, latent variables, or both;
» **Confirmatory factor analysis**, an extension of factor analysis in which specific hypotheses about the structure of the factor loadings and intercorrelations are tested;
» **Second order factor analysis**, a variation of factor analysis in which the correlation matrix of the common factors is itself factor analyzed to provide second order factors;

» **Regression models**, an extension of linear regression analysis in which regression weights may be constrained to be equal to each other, or to specified numerical values;
» **Covariance structure models**, which hypothesize that a covariance matrix has a particular form. For example, you can test the hypothesis that a set of variables all have equal variances with this procedure;
» **Correlation structure models**, which hypothesize that a correlation matrix has a particular form. A classic example is the hypothesis that the correlation matrix has the structure of a circumplex (Guttman, 1954; Wiggins, Steiger, & Gaelick, 1981).

3.4.5.1. Basic concept

SEM's have two components, **a measurement model and a structural model**. The measurement model is concerned with how well various measured exogenous variables measure latent variables. A classical factor analysis is a measurement model, and determines how well various variables load on a number of factors or latent variables. The measurement models within a SEM incorporate estimates of measurement errors of exogenous variables and their intended latent variable. The structural model is concerned with how the model variables are related to one another. SEMs allow for direct, indirect, and associative relationships to be explicitly modeled, unlike ordinary regression techniques with implicitly model associations. It is the structural component of SEMs that enables substantive conclusions to be made about the relationship between latent variables, and the mechanisms underlying a process of phenomenon. Because of the ability of the SEMs to specify complex underlying relationships, SEMs lend themselves to graphical representations and these graphical representations have become the standard means for presenting and communicating information about SEMs (Washington et al., 2011).

Like factor and principal components analyses, SEMs rely on information contained in the variance-covariance matrix. Similar to other statistical models, the SEM requires the specification of relationships between observed and unobserved variables. Observed variables are measured, whereas unobserved variables are latent variables – similar to factors in a factor analysis - which represent underlying unobserved constructs. Unobserved variables also include error terms that reflect the portion of the latent variable not explained by their observed counterparts. In a SEM, there is a risk that the number of model parameters sought will exceed the number of model equations needed to solve them. Thus, there is a need to distinguish between fixed and free

parameters - fixed parameters being set by the analyst and free parameters being estimated from the data. The collection of fixed and free parameters specified by the analyst will imply a variance-covariance structure in the data, which is compared to the observed variance-covariance matrix to assess model fit.

There are three types of relationships that are modeled in the SEM. An association is a casual (not causal) relationship between two independent variables, and is depicted as a double headed arrow between variables. A direct relationship is where the independent variable influences the dependent variable, and is shown with a directional arrow, where the direction of the arrow is assumed to coincide with the direction of influence from the exogenous to the endogenous variable. An indirect relationship is when an independent variable influences a dependent variable indirectly through a third independent variable. For example, variable *A* has a direct effect on variable *B*, which has a direct effect on variable *C*: so variable *A* has an indirect effect on variable *C*. Note that in this framework a variable may serve as both an endogenous variable in one relationship, and an exogenous variable in another.

Figure 3.5 shows a graphical representation of two different linear regression models with two independent variables, as is often depicted in the SEM nomenclature. The independent variables X_1 and X_2, shown in rectangles, are measured exogenous variables, have direct effects on variable Y_1, and are correlated with each other. The model in the bottom of the Figure reflects a fundamentally different relationship among variables. First, variables X_3 and X_4 directly influence Y_2. Variable X_4 is also directly influenced by variable X_3. The SEM model shown in the top of the Figure implies a different variance - covariance matrix then the model shown in the bottom of the Figure. The models also show that although the independent variables have direct effects on the dependent variable, they do not fully explain the variability in Y, as reflected by the error terms, depicted as ellipses in the Figure. The additional error term, error 3, is that portion of variable X_4 not fully explained by variable X_3. Latent variables, if entered into

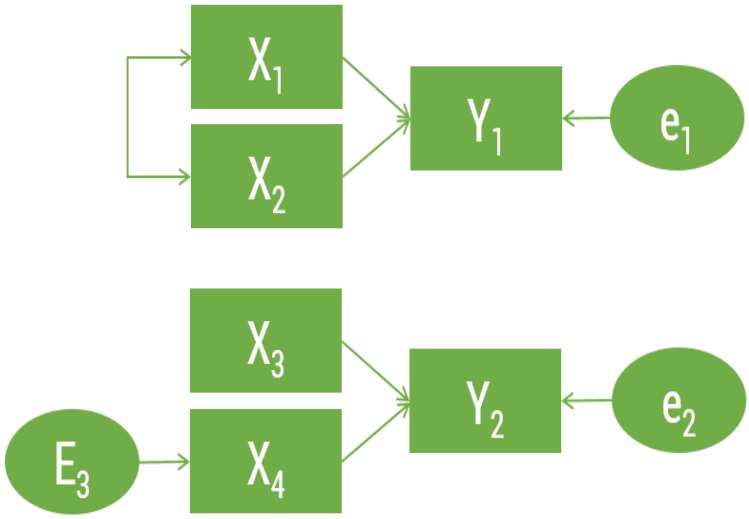


Figure 3.5. Example of SEM

these models, would also be depicted as ellipses in the graphical representation of the SEM (Washington et al., 2011).

An obvious issue of concern is how these two different SEMs depicted in Figure 3.9 imply different variance-covariance matrices. The model depicted in the top of Figure 3.9 represents a linear regression model with two independent variables that covary, such that

$$\mathbf{Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + error_1} \quad (3.9)$$

The model depicted in the bottom of the Figure represents two simultaneous regressions:

$$\mathbf{Y_2 = \beta_0 + \beta_3 X_3 + \beta_4 X_4 + error_2} \quad (3.10)$$

$$\mathbf{X_4 = \beta_0 + \beta_5 X_3 + error_3} \quad (3.11)$$

In this second SEM model, the variable X_4 serves as both exogenous and an endogenous variable. The collective set of constraints implied by these two SEMs determines the model implied variance-covariance structure. The original correlation matrix is completely reproduced if all effects, direct, indirect, and correlated, are accounted for in a model. This saturated model is uninteresting simply because there is no parsimony achieved by such a model. Without compromising the statistical validity of the model, a natural goal is to simplify an underlying complex data generating process with a relatively simple model. How the path is drawn in the development of SEMs determines the presumed variance-covariance matrix.

3.4.5.2. Fundamentals of structural equation modeling

The focus here is to provide a general framework of SEMs, to demonstrate how the parameters are estimated, and to illustrate how results are interpreted and used.

Structural equation models, similar to other statistical models, are used to evaluate theories or hypotheses using empirical data. The empirical data are contained in a *P x P* variance-covariance matrix S, which is an unstructured estimator of the population variance-covariance matrix Σ. A SEM is then hypothesized to be a function of Q unknown structural parameters (in parameter vector θ), which in turn will generate a model-implied variance-covariance matrix $\Sigma(\theta)$. All variables in the model, whether observed or latent, are classified as either independent (endogenous) or dependent (exogenous). A dependent variable in a SEM diagram is a variable that has a one-way arrow pointing to

it. The set of these variables is collected into a vector η, while independent variables are collected in the vector ξ, such that (Bentler and Weeks, 1980).

$$\boldsymbol{\eta = \beta\eta + \gamma\xi + \varepsilon} \tag{3.12}$$

Where β and γ are estimated vectors of coefficients that contain regression coefficients for the dependent and independent variables, respectively, and ε is a vector of regression errors. The exogenous factor covariance matrix is represented as $\boldsymbol{\Phi = COV\ [\varepsilon, \varepsilon^T]}$, and the error covariance matrix as $\boldsymbol{\psi = COV\ [\varepsilon, \varepsilon^T]}$. The variance-covariance matrix for the model in Equation 3.13 is:

$$\boldsymbol{\Sigma(\theta) = G\cdot(I-\beta)^{-1}\cdot\gamma\cdot\Phi\cdot\gamma^{T}\cdot(I-\beta)^{-1T}\cdot G^{T}} \tag{3.13}$$

Where G is a selection matrix containing either 0 or 1 to select the observed variables from all the dependent variables in η. There are P^2 elements or simultaneous equations in Equation 6, one for each element in $\Sigma(\theta)$. Some of the P^2 equations are redundant, however, leaving $P^*=P(P-1)/2$ independent equations. These P^* independent equations are used to solve the unknown parameters θ, which consist of the vector β, the vector γ, and Φ. The estimated model-implied variance-covariance matrix is then given as $\Sigma(\hat{\theta})$.

Model identification in SEM can present serious challenges. There are Q unknown model parameters (comprising θ), which must be solved using P^* simultaneous independent equations. There are two necessary and sufficient conditions for SEM identification. The first is that the number of simultaneous equations must be equal to or greater than the number of unknown model parameters, such that $Q \leq P^*$. The second is that each and every free model parameter must be identified, which often is difficult (Hoyle, 1995). Once the SEM has been specified, and identification conditions are met, solutions for the parameters are obtained. Parameters are estimated using a discrepancy function criterion, where the differences between the sample variance-covariance matrix and the model-implied variance-covariance matrix are minimized. The discrepancy function is:

$$\boldsymbol{F = F\ (S, \Sigma(\hat{\theta}))} \tag{3.14}$$

Different estimation methods in SEM have varying distributional assumptions, and in turn require different discrepancy functions. For example, maximum likelihood (MLE) estimated model parameters, which requires that specific distributional and variable assumptions are met, are obtained using the discrepancy function:

$$\mathbf{F_{MLE} = LN|\Sigma(\theta)| + TRACE[\Sigma(\theta)^{-1}S] - LN|S| - p} \quad (3.15)$$

For detailed discussions on other discrepancy functions and corresponding estimation methods, including MLE, generalized least squares (GLS), asymptotically distribution-free (ADF), scale-free least squares (SLS), unweighted least squares (ULS), and Browne's method (Arbuckle and Wothke, 1995; Hoyle,1995; Arminger et al., 1995).

A useful feature of discrepancy functions is that they are useful for testing the null hypothesis that H_0: $\Sigma(\theta)=\Sigma$, where

$$\mathbf{X^2 = F(n-1) = \chi^2 (\alpha, P^*-Q)} \quad (3.16)$$

This equation shows - given that the model is correct, variables are approximately multivariate normally distributed, and the sample size is sufficiently large – that the product of the minimized discrepancy function and sample size minus one is asymptotically chi-square distributed with degrees of freedom equal to P^*-Q. Also, it is g straightforward to show that SEM parameter estimates are asymptotically unbiased, consistent, and asymptotically efficient (Hoyle, 1995).

Equation 3.12 needs to be applied with care. Its unsuitability as a criterion for model assessment and selection was pointed out early in SEM theory development because the test statistic is largely a function of sample size (Bentler and Bonett, 1980; Gullikson and Tukey, 1958; Joreskog, 1969). Thus, the X^2 best serves the analyst in the selection of the best from competing models estimated on the same data, and whose absolute value should be evaluated with respect to sample size on which the statistic is estimated.

3.4.5.3. Non-ideal conditions

As previously mentioned, ideal conditions in SEM include multivariate normality of independent variables, the correct model functional form, independent and dependent variables measured on the interval or ratio scale, and a sufficiently large sample size. A large number of studies have been conducted to assess the impact of continuous yet non-normal variables on SEMs (Browne, 1984; Chou et al., 1991; Finch et al., 1994; Hu et al., 1992; Kline, 1998). Non-normality can arise from poorly distributed continuous variables or coarsely categorized continuous variables. Non-normality is detected in a number of ways, including box plots, histograms, normal probability plots, and by

inspection of multivariate kurtosis. Numerous studies have arrived at similar conclusions regarding the impact of non-normality in SEMs. The X^2 test statistic becomes inflated as the data become more non-normal. In addition, the GLS and MLE methods of parameter estimation produce inflated X^2 test statistics with small sample sizes, even if multivariate normality is satisfied. In addition, model GOF indices are underestimated under non-normality and non-normality leads to moderate to severe underestimation of standard errors of parameter estimates.

There are several remedies for dealing with non-normality. The asymptotically distribution-free estimator (ADF) is a GLS estimation approach that does not rely on multivariate normality (Browne, 1984). The ADF estimator produces asymptotically unbiased estimates of the X^2 test statistic, parameter estimates, and standard errors. The scaled X^2 test statistic, developed by Satorra and Bentler (Satorra, 1990), corrects or rescales the X^2 test statistic so that it approximates the referenced χ^2 distribution.

Bootstrapping is a third method for dealing with non-normal samples. Bootstrapping is based on the principle that the obtained random sample is a fair representation of the population distribution, and by resampling from this sample, estimates of parameters and their standard errors obtained are reliable estimates of the true population parameters. Efron and Tibshirani (1986) have demonstrated that in many studies the sampling distribution is reasonably approximated by data obtained from a single sample. Details of the bootstrap approach to SEM is provided in Bollen and Stine (1992).

Nominal and ordinal scale variables also cause problems in SEMs - resulting in biased estimates of X^2 test statistics and estimated parameters and their standard errors. One approach, developed by Muthen (1984), consists of a continuous/categorical variable methodology (CVM) weighted least squares estimator and discrepancy function, which results in unbiased, consistent, and efficient parameter estimates when variables are measured on nominal and ordinal scales. However, this estimator requires large sample sizes (at least 500-1.000 cases), and is difficult to estimate for overly complex models (Hoyle, 1995). Other approaches include variable re-expressions (Cattell and Burdsal 1975), variable transformations (Daniel and Wood 1980; Emerson and Stoto 1983), and alternating conditional expectations and Box-Cox transformations (De Veaux, 1990).

Interactions and nonlinear effects arise frequently in the modeling of real data. In SEM, interactions and nonlinear effects present challenges above and beyond those encountered in simple linear regression. There are two general approaches to handling

these problems; the indicant product approach, and the multisample approach. The indicant product approach is only well developed for multiplicative cases, and requires a centering transformation. The multisample approach is more flexible, avoids some multicollinearity and distributional problems associated with the product indicant approach, and is suitable under the widest range of conditions (Rigdon et al., 1998). Most currently available SEM software packages can accommodate the multisample approach.

3.4.5.4. Model goodness-of-fit measures

Model *Goodness-of-Fit* (GOF) measures are an important part of any statistical model assessment. GOF measures in SEMs are an unsettled topic, primarily as a result of lack of consensus on which GOF measures serve as "best" measures of model fit to empirical data (Arbuckle and Wothke, 1995). Several researches are implemented discussing these debates and a multitude of SEM GOF methods such as Mulaik et al., (1989), MacCallum (1990), Steiger (1990), Bollen and Long (1993), Arbuckle and Wothke (1995).

Several important concepts are routinely applied throughout SEM GOF tests that enable the assessment of statistical models. A saturated model is a model that is perfectly fit to the data - the variance-covariance structure is completely unconstrained and represents an unappealing model. It is the most general model possible, and is used as a standard of comparison to the estimated model. Because the saturated model is as complex as the original data, it does not summarize the data into succinct and useful relationships. In contrast, the independence model is constrained such that no relationships exist in the data and all variables in the model are independent of each other. This model presents the "worst case" model. The saturated and independence models are typically viewed as two extremes within which the best model lies.

There are a large number of GOF criteria available for assessing the fit of SEMs. Several important and widely used GOF measures are described below, however the majority of them can be found in the references provided.

The first class of GOF indices includes measures of parsimony. Models with few parameters are preferred to models with many parameters, providing that the important underlying model assumptions are not violated. This modeling philosophy is born by a general desire to explain complex phenomena with as simple a model as possible. Three

simple measures of parsimony are the number of model parameters *Q*, the degrees of freedom of the model being tested $df=P^*-Q$ and the parsimony ratio:

$$\mathbf{PR}= \boldsymbol{d/d_1} \tag{3.17}$$

where d is the degrees of freedom of the estimated model and d_1 is the degrees of freedom of the independence model. The *PR* represents the number of parameter constraints of the estimated model as a fraction of the number of constraints in the independence model (a higher *PR* is preferred).

There are several GOF indices based on the discrepancy function *F*. As stated previously, the χ^2 test statistic, derived from the discrepancy function, needs to be treated with care because it is dependent largely on sample sizes - small samples tending to accept (fail to reject) the null hypothesis, and large samples tending to reject the null hypothesis.

The X^2 statistic is the minimum value of the discrepancy function F times its degrees of freedom. The *p*-value is the probability of obtaining a discrepancy function as large as or larger than the one obtained by random chance if the model is correct, distributional assumptions are correct and the sample size is sufficiently large. The statistic X^2 /(model degrees of freedom) has been suggested as a useful fit measure. Rules of thumb have suggested that this measure (except under ULS and SLS estimation) should be close to 1 for correct models. In general, it is recommended that this statistic should lie less than 5, with values close to 1 being preferred (Byrne, 1989; Carmines and McIver, 1981; Marsh and Hocevar, 1985).

Another class of fit measures is based on the population discrepancy. These measures rely on the notion of a population discrepancy function (as opposed to the sample discrepancy function) to estimate GOF measures, including the noncentrality parameter (NCP), the root mean square error of approximation (RMSEA), and PCLOSE, the p-value associated with a hypothesis test of RMSEA $\leq$ 0.05. For details on these measures the reader should consult Steiger et al. (1985) and Browne and Cudeck (1993).

Information theoretic measures are designed primarily for use with MLE methods, and are meant to provide a measure of the amount of information contained in a given model. There are many measures used to assess fit in this class. The Akaike information criterion (Akaike, 1987) is given as

$$AIC = 2Q - 2LL(\theta) \quad (3.18)$$

where *Q* is the number of parameters and *LL(θ)* is the log-likelihood at convergence. Lower values of AIC are preferred to higher values because higher values of *-2LL(θ)* correspond to greater lack of fit. In the AIC criterion a penalty is imposed on models with larger numbers of parameters, similar to the adjusted R-square measure in regression. The Browne-Cudeck (1989) criterion is similar to AIC, except it imposes a slightly greater penalty for model complexity than does AIC. It is also the only GOF measure in this class of measures designed specifically for the analysis of moment structures (Arbuckle and Wothke, 1995). Other GOF measures in this category include the relative fit index (RFI), the incremental fit index (IFI), the Tucker-Lewis coefficient, and the comparative fit index (CFI), discussion on which is found in Bollen (1986), Bentler (1990), and Arbuckle and Wothke (1995).

3.5. Synopsis of methodology

This PhD thesis aims to investigate the effect of road, traffic, risk factors and the effect of neurological diseases affecting cognitive functions on driver behaviour and road safety. Within this framework, one of the main objectives of the overall research is the development of an **innovative statistical analysis methodology** in the field of driving behaviour of drivers with cerebral diseases. This innovative methodological approach is based on literature review regarding simulator experiment, neurological and neuropsychological design principles, driving performance, cognitive and neurological state measures and statistical analysis methods (Figure 3.6).

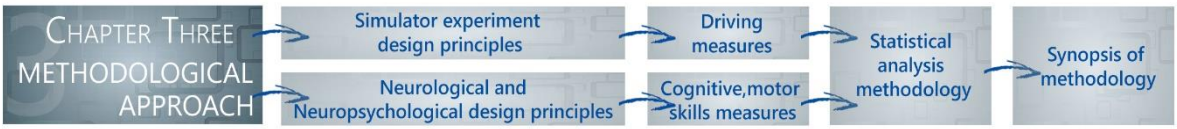


Figure 3.6. Methodological approach of this PhD thesis

Regarding the methodological review presented in this chapter, it revealed that:

» The **driving simulator experimental design** could be within or between-subject or full factorial and there are possible methodological threats that are need to be taken into consideration when designing an experiment.

» Driver behaviour is a multidimensional phenomenon which means that **no single driving performance measure can capture** all effects of neurological diseases affecting cognitive functions.
» A lot of different methods and measures exist for evaluating driving performance the most common of which include **lateral control, longitudinal control, reaction time, eye movement and workload measures**.
» The selection of the specific measures should be guided by the nature of the task examined as well as the **specific research questions**.
» The **neurological experimental design** should deal with several domains: memory, orientation in time/space, motor system, daily activities, emotional state, sleep behaviour and motor abilities.
» The **neuropsychological experimental design** should deal with several cognitive domains: global cognitive status, verbal memory and learning, verbal working memory, visual scanning and spatial memory and learning, visuospatial perception and working memory, constructional ability, attention/information processing speed/perception, selective and divided attention, executive functions and psychomotor vigilance.
» **Latent model analysis and especially structural equation models have never been implemented** in the field of driver behaviour of patients with neurological diseases affecting cognitive functions.

Based on these literature reviews the **statistical analysis research questions** of the present PhD dissertation will focus to the **investigation of the effect of neurological disease affecting cognitive functions** on different road, traffic and distraction conditions on selected driving performance measures by **implementing an innovative statistical analysis** in this scientific field.

The innovative statistical analysis methodology that has been developed, and the theoretical background of which was presented analytically in the present chapter consists of five steps:

In the first step, the **descriptive analysis** of all the experiment variables takes place, which allows for a first understanding of the large number of parameters examined. More precisely, an overview of all variables that are provided by the driving simulator is provided investigating the effect of specific driving characteristics on selected driving performance measures.

Moving on, **Analysis Of Variance** (**ANOVA**) is taking place in order to extract significant differences in the driving performance indexes extracted from the driving simulator assessment.

In the third step, within the framework of the explanatory analysis, the development of **Regression Models** takes place regarding key performance parameters in order to estimate the effect of cerebral diseases and driving characteristics on specific driving performance parameters and indirectly on driving behaviour and road safety.

In the fourth step, **Principal Component Analysis (PCA)** is implemented regarding driving performance, driving errors, neuropsychological state and neurological state, in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data.

In the fifth step, the core statistical analysis of the present PhD thesis takes place, including the implementation of **Structural Equation Models** for the first time in the scientific field of driving behaviour of drivers with neurological diseases affecting cognitive functions. Within the framework of latent analysis, four Structural Equation Models are developed aiming to investigate the quantification of the impact of neurological diseases affecting cognitive functions, driver distraction, driver characteristics as well as road and traffic environment directly on driving performance, driving errors, reaction time and accident probability.

The results extracted by the implementation of this innovative statistical methodology are presented thoroughly in Chapter Five.

Chapter Four
Driving Simulator Experiment

A central component of the present PhD thesis is the design and implementation of a large driving simulator experiment. Based on the methodology review which was carried out and presented in the previews chapters, a large driving simulator experiment took place at the Department of Transportation Planning and Engineering of the School of Civil Engineering of the National Technical University of Athens aiming to assess driving performance of patients with neurological diseases affecting cognitive functions.

The objective of the present chapter is to present the experiment design both in terms of conceptual framework and implementation as well to record basic parameters regarding the data storage/processing and sample characteristics.

In the beginning, an overview of the driving simulator experiment is taking place including details regarding the interdisciplinary research teams who contributed in the design of the experiment. Furthermore, several other information are provided concerning driving simulator characteristics, sample characteristics, the inclusion criteria, and the ethical issues.

In this chapter, the design of the driving simulator experiment is deeply investigated as it constitutes an innovating component of the PhD dissertation. Participants were asked to drive under different types of distraction (no distraction, conversation with passenger, mobile phone use) in different road (urban/rural) and traffic conditions (high/moderate). In this framework, all these conditions are analyzed within a full factorial within-subject design. Furthermore, several other relevant aspects of the design are provided concerning dealing with simulator sickness, conversation topics, incidents, and randomization of trials as well as how the driving simulator scenarios were programmed.

Then, the procedure of the driving simulator experiment is presented. More specifically, the organization of the research team is provided and the oral instructions to the participants are recorded. Furthermore, special emphasis is given to the familiarization part, as specific performance measures were used to assess the driver's familiarization with the simulator before proceeding to the main part of the experiment. Then, the process of the main driving scenarios is described.

Moving on to the next chapters, the neurological and the neuropsychological part of the experiment is presented, followed by the questionnaire assessment. After the completion of the driving simulator tasks, the neurological and neuropsychological assessments, all participants were asked to fill in a questionnaire which concerned their driving habits and their self-stated driving behaviour. In this section, all the different parts as well as indicative questions of the questionnaire are presented.

Finally, as the dataset form the driving simulator experiment and the questionnaires is extremely large, information regarding the data processing are provided including data files, data storage and the processing levels, while characteristics regarding the sample are provided (Figure 4.1).

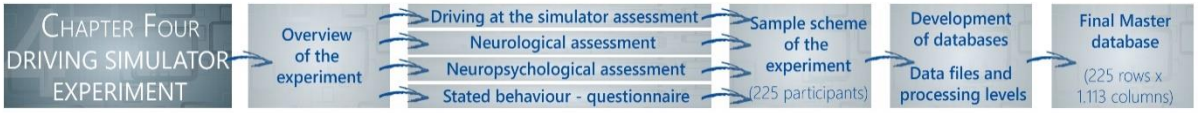


Figure 4.1. Driving simulator experiment outline

4.1. Overview of the experiment

The large driving simulator experiment of the present PhD study was designed and carried out in the framework of two interdisciplinary research projects:

» **"DISTRACT** Causes and impacts of driver distraction: a driving simulator study" - www.nrso.ntua.gr/distract

» **"DriverBRAIN** Performance of drivers with cerebral diseases at unexpected incidents" - www.nrso.ntua.gr/driverbrain

The methodological framework is based on the combined assessment of traffic, behavioural, medical, neurological and neuropsychological parameters on driving performance. Moreover, the aspects of driver behaviour and safety research addressed are inherently interdisciplinary and should be examined in a more integrated manner. For this purpose, the experiment is designed by an interdisciplinary team consisting of two research teams:

» The 1st research team includes Transportation Engineers of the National Technical University of Athens

» The 2nd Research team includes Neurologists, Neuropsychologists and a Psychiatrist of the Behavioural Neurology and Neuropsychology Unit, 2nd Department of Neurology, National and Kapodistrian University of Athens, "Attikon" University Hospital

The complementarity of the teams with respect to the objectives of this PhD dissertation, which is inherently interdisciplinary, lies in the integrated analysis of a wide range of factors that may contribute to driver behaviour, ranging from parameters of traffic flow, road safety and driver distraction (School of Civil Engineering), medical, neurological and psychiatric disorders (Faculty of Medicine) and neuropsychological and psychological parameters (Department of Psychology).

The three research teams collaborate to organize and implement the simulator experiment, which includes different stages. Each stage concerns a different scientific field, namely the planning and implementation of the clinical, neurological, and psychiatric evaluation of the participants, the planning and implementation of the neuropsychological and personality evaluation of the participants, and the planning and implementation of traffic flow scenarios in the driving simulator.

4.1.1. Inclusion criteria

To start with the very beginning of the experimental design and procedure, drivers who participated in this experiment **met certain basic criteria based on an examination of neurologists and neuropsychologists**. The detailed form is attached in Appendix. Each participant should:

» have a valid driving license
» have driving experience of more than 3 years
» have driven more than 2500km during the last year
» have driven at least once a week during the last year
» have driven at least 10km/week during the last year
» not have important psychiatric history for psychosis or major depression
» not have any important motor disorder that prevent them from basic driving moves
» not have dizziness or nausea either as a driver or as a passenger
» not be pregnant
» not be an alcoholic or had any other drug addiction
» not have any important eye disorder that prevent him from driving safely
» not have any other disease of the Central Nervous System except for AD or PD

In case one participant failed even in one of the above criteria, he was eliminated from the experiment from carrying out the experiment.

4.1.2. Ethical issues

The study was approved by the Ethics Committee of the University General Hospital "ATTIKON". Informed consent was obtained from all individuals studied; it was explained to them that participation was on a voluntary basis 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. Finally, participation was voluntary and no compensation was offered.

4.2. "Driving at the simulator" Assessment

The "driving at the simulator" 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 two sessions: Urban Driving Session and Rural Driving Session aiming to assess driving performance under typical conditions, with or without external distraction sources.

4.2.1. Driving simulator

4.2.1.1. General

Within the framework of this PhD study, the driving simulator experiment took place, on the 2nd floor in a special room of the Laboratory of Traffic Engineering of the Department of Transportation Planning and Engineering of the School of Civil Engineering of the National Technical University of Athens (NTUA), where the **FOERST Driving Simulator FPF** is located.

The FOERST GmbH is a DIN ISO 9001-certified company while the simulator used in the current experiment has been manufactured by the FOERST Company in order to serve research purposes. Figure 4.2 is presenting the driving simulator which consists of 3 LCD wide screens 40'' (full HD), total angle view 170 degrees, driving position and support base. The dimensions at a full development are 230x180 cm. with a base width of 78cm.

Figure 4.2. NTUA driving simulator

It features adjustable driver seat, steering wheel 27cm diameter, pedals (throttle, brake, clutch), dashboard and two external and one central mirror that appear on the side and on the main screen, and display in real time objects and events that are happening behind the 'vehicle'. The controls available to the driver are: 5 gears plus reverse gear, flash, wipers, lights, horn, brake and starter.

The virtual road environment is generated by the computer and displays the road environment. Users can drive along the road under realistic conditions. It is highlighted that driving conditions in the simulator cannot be absolutely identical to those perceived by the driver in real driving, but the change of the driver behaviour does not necessarily affect the relative influence of various parameters.

Moreover, in the specific driving simulator it is possible to simulate many conditions between alternative types of roads (urban-interurban road, highway), in different traffic conditions (normal - less - without - just oncoming traffic), and under different environment (good weather, fog, rain, snow, night). Furthermore, according to the experimental requirements, dangerous situations like unexpected appearance of an animal during driving, or unexpected course of a leading vehicle at predetermined or random points along the route were selected.

4.2.1.2. Driving simulator validation

Simulator validity refers to the degree to which behaviour in the simulator corresponds to behaviour in real-world environment under the same conditions (Kaptei et al., 1996; Blaauw, 1982). There are two types of validity: absolute validity and relative validity. If the numerical values for certain tasks obtained from the simulator and actual vehicles are identical or near identical, absolute validity is said to have been achieved (Godley et al., 2002). Relative validity is achieved when driving tasks have a similar affect (e.g., similar magnitude and direction of change) on driving performance in both the simulator and real vehicles (Harms, 1992).

In order to investigate the validity of the present driving simulator another similar research took place. The objective of this research was to compare the driving performance of young drivers in normal and simulation driving conditions. For this purpose, 31 young drivers aged 20-30 participated in an experimental process including driving both in a driving simulator as well in real traffic condition at an interurban road in the region of Paiania.

A central component of the experimental design was the driving simulator scenario which was programmed in order to simulate with high precision the interurban road task. Regarding the statistical analysis, lognormal regression models were developed for the identification of the impact of driving environment (simulated and real road conditions), driver characteristics (mileage, age, gender), as well as driving performance variables (average acceleration, deceleration and standard deviations of them) to average vehicle speed change.

Model results reveal that absolute values of drivers' traffic performance vary between simulated and real driving conditions. On the contrary, relative differences of driver behaviour at the two driving environments remain mostly the same. More precisely, speed difference between fast and slow drivers is the same at both driving environments, as the speed difference is also the same at the two driving environments between drivers conversing or not conversing to the passenger. Research results allow a clear view of the extent and manner in which driving conditions in conjunction with driver's characteristics affect driving performance. Thus, they provide with a substantiated explanation for the reliability of the particular simulator measurements.

4.2.2. Familiarization with the simulator

A **familiarization session** or "practice drive" is typically the first step of all simulator experiments. At this point, the coordinator assists participants to sit comfortably on the driving simulator, explains any questions and confirms that participants feel well.

The driving simulator provides a **"Free Driving"** scenario (Figure 4.3) that familiarizes the participants with the demands of an everyday drive. The greater part of the drive is designed in an inter-urban environment, but there is also a short crossing through a small city with traffic lights and junctions.

During the familiarization with the simulator, the following criteria must be verified (**there is no time restriction**) before the participant moves on to the next phase of the experiment (see also Annex):

» **Handling the simulator** (starting, gears, wheel handling etc.)
» **Keeping the lateral position of the vehicle**
» **Keeping stable speed**, appropriate for the road environment
» **Braking and immobilization of the vehicle**

Finally during this practice drive, two unexpected incidents take place.

Figure 4.3. Free driving - familiarization with the simulator

4.2.3. Dealing with simulator sickness

Figure 4.4. Simulator sickness symptom

Simulator sickness is a phenomenon that is affected by simulator features and participant characteristics. It produces symptoms that are similar to, but typically less severe than those of **motion sickness such as nausea, ocular discomfort, and disorientation** (Kennedy et al., 1993). It was possible, during and after the pilot driving, that the driver felt a mild or intense discomfort, dizziness or nausea. In that case, the coordinator asked the participant if he could carry on with the experiment. In case of a negative answer, it was essential that the experiment stopped. If the driver answered positively the experiment continued following an adequate brake, so that the participant felt better. In case the participant was not willing to continue, or reported - or was suspected to - experience more severe symptoms, the experiment was cancelled.

4.2.4. Main part of the experiment - Rural and Urban driving scenarios

The design of the driving simulator experiment constitutes an innovating component of the PhD thesis, considering that all individual parts are carefully designed based on limitations and needs of similar driving simulators that were reviewed in the previous chapters.

In this framework, this section presents all individual parts of the design of driving scenarios. First, trials characteristics such as area type and traffic conditions are analyzed and the distraction sources are examined. Then, special emphasis is given on the overall experiment design since within- and between-subjects designs are presented, and the full factorial or fractional factorial design implemented is further analyzed. Furthermore, several other relevant aspects of the design are provided, with regard to conversation topics, incidents, randomization of trials and concerning in what way the scenarios were programmed.

Rural and Urban sessions correspond to different road environments: divided urban arterial and undivided two-lane rural road. Figure 4.5 shows the horizontal design of the road in the two different sessions. It is worth mentioning that a programming code has

been developed - using the programming tool the simulator provides - in order to have these specific routes from the various 'maps' available in the simulator software.

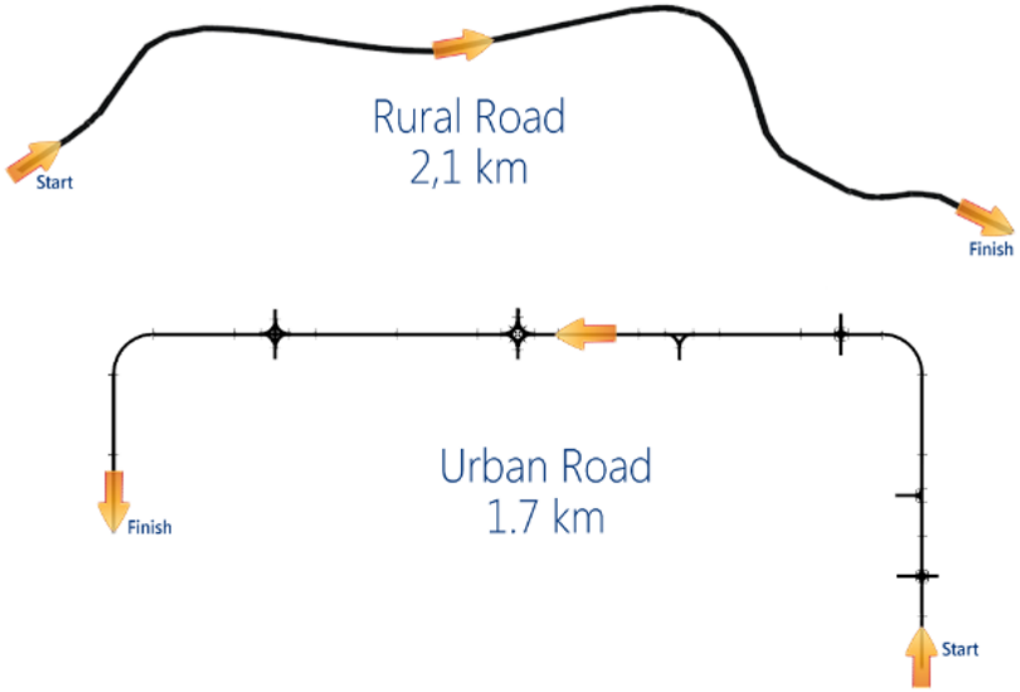


Figure 4.5. Rural and urban routes

The rural route is 2.1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves. The urban route is 1,7km long, at its bigger part dual carriageway, separated by guardrails, and the lane width is 3,5m. Moreover, narrow sidewalks, commercial uses and parking are available at the roadsides. Two traffic controlled junctions, one stop-controlled junction and one roundabout are placed along the route.

4.2.4.1. Traffic flow conditions

The effect of traffic flow on driving of patients with cerebral diseases is a key research parameter of the present research. The simulation of ambient traffic (i.e. the behaviour of other vehicles on the simulated road network) may be a very complex task. In some cases, the interest might be in simulating in detail the behaviour of no more than one or two vehicles in relation to the simulator vehicle. In other cases, such as in the present research, the interest might be in the "global" traffic conditions experienced by the participant during the simulated drive.

However, it should be acknowledged that the simulation of ambient traffic in driving simulators is much more demanding than classical traffic microsimulation, for the reason that it should be implemented in a 'moving window' framework, similarly to the driving simulator. In fact, the simulated environment is not static. The traffic flow parameters of the ambient traffic need to be specified in relation to the traffic parameters of the 'moving' simulator vehicle in the virtual environment, and within the limits of the 'window' corresponding to the screen view provided to the simulator driver. Most traffic microsimulation models are not appropriate under these conditions, and the researcher is requested to program his / her own traffic scenarios.

Recently, a promising approach was proposed by Olstam (2003) according to which, vehicles moving 'inside' the 'moving window' may be simulated in more detail, in accordance with sophisticated traffic micro-simulation or car-following models, whereas other vehicles in the simulated network – but 'outside' the moving window can be simulated probabilistically i.e. drawn from appropriate statistical distributions.

Within the present research, a key parameter is the traffic volume experienced by the driver, under the assumption that higher traffic volume may further impair distracted driving. Consequently, the behaviour of specific vehicles, or their response to driver behaviour, is not a priority for the experiment design – and can be covered by the default traffic behaviour features of ambient traffic in the simulator. Therefore, a probabilistic simulation of traffic conditions was opted for, and **two traffic scenarios were examined**:

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

These traffic arrivals distributions were appropriate for describing vehicle arrivals for the given traffic flow, whereas Gamma distributions are typical for describing vehicle arrivals for moderate to high traffic flows (Frantzeskakis and Giannopoulos, 1986). The selected Gamma distributions were opted for post-pilot testing various alternative combinations of distribution parameters with respect to theoretical and practical issues, including the simulated result on the virtual screen. In Figure 4.6 the gamma distributions for

simulated vehicle arrivals under moderate (blue panel) and high (red panel) traffic flow scenarios are presented.

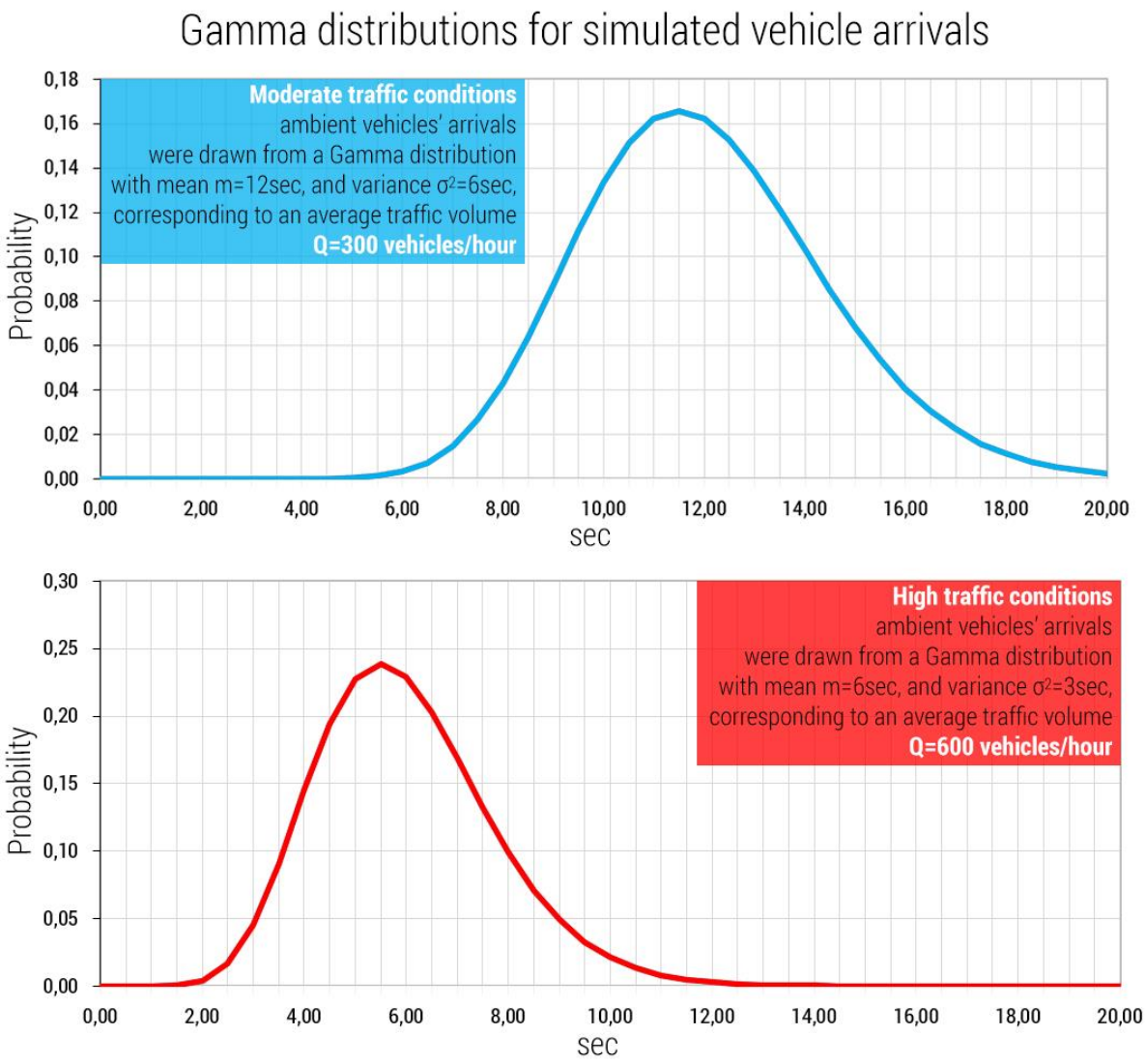


Figure 4.6. Gamma distributions for simulated vehicle time headways

4.2.4.2. Distraction conditions

After reviewing the literature, **two distraction conditions** were found to be more critical with respect to driver behaviour and safety, namely **conversation through mobile phone while driving and conversation with passenger**. Consequently, the distracted driving scenarios of the simulated experiment were based on these in-vehicle distraction causes. As already mentioned, each trial corresponds to different driving distractor and different area type and traffic volume. The trials that demand conversation as a distractor were covered by the following topics: family, origin, accommodation, travelling, geography, interests, hobbies, everyday life, news, and business. It worth

mentioning that if a participant didn't use a handheld mobile phone in their normal driving life, they skipped this part of the experiment.

4.2.4.3. Incidents

During each trial of the experiment, 2 **unexpected incidents** were scheduled to occur at fixed points along the drive (but not at the exact same point in all trials, in order to minimize learning effects). More specifically, incidents in rural area concerned the sudden appearance of an animal (deer or donkey) on the roadway (Figure 4.7), and incidents in urban areas concerned a car getting out of a parking position, or the sudden appearance of an adult pedestrian or of a child chasing a ball on the roadway (Figure 4.8).

Figure 4.7. Unexpected incident - deer crossing the lane ("over the shoulder" view)

Figure 4.8. Unexpected incident - child with ball crossing the road ("POV" view)

4.2.4.4. Scenarios design

The stages of the experimental design revealed a critical design question: "Will each participant drive under all conditions, or will the drivers be randomly split up, so that e.g. half of them drive in one condition and the other half in another?" In statistical

terminology, this question is asking whether a study should be within-subject design or a between-subject design.

Within-subject factors refer to the variables of interest that are measured for all subjects, i.e. the variables pertaining to the experiment conditions. On the other hand, between-subject factors refer to the variables that apply only to some subjects. With regard to the driving simulator experiment, these are typically subject variables, such as demographic variables and participant type where part of the subjects are tested for some of the experiment conditions, while the rest of the subjects are tested for the remaining experiment conditions. In several cases, a mixture of both types of design is involved, given that there are variables which are by nature between-subject (e.g. gender, as a participant can be either male or female) while others can be within-subject (e.g. driving with distraction or without distraction - a condition that can be tested for all subjects). A mixed factorial design includes both within-subjects and between-subjects factors.

The main **advantage** of **within-subject** design is that tends to increase statistical power. Furthermore, there are several within-subject variables in the present experiment (e.g. driver characteristics). Therefore, a within-subject design was opted for the driving simulator experiment.

Moreover, a **full factorial within-subject design** was selected in this research as shown in Table 4.1. Full factorial or fractional factorial design means that each experiment is based on a synthesis of conditions, resulting from the combinations of levels of the variables of interest. The complete combination of all levels of the variables of interest results in a full factorial design. However, in several cases a fractional factorial design may be opted for, by eliminating some of the combinations of levels of the variables examined, on the basis of appropriate criteria (McLean and Anderson, 1984), especially when the number of variables is high, resulting to an unmanageable full factorial design. More specifically, a fractional factorial design is most often based on a full factorial design of some key variables of interest, complemented with selected combinations of these variables with other variables of interest (Montgomery, 2000).

This design was determined after examining various full or fractional factorial design alternatives (e.g. including night-time, or adverse weather driving conditions), and was finalized after the careful selection of **key research parameters**.

Table 4.1. Within-subject full factorial design parameters

	Road Traffic Conditions			
	Urban Area		Rural Area	
Distraction Sources	Q_M	Q_H	Q_M	Q_H
No distraction condition	●	●	●	●
Conversation with passenger	●	●	●	●
Conversation through **mobile phone**	●	●	●	●

Consequently there were **2 driving sessions with up to 6 trials each** (Table 4.2), which were randomized between and within sessions. Is should be noted that whenever a participant claimed that he, or she, does not use a mobile phone while driving under any circumstances, the 4 trials that include mobile phone distraction were subtracted.

Table 4.2. Sessions and trials characteristics

Session	Area Type	Trial	Traffic	Distractor	~Length (km)	~Duration (min)
A	Rural	**1**	Moderate	None	1,7	3
		2	High	None	1,7	3
		3	Moderate	Conversation	1,7	3
		4	High	Conversation	1,7	3
		5	Moderate	Cell Phone	1,7	3
		6	High	Cell Phone	1,7	3
B	Urban	**7**	Moderate	None	2,1	3.5
		8	High	None	2,1	3.5
		9	Moderate	Conversation	2,1	3.5
		10	High	Conversation	2,1	3.5
		11	Moderate	Cell Phone	2,1	3.5
		12	High	Cell Phone	2,1	3.5
				Total	**22,8km**	**40min**

4.2.4.5. Sequence of trials

The first principle of an experimental design is **randomization**, which is a random process of assigning treatments to the experimental units. The random process implies that every possible allotment of treatments has the same probability. An experimental unit is the smallest division of the experimental material and a treatment refers to an experimental condition whose effect is to be measured and compared. The purpose of randomization is to remove bias and other sources of extraneous variation, which are not controllable. Another advantage of randomization (accompanied by replication) is

that it forms the basis of any valid statistical test (Boyle, 2011). Hence the treatments must be assigned at random to the experimental units. Randomization is usually done by drawing numbered cards from a well-shuffled pack of cards, or by drawing numbered balls from a well-shaken container or by using tables of random numbers.

In this experiment randomization was implemented in the sequence of the **traffic scenarios** and **distraction scenarios** in which the participant was going to drive, but not in the order of **area type** (urban/rural). Rural scenario was always first for two reasons. Firstly because of the fact that a full randomization would demand a huge number of participants in order to be implemented properly and secondly because the urban area lead to more simulator sickness issues for the participants due to the more complex driving environment that constitutes. It was concluded that full randomization is not meaningful, as a huge number of combinations would be obtained, thus a limited number of combinations for each variable was selected. These scenarios were randomly assigned to participants (Table 4.3) in a counterbalanced way, so that eventually equal proportions of similar groups of participants were assigned to each scenario.

Table 4.3. Randomized trials' order - Possible sequences

	First	**Second**	**Third**	**Fourth**	**Fifth**	**Sixth**
1	Q_M-No	Q_M-Mob	Q_M-Conv	Q_H-No	Q_H-Mob	Q_H-Conv
2	Q_M-No	Q_M-Conv	Q_M-Mob	Q_H-No	Q_H-Conv	Q_H-Mob
3	Q_M-Conv	Q_M-Mob	Q_M-No	Q_H-Conv	Q_H-Mob	Q_H-No
4	Q_M-Conv	Q_M-No	Q_M-Mob	Q_H-Conv	Q_H-No	Q_H-Mob
5	Q_M-Mob	Q_M-Conv	Q_M-No	Q_H-Mob	Q_H-Conv	Q_H-No
6	Q_M-Mob	Q_M-No	Q_M-Conv	Q_H-Mob	Q_H-No	Q_H-Conv
7	Q_H-No	Q_H-Mob	Q_H-Conv	Q_M-No	Q_M-Mob	Q_M-Conv
8	Q_H-No	Q_H-Conv	Q_H-Mob	Q_M-No	Q_M-Conv	Q_M-Mob
9	Q_H-Conv	Q_H-Mob	Q_H-No	Q_M-Conv	Q_M-Mob	Q_M-No
10	Q_H-Conv	Q_H-No	Q_H-Mob	Q_M-Conv	Q_M-No	Q_M-Mob
11	Q_H-Mob	Q_H-Conv	Q_H-No	Q_M-Mob	Q_M-Conv	Q_M-No
12	Q_H-Mob	Q_H-No	Q_H-Conv	Q_M-Mob	Q_M-No	Q_M-Conv
13	Q_M-No	Q_H-No	Q_M-Mob	Q_H-Mob	Q_M-Conv	Q_H-Conv
14	Q_M-No	Q_H-No	Q_M-Conv	Q_H-Conv	Q_M-Mob	Q_H-Mob
15	Q_M-Conv	Q_H-Conv	Q_M-Mob	Q_H-Mob	Q_M-No	Q_H-No
16	Q_M-Conv	Q_H-Conv	Q_M-No	Q_H-No	Q_M-Mob	Q_H-Mob
17	Q_M-Mob	Q_H-Mob	Q_M-Conv	Q_H-Conv	Q_M-No	Q_H-No
18	Q_M-Mob	Q_H-Mob	Q_M-No	Q_H-No	Q_M-Conv	Q_H-Conv
19	Q_H-No	Q_M-No	Q_H-Mob	Q_M-Mob	Q_H-Conv	Q_M-Conv
20	Q_H-No	Q_M-No	Q_H-Conv	Q_M-Conv	Q_H-Mob	Q_M-Mob
21	Q_H-Conv	Q_M-Conv	Q_H-Mob	Q_M-Mob	Q_H-No	Q_M-No
22	Q_H-Conv	Q_M-Conv	Q_H-No	Q_M-No	Q_H-Mob	Q_M-Mob
23	Q_H-Mob	Q_M-Mob	Q_H-Conv	Q_M-Conv	Q_H-No	Q_M-No
24	Q_h-Mob	Q_M-Mob	Q_H-No	Q_M-No	Q_H-Conv	Q_M-Conv

Where:
Q_M: Moderate traffic
Q_H: High traffic
NO: No distraction
MOB: Cell phone
CONV: Conversation with passengers

The above scenarios were **programmed by means of the R8103 Programming Tool software version 3.4** of the driving simulator, in a scripting language supported by the simulator environment. An extract of the source code for one indicative scenario is provided in Annex.

4.2.4.6. Process of "driving at the simulator" assessment

The "driving at the simulator" research team consisted of:

» One researcher - **coordinator** of the experiment. The role of the coordinator is to welcome and guide the participants to the room of the driving simulator, at the specified date and time. The researcher is responsible for:
  » The oral briefing and the delivery of the instructions to the participant,
  » Assisting the participant during their familiarization drive,
  » Assisting the participant to fill in the Self-assessment and Memory questionnaire,
  » Filling a checklist (see Appendix) for the control of the experiment with any comments related to anything remarkable regarding the driving of the participant,
  » The monitoring for and handling of simulator sickness,
  » The accomplishment of the driving simulator experiment,
  » Assisting the participant in any other issue.

» One researcher responsible for the **distraction tasks and the statistical editing of the data output.** The role of this researcher is:
  » performing the distraction tasks during the experiment: the conversation task and the phone call with the participant,
  » assisting for any other secondary issues during the experiment,
  » organizing the files generated from the participants' driving and editing statistically the data.

As mentioned before, following the familiarization drive and the necessary short brake, rural and urban areas followed. **Within each road type, two traffic scenarios and three distraction conditions were examined in a full factorial within-subject design, as shown in Table 4.2**. More specifically, the distraction conditions were: no distraction, conversation through mobile phone and conversation with passenger. The traffic scenarios were: Q_M: Moderate traffic conditions (Figure 4.9) and Q_H: High traffic conditions (Figure 4.10). For rural area each participant drove approximately 12,6km within about 20min in total. After the end of each trial (when the driver reached a spot with road works obliging the driver to stop the vehicle - Figure 4.11), the screen instantaneously turned black for a few seconds, and restarted at the beginning of the route for the next trial. When the participant drove all six routes (2,1km each for 3,5min), was having a break. As mentioned, each trial was about a different driving distractor and different traffic volume. In addition two unexpected events were set, where the reaction of each driver was recorded. For **urban area** (Figure 4.12) each participant drove approximately 10,2km within about 20min in total. After the end of each trial, the screen instantaneously turned black and restarted at the beginning of the next trial. After the completion of all six routes (1,7km each for 3,5min), the participant had a break.

Figure 4.9. Rural area-moderate traffic volume

Figure 4.10. Rural area - high traffic volume

Figure 4.11. End of rural trial

Figure 4.12. Urban area high traffic volume

4.3. Neurological Assessment

Motor abilities are necessary for the safe operation of basic vehicle controls. Lower limb function is needed to quickly shift the right foot from the accelerator to the brake in an emergency situation, and to apply the correct pressure on the gas and brake for smooth stopping and speed control (Staplin, et al., 2003b). Upper limb control is required to operate the steering wheel to safely maneuver the car around obstacles and to operate secondary controls (directional signals, lights, ignition, etc.) Neck and trunk rotation are needed to shift one's gaze in each side visualizing better the space, amplifying the visual field, in order to change lanes, overtake, during the parking maneuver, before crossing an intersection. (Staplin, et al., 2003b).

The Medical/Neurological 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 (MCI, AD and PD) affecting cognitive functions. The **Clinical Neurological Assessment** includes the completion of the following **14 neurological scales/tests** + 4 specific motor speed/coordination tests + ophthalmological examination **(2.5 hours of testing in total)** :

1. Clinical Dementia Rating Scale (CDR)
2. Hachinski Ischemic Scale (HIS)
3. Unified Parkinson's Disease Rating Scale-motor (UPDRS-Motor)
4. Hoehn & Yahr Scale (H&Y)
5. Neuropsychological Inventory (NPI)
6. Frontal Behaviour Inventory (FBI)
7. Instrumental Activities of Daily Living (IADL)
8. Functional Activities Questionnaire (FAQ)
9. Informant Questionnaire on Cognitive Decline in Elderly (IQ-CODE)
10. Geriatric Depression Scale (GDS)
11. PHQ-9
12. Parkinson's Disease Sleeping Scale-2 (PDSS-2)
13. Athens Insomnia Scale (AIS)
14. Epworth Sleepiness Scale

15. Rapid pace walk
16. Head and trunk rotation modified

17. Alternate foot tapping modified
18. Tandem walking

The **Medical History** of the patient is the information obtained by the physician by asking specific questions directly to the patient himself, or indirectly to a person which is familiar with the patient, in order to formulate a diagnosis and provide or not an appropriate medical treatment. From the History of the present illness the physician obtains details about the current problem of the patient. Likewise from the Past Medical History the medical personnel obtain information about illnesses or surgeries/operations in the past, through the Drug history information about current or previous drug therapy of the Patient.

In the Medical examination the blood pressure, the cardiac rhythm and pulse, are being measured. The basic scheme of neurological examination consists of: **Assessing the higher mental functions** (Intellect, memory, personality and mood), the **communication capability** (speech), **testing the cranial and the peripheral nerves**, **evaluating the motor and sensory functions**. Through the medical history and the neurological examination the clinician should classify the participant as cognitively (Mentally) Healthy or as a person with Mild Cognitive Impairment (MCI) or with Dementia.

The **Clinical Dementia Rating Scale (CDR)** (Morris et al., 1993) includes the clinical (through the interview with the patient and one of his/her family members) the evaluation of the following cognitive domains: memory, orientation in time/space, judgment and problem solving, community affairs, home activities and hobbies, personal hygiene. The CDR permits the evaluation and the grading of the participant's cognitive decline (CDR=0 corresponds to cognitively normal, CDR=0.5 corresponds to the state of MCI, while CDR≥1 means dementia (mild dementia=1. Moderate dementia=2, severe dementia=3).

The **Hachinski Ischemic Scale (HIS)** represents a brief clinical tool helpful in the differentiation of the commonest dementia types, Dementia of Alzheimer's Type (DAT) and Vascular Dementia (VaD). A cut-off score ≤ 4 for DAT and ≥ 7 for VaD has a sensitivity of 89% and a specificity of 89% (Moroney 1997).

Scales such as the UPDRS-motor (Unified Parkinson's Disease Rating Scale) and **H&Y-modified** (Hoehn and Yahr) scales are administered in order to obtain precise

information about the motor system. The UPDRS-motor scale (Goetz et al., 2008) offers not only a detailed description but also a quantification of the EPS. Speech, Facial Expression, Tremor (at rest, postural or action type), rigidity, rapidity and width or alternate movements, arising from chair and Gait are some of the main features that are being evaluated in this scale. The Hoehn and Yahr scale is a commonly used system for describing how the symptoms of Parkinson's disease progress. It was originally published in 1967 in the journal Neurology by Melvin Yahr and Margaret Hoehn and included stages 1 through 5. Since then, a modified Hoehn and Yahr scale was proposed with the addition of stages 1.5 and 2.5 to help describe the intermediate course of the disease. The H&Y scale measures mainly the quality-expansion of the extrapyramidal signs (EPS): In stage 0 there are not EPS, in stage 1 there are EPS unilaterally, in stage 2 the EPS are bilateral, without impairment of balance, in stage 3 the EPS compromise the balance enough to bring postural instability, but the patient is still independent, in stage 4 the symptoms are with the patient still able to walk or stand unassisted and finally, in stage 5 the patient is wheelchair bound or bedridden unless aided.

The emotional state of all the participants is evaluated through **Patient Health Questionnaire** (**PHQ-9)** scale (Cameron et al., 2008) and **GDS (Geriatric Depression scale)** (Sheikh et al., 1986) , while the sleep behaviour is evaluated through **Athens Insomnia Scale** (Soldatos et al., 2000) and **Epworth sleepiness scale** (Johns 1991).

The **PDSS-2 (Parkinsonian Disease Sleeping Scale-2)** (Chaudhuri et al., 2002) is additionally administered to the Participants with Parkinson Disease.

The **Neuropsychiatric Inventory (NPI)** (Cummings 1997) and the **Frontal Behaviour Inventory (FBI)** (Kertesz et al., 1997) are used for evaluating the participant's behaviour in relation to brain diseases. The NPI assesses 12 neuropsychiatric-behavioural domains: Hallucinations, Delusions, Agitation/aggression, Dysphoria/depression, Anxiety, Irritability, Disinhibition, Euphoria, Apathy, Aberrant motor behaviour, Sleep and night-time behaviour change, Appetite and eating change, evaluating their frequency and severity. The NPI is administered by the clinician to the caregiver. The caregiver is usually a family member involved in the daily care of the patient. In the FBI domains such as apathy, emotional indifference, inattention, loss of insight, the presence of comprehension deficit and many others are being evaluating. The FBI has been designed to detect and grade neuropsychiatric-behavioural disorders associated with disorders of the frontal lobes.

Daily activities are evaluated with the **IADL scale (Instrumental Activities of Daily Living)** (Lawton 1969), the **FAQ (Functional Activities Questionnaire)** and the **IQ-CODE (Informant Questionnaire on Cognitive Decline in Elderly)** (Jorm et al., 1991). The short-term change in daily activities (weeks to month) is evaluated through scales such as the Instrumental Activities of Daily Living (IADL) and Functional Assessment Questionnaire (FAQ). The IQ-CODE helps in the corroboration of the patients complaints about his/her cognitive deficits (most often in the domain of memory).

Other administered inventories for behaviour discrimination are the Adult Self-Report Scale-V1.1 (ASRS-V1.1) and the Simple Screening Instrument for Substance Abuse Self-Administered Form. The information from the aforementioned scales-test, from Neuroimaging (cerebral MRI or CT scan) and specific blood tests (General blood count, electrolytes, Liver and Kidney function tests, thyroid hormones, Vit.B12, Folic Acid levels, autoimmune antibodies) and the Clinical examination and interview is used in order to make a correct diagnosis of the patient's disease.

Motor speed/coordination tests

Additionally, during the neurological assessment those motor abilities related to driving performance were evaluated by the: **Rapid Paced Walk**, **Head and Trunk rotation task (modified)**, **Alternate foot tapping (modified)**, **Tandem Walking at 2 meter distance**, **Tandem Walking at 2 meter distance (modified)**. In the next paragraphs a brief description of all these tests will be presented.

» ***Rapid paced walk***

The participant is invited to cover a distance of 3+3 meters long, as quickly as possible. A measuring tape is laid on the floor, pulled out to its full 3 meter length, and locked open at this length. The patient walks next to the measuring tape, turns at the end, and walks back to the start position. The total walking distance is 6 meter. The examiner says, "*I want you to walk along side of this tape measure (tape line) to the end, turn around, and walk back here as quickly as you can.*" The examiner records the time involved.

Parameters to be evaluated: Gait-balance-speed.

Conclusion: Time>7.5sec: 2.5x Time>9sec: 3x possibility to get involved in car accident or to commit traffic violation (Staplin et al. 2003).

» ***Head and trunk rotation modified***

The patient does this test while seated in a chair. The examiner stands 3.5 meters behind the client at a pre-marked location, and holds up a random number of fingers while the client is facing straight forward. The examiner delivers the instruction, "*Just as you would turn your head and upper body to look over your right shoulder to back your car or change lanes, please turn and tell me as quick as possible, how many fingers I have raised and return to the straight forward position*". The fingers is raised for only 1 second at each time. This task is repeated three times towards to Right and afterwards, three times to the Left. The examiner records whether the client can accurately identify the number of fingers raised. The examiner records the correct and the false answers to both sides.

Parameters to be evaluated: Visual field, Ability to perceive objects in field of view, Time of reaction.

Application: Ability to change direction while driving. Ability to park.

Conclusion: To be evaluated

The Head and Trunk rotation task, was introduced for the first time from Marottoli (Marottoli et.al 1998) and later from Staplin (Staplin et al., 1999). In that task the participant had to turn his head only one time to each side. Failure to this task was related to poor driving performance with higher possibility to get involved to car accident. In comparison with head and trunk rotation proposed by Marottoli, in which the participant has to make one head turn at each side, in the modified Head-Trunk rotation task the participant have to make three turns to each side. This task remains to be evaluated.

» ***Alternate foot tapping modified***

This task is performed while the participant is seated. The examiner places on the floor a piece of paper (A4 format page) in front of the participant, at a distance of 40-50cm from the front edge of the chair. The participant have to touch their right foot to the floor 5 times alternately on each side of the A4 paper moving from one side to the other on every tap. The total number of taps is 10. The participant must make sure to lift the foot sufficiently high in order to keep the paper steady. The examiner records the mistakes and the time involved. In the foot tapping test proposed by Marottoli et.al, 1994 the participant while seated was invited to move his right foot, over a 2" 3-ring binder, placed at a distance of 16 to 24 inches from the front edge of the chair. In our study a modification of this test was used.

» ***Tandem Walking - 2m***

The patient is invited to walk through a straight line 2m long in heel-toe mode (Figure 4.13), with simultaneous aloud number counting from number zero to 20 subtracting 2 numbers at each time (0-2-4-6-...), and then from number 20 to zero subtracting 2 numbers at each time (20-18-16-...). Balance, movement coordination, mistakes and time of execution are to be evaluated.

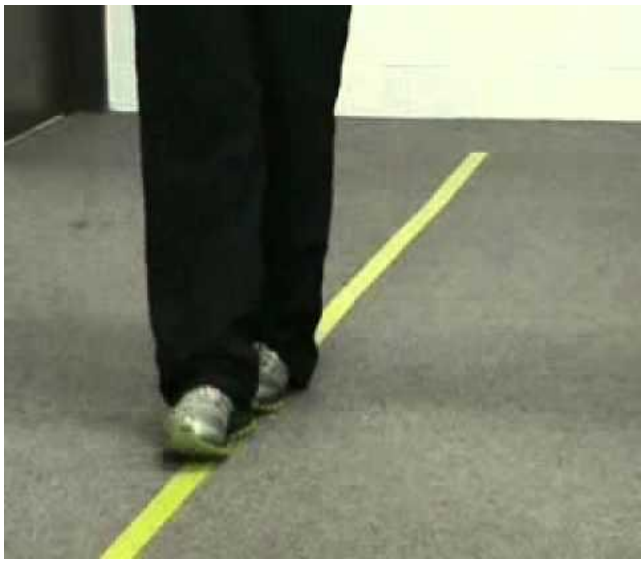


Figure 4.13. Tandem Walking Test

Ophthalmological Examination

Finally, all patients and control subjects went through a complete ophthalmological examination (Figure 4.14) including assessment of visual acuity, visual field examination, color vision test, slit lamp biomicroscopy, slit lamp fundus examination with super field lens after pupil dilation by using tropicamide and phenylephrine hydrochloride. Finally macular thickness and macular volume were measured with optical coherence tomography (OCT). All the participants should have best corrected visual acuity better than 10/10. Their ophthalmic history should be free of any retinal vascular occlusive disease, glaucoma or any other ocular disease. Eyes with posterior pole pathology such as macular degeneration, diabetic retinopathy, glaucoma suspect, or glaucoma and patients with media opacification such as cataract that obstruct ocular and OCT examination were excluded.

Figure 4.14 Ophthalmological Examination

4.4. Neuropsychological Assessment

The neuropsychological assessment includes a detailed screening of various cognitive domains with the use of appropriate tools. The elected neuropsychological tests cover a large spectrum of cognitive functions: visuo-spatial and verbal episodic memory, working memory, general, sustained, selective and divided attention, reaction time, psychomotor speed, mental flexibility and task shifting etc. More specifically, the following **20 neuropsychological tests (2.5 hours of testing in total)** were administered to all participants. A detailed review of the utility of these tests for cognitive evaluation in neurodegenerative diseases can be found in Joint Programme Neurogenerative Disease Research Strategic Research Agenda 2016 (JPND-SRA 2016).

» **Mini Mental State Examination** (**MMSE**; Folstein, Folstein, & McHugh, 1975): MMSE is a test of general cognitive functioning. Components that are assessed are: a) attention, b) time and space orientation, c) memory, d) language, and e) visuospatial skills.

» **Montreal Cognitive Assessment** (**MoCA**; Nasreddine et al., 2005): MoCA is a brief (10–15 minute) 30-point cognitive screening instrument which has proved useful in identifying patients with dementia and with mild cognitive impairment (MCI). Individual items on the MoCA are divided into 5 cognitive-specific domains (attention/executive function, visuospatial, language, memory, and orientation) The attention/executive function items include Trail Making Test B (1 point), digit span (2 points), target detection (1 point), verbal fluency (1 point), abstraction (2 points), and serial seven subtraction (3 points). The visuospatial items include clock drawing (3 points) and cube copying (1 point). The language items include object naming (3 points) and sentence repetition (2 points). The memory items include recall of 5 previously presented words (5 points). The orientation items include 6 orientation-based questions (6 points)

» **Clock Drawing Test**
The participant is asked to draw a clock face with numbers and the hands at twenty to four (Figure 4.15 presents four examples from our participants). It primarily relies on visual-spatial, constructional, and executive abilities (Strauss, Sherman, & Spreen, 2006).

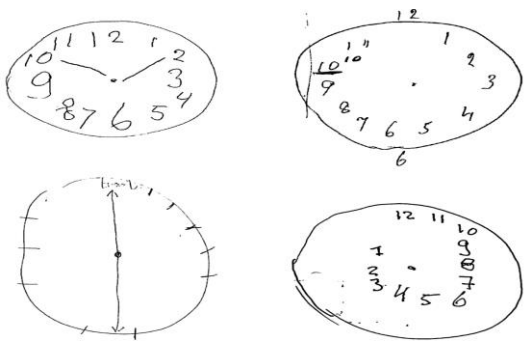


Figure 4.15. Clock Drawing Test example

» **Phonemic fluency**: In this version the examinee must produce orally as many words as possible beginning with a specified letter during a fixed period of time, usually one minute.

» **Semantic fluency**: The most common category is "animals" and the examinee is asked to produce as many animal names as possible within a one-minute interval. Cognitive functions that are considered to be engaged by the specific tasks are: word knowledge, episodic memory, working memory, speed of processing information, and effortful self-initiation (Strauss et al., 2006).

» **Frontal Assessment Battery** (**FAB**; Dubois, Slachevsky, Litvan, & Pillon 2000): The FAB takes about 10 minutes to be administered. It consists of six subtests that explore neurocognitive processes related to the frontal lobes: conceptualization (Similarities task), mental flexibility (Phonological Lexical Fluency task), motor programming (Luria's motor series), sensitivity to interference (Conflicting Instructions task), inhibitory control (Go-No-Go task) and environmental autonomy (evaluation of Prehension Behaviour). Each subtest is scored between 0 and 3; a composite score ranging between 0 and 18 indicates whether or not executive dysfunction is present and, if yes, its severity.

» **Upper Limb apraxia screening test**: This test aims at detecting ideomotor apraxia. The task that the examinee has to perform is to correctly imitate hand gestures that are made by the examiner.

» **Letter Number Sequencing** (**LNS**; Wechsler, 1997a): A series of numbers and letters are read aloud to the participant in a mixed-up order at an approximate rate of one item per second. The participant is instructed to recall first all numbers in numerical order and then all letters in alphabetical order. LNS is considered to engage the executive component of working memory because it does not only require the temporary storage of information, but also the manipulation of the information that is temporarily maintained (Emery, Heaven, Paxton, & Braver 2008; Shelton, Elliott, Hill, Calamia, & Gouvier, 2009).

» **Spatial Span Task** (Wechsler, 1997b): This task is a variation of Corsi's block-tapping test (Lezak, Howieson, & Loring, 2004) and is considered as a measure of visuospatial working memory (Figure 4.16). It is part of the 3rd Edition of the Wechsler Memory Scale (Wechsler, 1997b). Participants are shown a white board with raised, equally-sized blue blocks. In the Forward condition, the experimenter taps the blue blocks in a sequence and participants attempt to repeat the correct order. In the Backwards condition, the test procedure is the same, except that participants have to repeat the tapped sequence in the reverse order. Both conditions are composed of eight sets of items with two trials in each set. The sequence length is two for trial 1 and increases by one for each successive set. Administration is terminated if participants miss both trials of any set. Scores reflected a sum of the total number of correct trials from the Forward and Backward conditions.

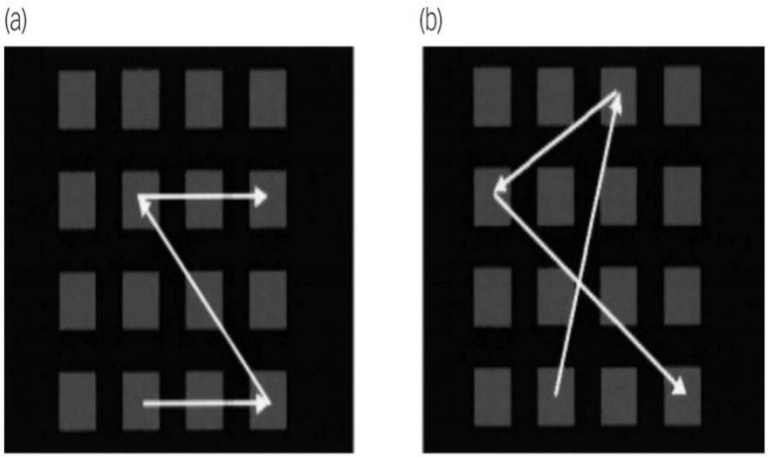


Figure 4.16. Spatial Span Task example

» **Symbol Digit Modalities Test** (Smith, 1991): A coding key is presented consisting of nine abstract symbols, each paired with a number, and the respondent is required to scan the key and write down (written form) or say orally (oral form) the number corresponding to each symbol, as rapidly as possible. It is considered to measure speed of information processing.

» **Driving Scenes Test-Neuropsychological Assessment Battery** (NAB; White & Stern, 2003): Participants are presented with a drawing of a driving scene (Figure 4.17) as viewed from behind the wheel. After a 30 sec exposure, participants are shown another similar picture, and are asked to identify new, different or missing items relative to the previous scene. The test measures working memory, visual scanning, attention to detail and selective attention.

Figure 4.17. Driving Scenes Test-Neuropsychological Assessment Battery

» **Useful Field of View** (**UFOV**; Ball & Owsley, 1993): The UFV (Figure 4.18) is a computerized test that captures both speed of visual attention as well as ability to focus visual attention despite distractors and was developed especially for the assessment of driving fitness in various populations. It includes three subtests that assess various aspects of visual perception and attention, namely central vision and processing speed, divided attention, and selective attention.

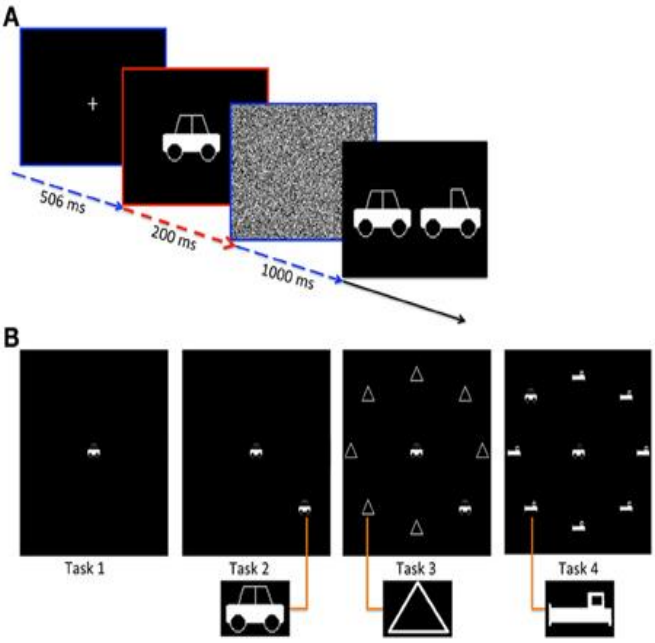


Figure 4.18. Useful Field Of View Test

» **Psychomotor Vigilance Test** (**PVT**): PVT is a computerized test that is considered to measure sustained attention, alertness, and vigilance. In the version that is used in the present study the participants should click the left mouse button as soon as possible, after the appearance of red numbers in a box that is placed in the center of the screen. The red numbers appear at random times and the test lasts 2 minutes. The specific version of the test is free ware and is retrieved from the Sleep Disorders Center at Florida, USA.

» **Hopkins Verbal Learning Test-Revised** (**HVLT-R**; Benedict, Schretlen, Groninger, & Brandt, 1998): HVLT-R is a brief verbal learning and memory instrument. It consists of a 12-item word list presented in three consecutive trials. Also, the test includes a delayed free recall and a recognition trial. The recognition task consists of 24 words, 12 from the recall list, 6 distracters that are semantically related to the recall items, and 6 unrelated words.

» **Brief Visuospatial Memory Test-Revised** (**BVMT-R**; Benedict, 1997): BVMT-R is used as a measure of visuospatial memory (Benedict, 1997). The test consists of six geometric designs that are shown for a period of 10 seconds. Subjects are asked to reproduce the drawings immediately after each trial. They are instructed to draw them as accurately as possible and in the correct location on the answer sheet. Each reproduction is awarded 2 points if it is reproduced accurately and is placed correctly. One point is given to those responses that are either placed appropriately or drawn correctly. Those designs that are missing from the answer sheet or for which no recognizable attempt is found are scored 0. The range of possible scores extends from 0 to 12 for each free recall trial. The "total learning" score is the sum of scores across the three learning trials. Subjects are asked to reproduce the designs for a fourth time, approximately 25 minutes after the learning trials. This score, computed with the same criteria used in the immediate recall trials, provides a measure of "delayed recall." This delayed reproduction is followed by recognition testing, composed of the six targets interspersed with an equal number of distractor Figures.

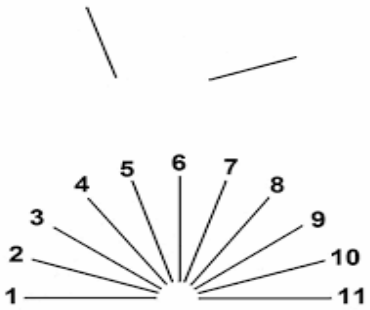


Figure 4.19. JLO Test

» **Judgment of Line Orientation Test** (**JLO**; Benton, et al., 1994): JLO is considered to measure visuospatial perception (Figure 4.19). The respondent is required to identify

which two lines, from a multiple-choice array, match the directions of the lines on the stimulus card.

» **Witkin's Embedded Figure Test** (Witkin et al., 1971): The participant is required to locate simple geometric figures within larger complex designs. It measures the ability to distinguish a target object from an organized visual field. According to their performance, the participants can be categorized as having "Field-dependent cognitive style" or "Field-independent cognitive style". "Field-dependent cognitive style" means that the perception is dominated by the overall organization of the surrounding field whereas "Field-independent cognitive style" indicates the ability to break-up parts of the field discretely from an organized ground.

» **Spatial addition test** (Wechsler, 2009): The Spatial Addition test is part of the Wechsler Memory scale-Fourth Edition (WMS-IV) and is considered as a measure of visuospatial working memory that puts a heavy load on the executive component of the working memory schema. Initially, the examinee is shown a grid with blue dots, red dots, or both for 5 seconds. Then the examinee is shown a second grid with additional dots. Finally, the examinee must add the spatial locations of the blue dots that were presented in both grids and ignore any red dots. Specifically, the instruction that is given to the examinee is to respond by placing blue or white cards in an empty grid (blue for location of blue, white for subtracting 2 blues in the same location).

» **Trail Making Test** (**TMT**; Reitan, 1979): The version of the TMT (Figure 4.20) used has two subtasks Part A (TMT-A) and Part B (TMT-B). Each subtask is shown on a white paper (A4 dimension) and the participants are asked to connect randomly located circles, as fast as possible. Part A includes circles with numbers only (1-25) that have to be connected in numerical order, while Part B includes circles with both numbers (1-13) and letters (A-M) that have to be connected alternately. Abilities such as visual search, motor speed, and spatial skills are examined in both parts of the test. In addition, part B is considered to assess aspects of executive control, such as mental flexibility and task shifting (Strauss et al., 2006).

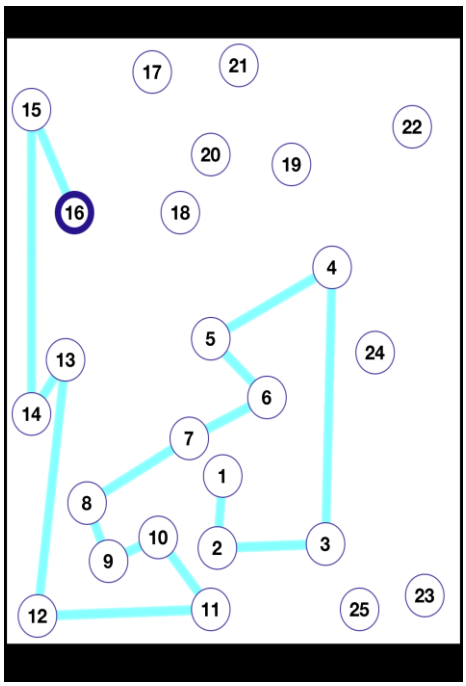


Figure 4.20. Trail Making Test Part A

» **Comprehensive Trail Making** (**CTMT**; Reynolds, 2002): The CTMT consists of five trails that assess psychomotor speed, visual scanning, sequencing, task switching/cognitive flexibility, attention, inhibition, and distractibility. Trail1 of the CTMT, like Part A of the original TMT, instructs participants to draw a line connecting numbered circles in ascending order as quickly as possible. For Trail 2, participants connect numbered circles in ascending order from 1 to 25 while ignoring 29 empty distractor circles that are included to assess inhibition and distractibility. Trail 3 includes 13 empty distractor circles and19 distractor circles with line drawings inside, providing a further measure of visual scanning, attention, and distractibility. On Trail4, participants connect numbers from 1 to 20, 11 of which are Arabic numerals, whereas the other nine are written words. Trail 5 is similar to TMT-B in which the participant not only alternates between numbers and letters in sequence but also includes five empty distractor circles. Trails 4, 5 were included to assess different types of task-switching abilities, thus increasing the sensitivity of the CTMT to brain dysfunction.

4.5. Self-stated driving behaviour questionnaire

After completing the driving simulator tasks, participants were asked to fill a questionnaire concerned their **driving habits** and their **driving behaviour**. The questions were chosen carefully on the basis of the existing literature on drivers' self-reported behaviour. The sections of the questionnaire were: driving experience - car use, self - assessment of the older driver, distraction-related driving habits, emotions and behaviour of the driver, anger expression inventory during driving, and history of accidents, near misses, and traffic violations

The **driving experience** section included questions about the driving experience and driving habits of the participants that were used in analysis as potential moderating factors for the evaluation of driving simulator performance. The section also incorporated questions that examine the driving experience of the participants in different driving environments or situations, e.g., frequency of driving during rush hour, thus providing more detailed information on the driving experience of the participants.

The **self-assessment** of the older driver section included two sub-sections. The questions of the first one required the self-evaluation of the perceptual-motor and the safety skills of the driver. The items of the section were derived from the Driver Skill Inventory (Lajunen & Summala, 1995), with adaptations and modifications by the research team. This section employs a 4-point scale (from weak to strong), in order to

prevent the bias of responses that cluster in the middle. The section included an original questionnaire, developed by the research team, which asked the participants to rate their driving skills in relation to their skills of 5 years ago. The rating scale ranged from no difference to significantly worse with respect to driving in different conditions (on a highway, at night, in heavy traffic, etc.). In addition, participants rated whether or not they avoid each one of the conditions included, how often, and if so, whether their avoidance was attributed to their own hesitation, the discouragement of their family, or other reasons. This section offered valuable information on self-awareness of possible driving impairment, as well as possible compensatory mechanisms to avoid safety risks. A questionnaire that inquired about the frequency of various driving difficulties was also included, on a 5-point scale (never-always). The information provided in this section was related to the driving performance of the drivers in the different conditions of the driving simulator experiment.

The **distraction-related driving habits** section included an original questionnaire, developed by the research team, that inquired about the attitudes of the participants with respect to distracting behaviours, e.g., use of cell phone in the city in heavy traffic. The questionnaire employed a 4-point scale (not at all dangerous-very dangerous). The section also included two questions on engaging in distracting behaviours, on a 4-point scale (never-many times), and questions on the use of behavioural adaptations when engaging in distracting behaviour, e.g., slowing down and driving more carefully, on a 5-point scale (never-always). The information provided by this section were specifically related to performance in the distraction conditions of the driving simulator experiment.

The **anger expression** inventory section measured different aspects of the emotions and behaviours of the drivers. It included questions on the frequency of engaging in quarrels (0-9+ times a year); questions on safety behaviours, e.g., driving under the influence of alcohol, on a 4-point scale (not at all-very frequently); and a driving anger scale, adapted and modified by the research team from the Driving Anger Expression Inventory (Deffenbacher et al., 1994), rated on a 4-point scale (almost never-almost always). The results of this section were related to performance in those conditions of the driving simulator more likely to result in impatience or anger, e.g., driving in heavy traffic. Moreover, the results of the section enter further analyses in order to construct an instrument that may be utilized in future research on driver behaviour. The **history of accidents**, near-misses and traffic violations section aimed to elicit specific information on the above, measured in terms of frequency of occurrence (0-9+ times in total, or in the past 2 years, depending on the section).

4.6. Sample characteristics

Within the framework of the present PhD dissertation, 225 participants went through the whole experimental procedure that was described analytically in the above chapters, between February 2013 and April 2015. More specifically, 225 participants went through the driving at the simulator assessment, the neurological assessment, the neuropsychological assessment, and the questionnaire assessments. In the present section sample characteristics are presented regarding driver parameters (age, gender, education, experience) as well as driving characteristics. For the purpose of this study **274 participants started** the driving simulator experiment that was described analytically in the above chapters. **49 participants were eliminated from the study because they had simulator sickness issues** from the very beginning of the driving simulator experiment.

Thus, **the sampling scheme included 225 participants** (76% males - 24% females) (Figure 4.21):

- **133 "patients"** with a neurological disease affecting cognitive functions:
  - 28 AD patients,
  - 45 MCI patients,
  - 25 PD patients,
  - 35 patients with other neurological disorders affecting cognition
- **92 "Controls"** without any cognitive disorder

From the age perspective, three age groups were developed and the sampling scheme is also divided as follows:

- **30 Young participants (age<34 years old)**
  - 28 Controls
  - 2 patients with other neurological disorders affecting cognition
- **42 Middle Aged participants (35 years old<age<54 years old)**
  - 30 Controls
  - 2 MCI patients
  - 5 PD patients
  - 5 patients with other neurological disorders affecting cognition
- **153 Old participants (age>55 years old)**
  - 34 Controls
  - 43 MCI patients
  - 28 PD patients
  - 20 PD patients

» 28 patients with other neurological disorders affecting cognition

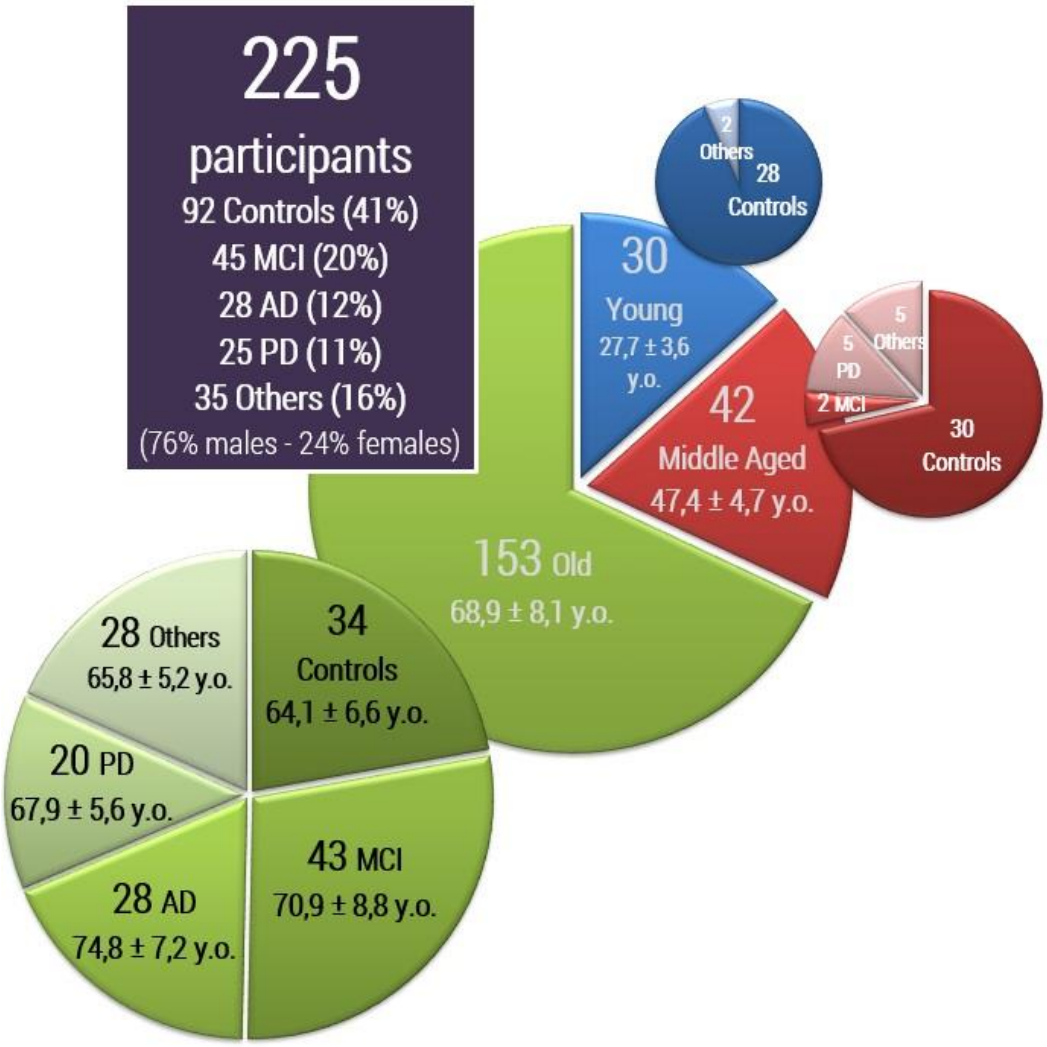


Figure 4.21. Sample Scheme of the PhD thesis

In the next step of this sample scheme presentation we will focus on the 153 old participants. This specific group is inserted in the majority of the regression analyses and it is of critical importance that there are no significant differences between the group of old patients (MCI, AD and PD) and the group of old healthy controls. In Table 4.4, the between-group comparisons in age, driving experience, 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 their self-reported levels of simulator sickness (caused by the driving simulator) are presented for the group of older drivers (> 55 years old). There were not statistically significant differences in the demographic characteristics of the two groups.

Table 4.4. Comparison of patients with neurological diseases affecting cognitive functions and of the Control group without neurological history on various demographics with the use of the Wilcoxon Rank Sum Test **(age >55 y.o.)**

	"MCI, AD, PD Patients" group	"Control" group	**P-values**
Age, y, mean±SD	71.2±7.2	64.1±6.6	0.122
N, M/F (Gender)	91, 59/32	34, 25/9	0.141
Driving experience, y, mean±SD	41.3±5.8	38.7±2.8	0.271
Days/week, median (range)	4 (2-7)	5 (2-7)	0.359
Kilometers driven/week[a], median (range)	3 (2-5)	3 (2-5)	0.416
Accidents (2 years) - reported, median (range)	0 (0-0)	0 (0-0)	1.000
Education, y, mean±SD	12.1±3.5	13.5±2.2	0.812
Simulator sickness[b] - reported, median (range)	0.23 (0-3)	0.18 (0-3)	0.726

[a] 1=1-20km; 2=21-50km; 3=50-100km; 4=100-150 and 5>150

[b] Question: Did you feel dizzy at the simulator? 0=Not at all, 1=Just a little, 2=To some extent, 3=A lot

Moreover, boxplots charts are presented regarding age, years of education and driving experience of Controls, MCI, AD, and PD participants (Figures 4.22, 4.23, 4.24). With regard to the interpretation of boxplots, it should be noted that the spacing between the different parts of the box plot indicates the degree of dispersion (spread) and skewness in the data and identifies outliers. More specifically the line in the middle of the boxes is the median, and the bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile. The top of the box represents the 75th percentile. Twenty-five percent of cases have values above the 75th percentile. Finally, half of the cases lie within the box.

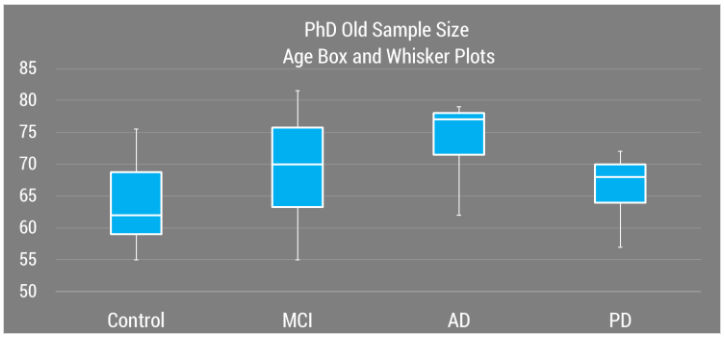


Figure 4.22. Participants >55 years old: age box-plots

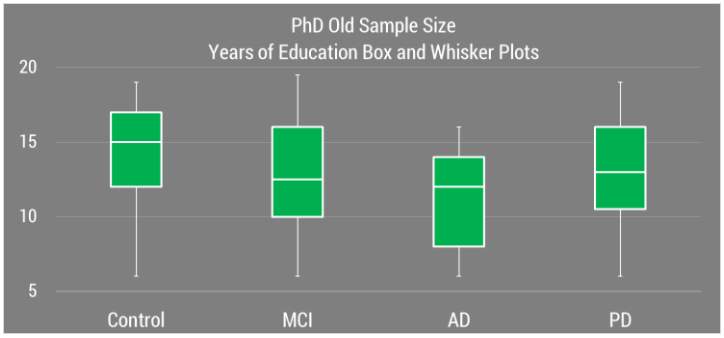


Figure 4.23. Participants >55 years old: years of education

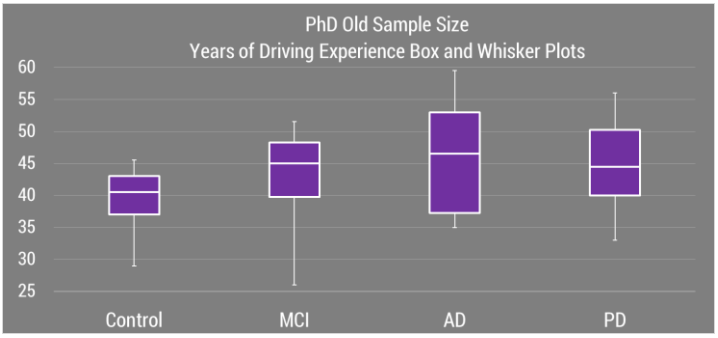


Figure 4.24. Participants >55 years old: driving experience

4.7. Development of databases - data files and processing levels

In this section, considering **the extremely large dataset** from the driving simulator experiment, information regarding the data processing are provided including data files, data storage and the processing levels in order to **conclude to the Master Database and the Final Master File** which will be used for all the statistical analyses that will be presented in the next chapter.

At first one **Driver Control File** was stored with basic information for each driver and for every assessment leg aiming to support the execution of the experiments. This file was used and filled in by several members of the experiment team, and its aim was basically the scheduling of the driving simulator, the neurological, and neuropsychological assessments. Moreover it contains basic information about all participants.

Then, we constructed 6 discrete **Driving Simulator Data Processing Levels:**

» **Processing Level 0.** Traffic Session Original Log Files
» **Processing Level 1.** Driver Original Data Excel Files
» **Processing Level 2.** Driver Processed Data Excel Files
» **Processing Level 3.** All Drivers Processed Data Excel File
» **Processing Level 4.** All Drivers Summary Data Excel File
» **Processing Level 5.** All Drivers and All Assessments Processed Data File

The driving at the simulator experiment **data storage** was performed automatically at the end of each experiment. The data was stored in text format (*.txt). The simulator records data at intervals of 33 to 50 milliseconds which means that each second measured values for each variable up to 30 times. At first, 33 variables were recorded in each session.

In **Processing Level "0"** the traffic session original log files extracted from the driving at the simulator experiment are placed. More specifically there are two .txt files per driver (logfile.txt, errorfile.txt) per driving area (Rural/Urban). Thus there are four files per driver (**4x225 drivers=900 files in total**). Each line of these files corresponds to each measurement (30 measurements per second). In Table 4.5 all these 33 variables the simulator record and extract are presented and explained:

Table 4.5. Driving simulator variables

	Variable	Explanation
1	Time	current real-time in milliseconds since start of the drive.
2	x-pos	x-position of the vehicle in m.
3	y-pos	y-position of the vehicle in m.
4	z-pos	z-position of the vehicle in m.
5	road	road number of the vehicle in [int].
6	richt	direction of the vehicle on the road in [BOOL] (0/1).
7	rdist	distance of the vehicle from the beginning of the drive in m.
8	rspur	track of the vehicle from the middle of the road in m.
9	ralpha	direction of the vehicle compared to the road direction in degrees.
10	Dist	driven course in meters since begin of the drive.
11	Speed	actual speed in km/h.
12	Brk	brake pedal position in percent.
13	Acc	gas pedal position in percent.
14	Clutch	clutch pedal position in percent.
15	Gear	chosen gear (0 = idle, 6 = reverse).
16	RPM	motor revolvation in 1/min.
17	HWay	headway, distance to the ahead driving vehicle in m.
18	DLeft	distance to the left road board in meter.
19	DRight	distance to the right road board in meter.
20	Wheel	steering wheel position in degrees.
21	THead	time to headway, i. e. to collision with the ahead driving vehicle, in seconds.
22	TTL	time to line crossing, time until the road border line is exceeded, in seconds.
23	TTC	time to collision (all obstacles), in seconds.
24	AccLat	acceleration lateral, in m/s^2
25	AccLon	acceleration longitudinal, in m/s^2
26	EvVis	event-visible-flag/event-indication, 0 = no event, 1 = event.
27	EvDist	event-distance in m.
28	ErrlNo	number of the most important driving failure since the last data set
29	ErrlVal	state date belonging to the failure, content varies according to type of failure.
30	Err2No	number of the next driving failure (maybe empty).
31	Err2Val	additional date to failure 2.
32	Err3No	number of a further driving failure (maybe empty).
33	Err3Val	additional date to failure 3.

Moving on to the **Processing Level "1"**, the driver original data files are placed (**225 drivers=225 files in total**). More specifically one excel file per driver is implemented including 4 sheets: rural-data **(~60.000 rows)**, urban-data **(~60.000 rows)**, rural-errors **(~30 rows)** and urban-errors **(~30 rows)**. Each line corresponds to each measurement (30 measurements per second).

For the purposes of **Processing Level "2"**: Driver Processed Data Files, apart from the 33 variables extracted from the simulator, we added some other columns regarding the sequence of the trials, the traffic volume and the distraction condition that every groups of rows corresponds to, reaction time and crash if there was any. There is one excel file per driver (2 sheet per logfile-rural/urban**~60.000 rows** each) in which processed data per driver is added (**225 drivers=225 files in total**). There are 2 sheet per logfile and each line corresponds to each measurement (30 measurements per second). In Figure 4.25 the first rows of a participant's file at Processing Level "2" is presented as an example.

PersonID	Trial	Traffic	Distracto	State	Time	x-pos	y-pos	z-pos	road	richt	rdist	rdistN	rspur	ralpha	Dist	Speed	Brk	Acc	Clutc	Gear	RPM	HWay	DLeft	DRigl	Whee	THead	TTL	TTC	AccLa	AccLa	Event	EvVis	EvDist	ioDat	React	Crash
D288	1	QH	NO	SPEED 0	45	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	0	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	79	2,24	0	155	1	0	5	-395	2	0	0	0	0	100	100	1	0	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	112	2,24	0	155	1	0	5	-395	2	0	0	0	0	100	100	1	0	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	162	2,24	0	155	1	0	5	-395	2	0	0	0	0	100	100	1	0	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	195	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	0	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	228	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	0	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	262	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	722	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	295	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	739	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	328	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	754	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	361	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	766	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	395	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	777	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	428	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	786	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	461	2,24	0	155	1	0	5	-395	2	0	0	0	0	2	100	1	793	10000	1,2	1,2	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	494	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	798	10000	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	528	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	803	10000	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	561	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	806	10000	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	594	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	809	10000	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	627	-218	0,2	1859	2	0	400	0	1,5	62.832	0	0	0	2	100	1	812	10000	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	661	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	814	10000	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	694	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	816	10000	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	727	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	818	64,2	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	760	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	820	64,2	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	794	-218	0,2	1859	2	0	400	0	1,5	0	0	0	0	2	100	1	821	64,2	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0
D288	1	QH	NO	SPEED 0	827	-218	0,2	1859	2	0	400	0	1,5	62.832	0	0	0	2	100	1	823	64,2	0,7	0,85	8	10000	10000	10000	0	0	0	0	100000	7dff8	0	0

Figure 4.25. Example of a driver's processed data files

Moving on to **Processing Level "3"** all drivers processed data files are inserted in a database in *.accdb format. **225 drivers' data** in two area types, in two traffic volumes, in three distraction conditions that correspond to more than **200 hours of driving at the simulator**, develop **a master .accdb database** with more than **20 million rows** x 40 columns (6 GB of data).

Then, in **Processing Level "4",** data reduction techniques are being developed and all drivers' summary data are extracted using specific queries. There is one master excel file for all drivers. Each driver corresponds to 12 rows (2 areas x 2 traffic volumes x 3 distraction conditions) which include summarized data for each driving trial regarding mean values and their variabilities of the 33 driving variables as well as the reaction

times and accident probabilities of each trial. Thus this file includes **2.700 rows** x 40 columns.

Finally, **Processing Level "5": All Drivers and All Assessments Processed Data File** include the data from the previous processing level added with the data extracted from the neurological, neuropsychological and the questionnaire assessments. A reconstruction is carried out in order to have a **Final Master File with one row per participant including all summarized "driving at the simulator" data, all neurological data, all neuropsychological data and all data from the questionnaires.**

This **Final Master File**, which was extracted in both .xls and .csv formats, includes in total:

» **225 rows** x **1.113 columns**:
  » (225 participants) x (**7 general information** variables + **535 driving at the simulator** variables[6] + **321 questionnaire** variables + **250 neurological and neuropsychological** variables).

This Final Master File will be examined and analyzed by an innovative statistical methodology, and the results of all analyses will be presented thoroughly in the following chapter.

[6] because 12 trials per driver were reconstructed in one row

Chapter Five
Statistical Analysis

In the present chapter, the data collected from the driving simulator experiment, the neurological and neuropsychological assessments and the respective questionnaires, which constructed the master database, are analyzed by means of **a dedicated and innovative statistical analysis method**. The choice of this method was based on the limitations and needs of statistical analysis methods, which were analyzed in the literature review part on driver experiments. The overall statistical analysis method consists of five steps, namely a descriptive analysis, analysis of variance (ANOVA), regression modeling techniques, Principal Component Analysis (PCA) and finally, Structural Equation Modeling techniques using latent variables. The five individual steps of the overall statistical method are presented in Figure 5.1. It should be noted that both regression and PCA analyses are parts of the explanatory and preliminary analysis of the database and are considered to be crucial for the development and application of the SEMs.

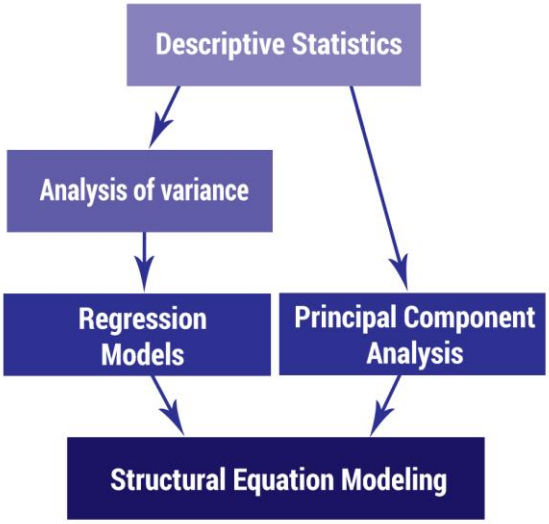


Figure 5.1. Statistical analysis method

In the first step, the **descriptive analysis** of all the experiment variables takes place, which allows for a first understanding of the large number of parameters examined. More precisely, an overview of all variables that are provided by the driving simulator is provided. Then, several boxplots are presented investigating the effect of specific driving characteristics on selected driving performance measures. Furthermore, a correlation Table is investigating any of a broad class of statistical relationships between driving simulator variables.

Moving on, two **analyses of variance** (**ANOVA**) are presented regarding significant differences in the driving performance indexes extracted from the driving simulator assessment and in the answers extracted from the behaviour questionnaires, between

two groups: groups of healthy controls and patients with neurological diseases affecting cognitive functions.

Then, in the framework of the explanatory analysis, the development of **Regression Models** takes place regarding key performance parameters such as average speed, lateral position, average headway, steering angle variability, reaction time of drivers at unexpected incidents, accident probability and driving errors.

In the next step, **Principal Component Analysis (PCA)** is implemented regarding driving performance, driving errors, neuropsychological state and neurological state, in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data.

In the fifth step, the core statistical analysis of the present PhD thesis takes place, including the implementation of **Structural Equation Models (SEMs)** for the first time in the scientific field of driving behaviour of drivers with neurological diseases affecting cognitive functions. Within the framework of latent analysis, four Structural Equation Models are developed aiming to investigate the quantification of the impact of neurological diseases affecting cognitive functions, driver distraction, driver characteristics as well as road and traffic environment directly on driving performance, driving errors, reaction time and accident probability.

5.1. Descriptive analysis

In the present research the large dataset exported from the driving simulator experiment as well as the driving behaviour and self-assessment questionnaires make the descriptive analysis of a large number of variables essential. In the beginning several boxplots are presented in order to explain the effect of age and neurological diseases affecting cognitive functions on several driving performance measures extracted from the driving simulator experiment.

Finally, a correlation table is investigating any of a broad class of statistical relationships between driving simulator variables. With regard to the interpretation of boxplots, it should be noted that the spacing between the different parts of the box plot indicates the degree of dispersion (spread) and skewness in the data and identifies outliers. More specifically:

» The line in the middle of the boxes is the median
» The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile.
» The top of the box represents the 75th percentile. Twenty-five percent of cases have values above the 75th percentile.
» Half of the cases lie within the box.

The 7 driving performance measures that were examined are:

» **Mean speed** (mean speed of the driver's vehicle along the route, excluding the small sections in which incidents occurred, and excluding junction areas)
» **Time headway** (time distance between the front of the simulator vehicle and the front of the vehicle ahead)
» **Lateral position** (vehicle's 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 incident on the road and the moment the driver starts to brake in milliseconds)
» **Accident probability** (the proportion of unexpected incidents resulting in accidents, to total incidents)
» **Driving errors** (outside road lines, hit of sidebars and speed limit violations)

5.1.1. Descriptive analysis by age group (Control group)

For the purposes of this analysis, the control group (92 Healthy Controls) is isolated and the effect of age is examined regarding several critical driving performance measures, in **rural and urban areas**, **low and high traffic volumes**, in **no distraction condition**. The sample scheme is divided in three categories:

» **Young**	(age<34 years old)	**28 Healthy Controls**
» **Middle Aged**	(35 years old<age<54 years old)	**30 Healthy Controls**
» **Old**	(age>55 years old)	**34 Healthy Controls**

Firstly, regarding mean speed of healthy participants in no distraction condition it is observed that in both rural and urban driving areas the advanced age leads to lower mean driving speeds - old group has the lowest mean speed in every condition. Moreover it is observed that in urban area drivers of all ages are slower than in rural roads. Figure 5.2 presents the average speed of control drivers per area type (rural/urban area), traffic volume (low/high) and age group (young, middle aged, older) in no distraction condition.

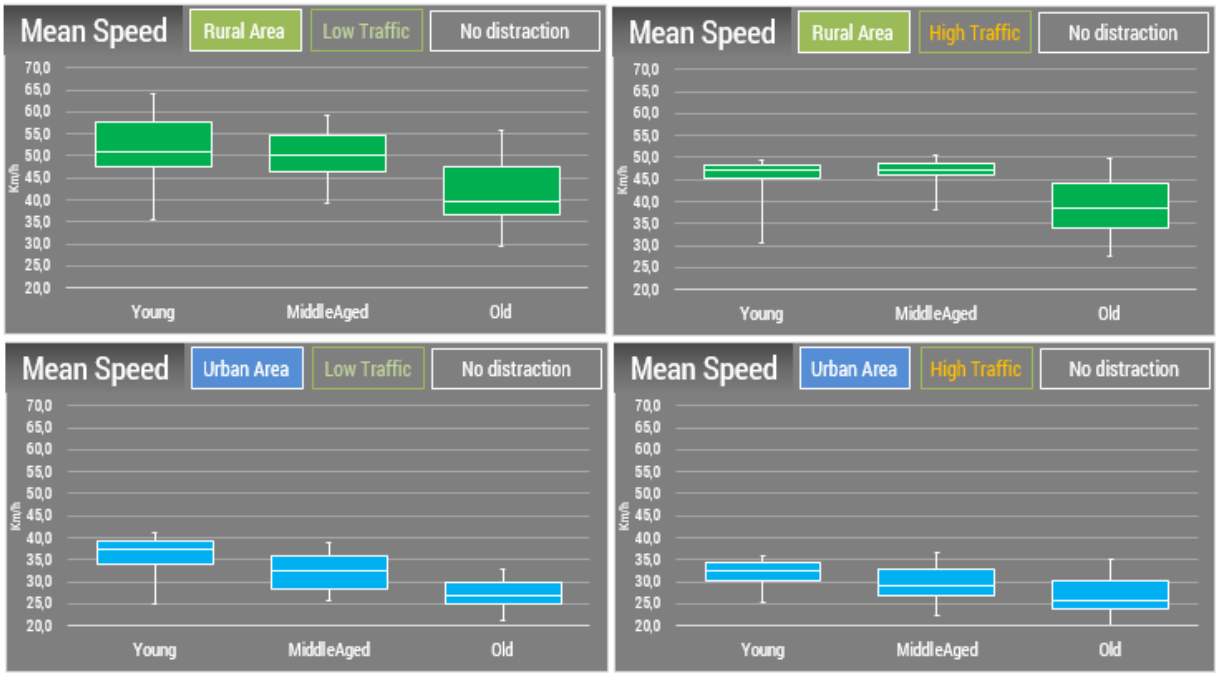


Figure 5.2. Mean speed - Controls, rural and urban areas, low and high traffic volumes, no distraction condition

Moving on to another longitudinal control driving measure namely time headway of healthy participants in no distraction condition it is observed that older drivers in high traffic volume have larger time headways than young or middle aged participants. Overall, young participants keep at least 15% shorter headways than the other two groups in all driving conditions. Figure 5.3 presents the time headways of control drivers per area type (rural/urban area), traffic volume (low/high) and age group (young, middle aged, older) in no distraction condition.

Figure 5.3. Time Headway - Controls, rural and urban areas, low and high traffic volumes, no distraction condition

Moving on to the first lateral controls driving measure namely the lateral position of healthy participants in no distraction condition and after highlighting that positive values mean driving more closely to the right border of the road, it is observed that older drivers tend to place the vehicle more closely to the right border of the road, whereas young drivers tend to place the vehicle more closely to the left as expected. Lateral position in urban road cannot be compared to that of rural area because of the different width of the lane and the different number of lanes.

Figure 5.4 presents the lateral position of control drivers per area type (rural/urban area), traffic volume (low/high) and age group (young, middle aged, older) in no distraction condition.

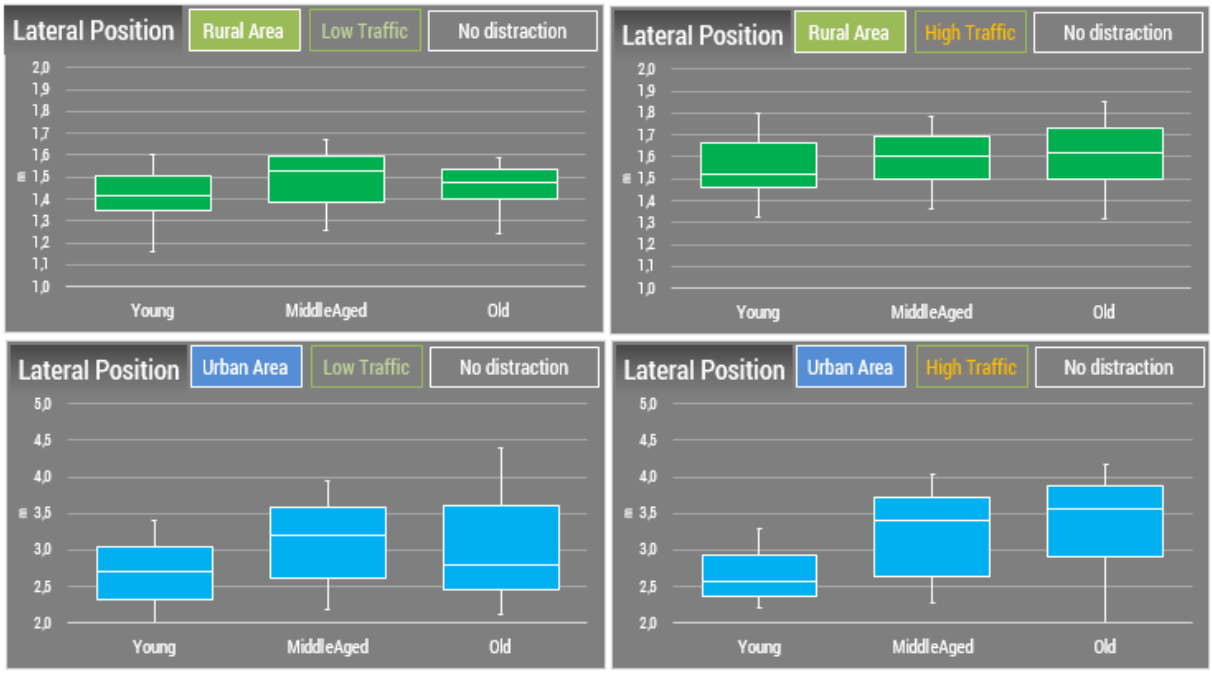


Figure 5.4. Lateral position-Controls, rural and urban areas, low and high traffic volumes, no distraction condition

Moving on to the second lateral controls driving measure namely the steering angle variability of healthy participants in no distraction condition, it is observed that older drivers have little variability in wheeling angle that they use during driving, except for the urban area in low traffic road condition. Figure 5.5 presents the steering angle variability of control drivers per area type (rural/urban area), traffic volume (low/high) and age group (young, middle aged, older) in no distraction condition.

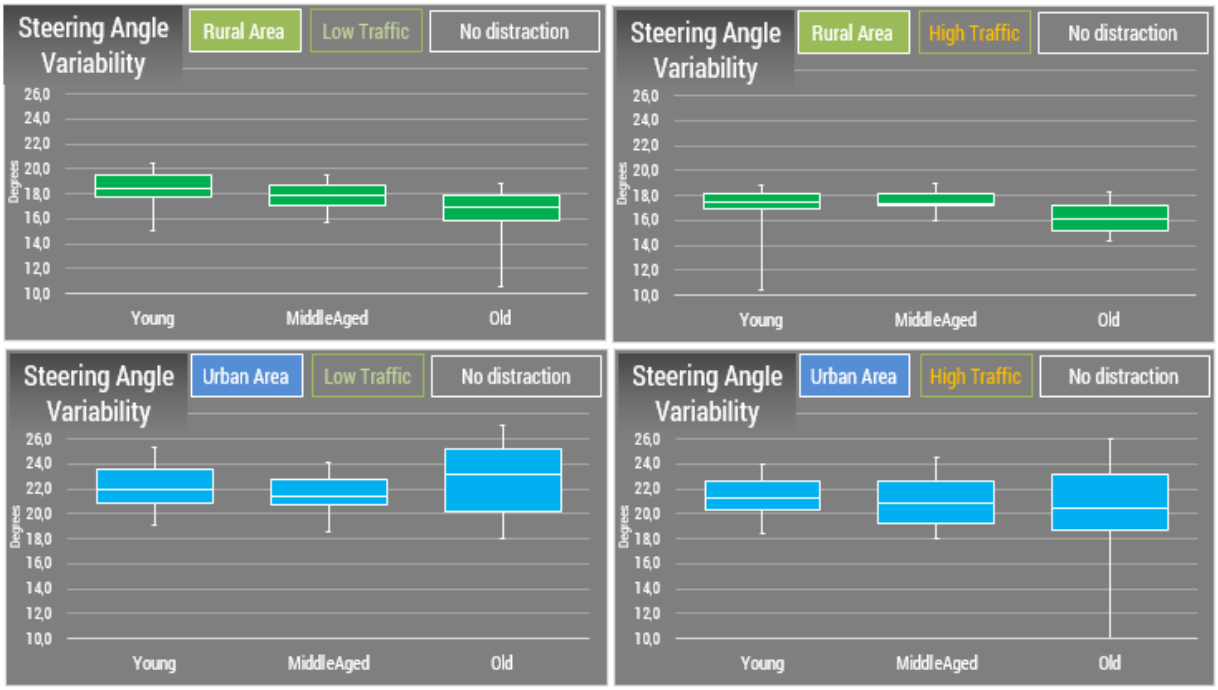


Figure 5.5. Variability of Steering angle - Controls, rural and urban areas, low and high traffic volumes, no distraction condition

Moving on to the reaction time of healthy participants in no distraction condition, it is observed that older drivers have much larger reaction times than the other two groups (at least 20% larger reaction times in all examined conditions). Figure 5.6 presents the reaction time of control drivers per area type (rural/urban area), traffic volume (low/high) and age group (young, middle aged, older) in no distraction condition.

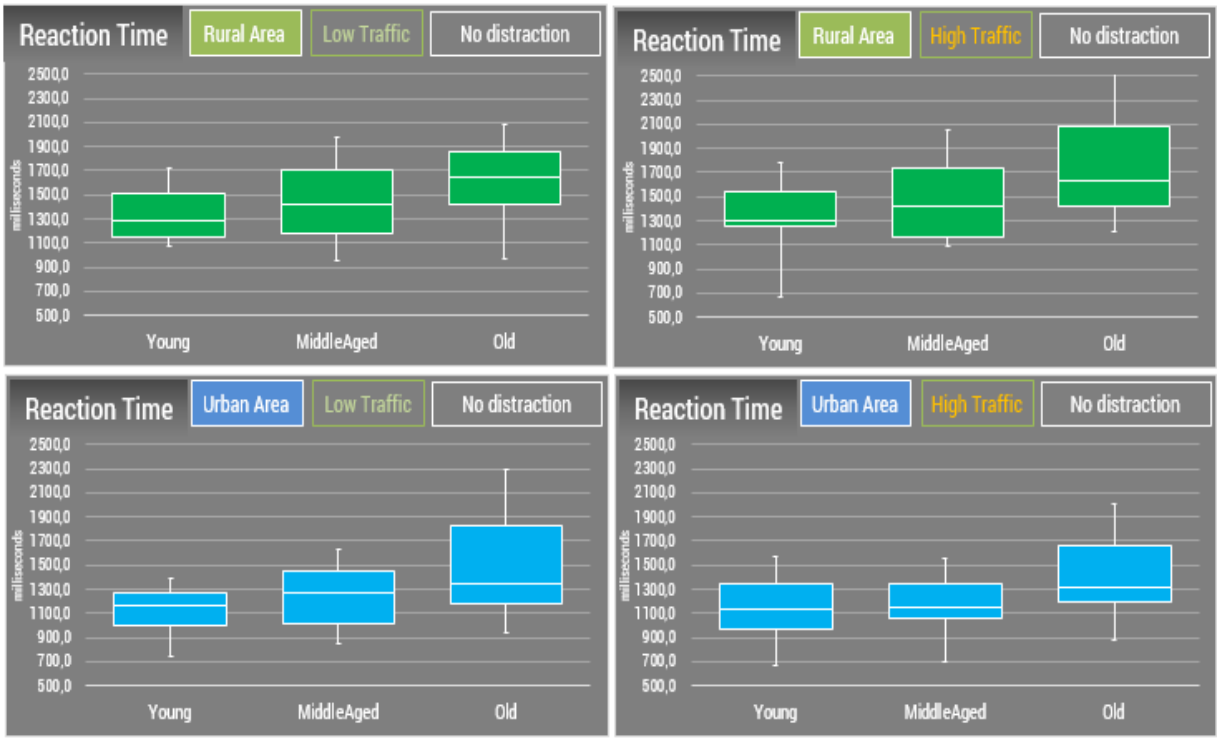


Figure 5.6. Reaction time - Controls, rural and urban areas, low and high traffic volumes, no distraction condition

Regarding accident probability of healthy participants in no distraction condition, it is observed that in rural area in low traffic condition young drivers have an accident probability of more than 20%. In urban area though, older drivers appear to have the higher accident probability in both traffic environments. Figure 5.7 presents the accident probability of control drivers per area type (rural/urban area), traffic volume (low/high) and age group (young, middle aged, older) in no distraction condition.

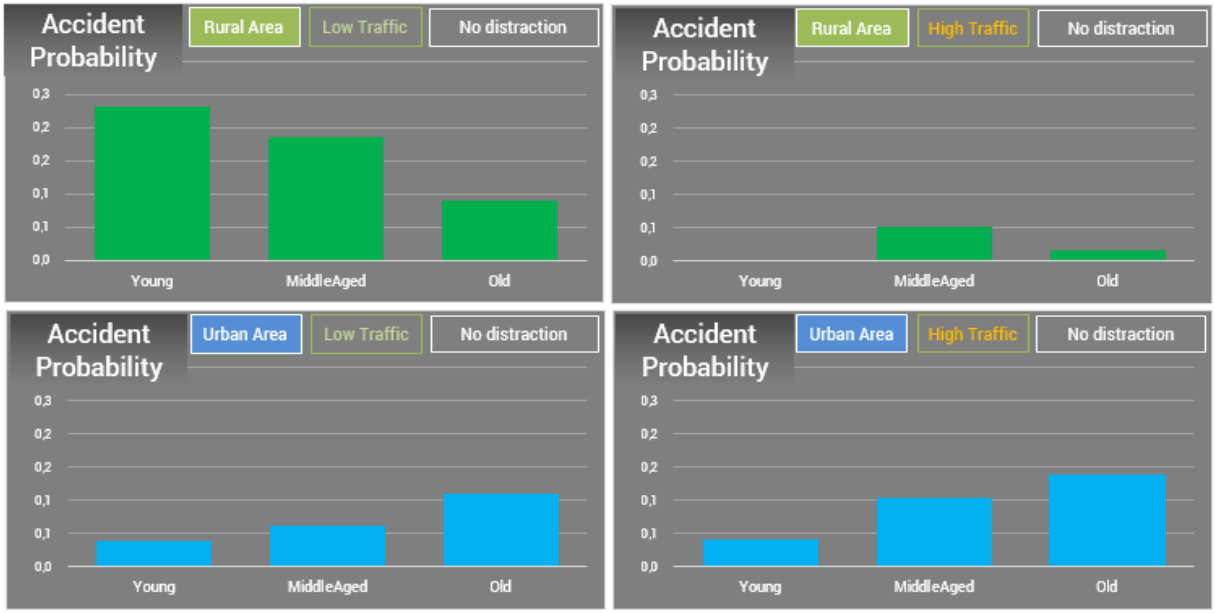


Figure 5.7. Accident probability - Controls, rural and urban areas, low and high traffic volumes, no distraction

Regarding driving errors of healthy participants in no distraction condition, it is observed that except rural area and high traffic condition, in all other conditions all control drivers have the same results. Figure 5.8 presents the driving errors of control drivers per area type (rural/urban area), traffic volume (low/high) and age group (young, middle aged, older) in no distraction condition.

Figure 5.8. Driving errors - Controls, rural and urban areas, low and high traffic volumes, no distraction condition

5.1.2. Descriptive analysis by clinical group

For the purposes of this analysis, the "old" group (125 participants) is isolated (for representativeness reasons the young group, the middle aged group and the patients of "other" neurological diseases are eliminated from the analysis) and the effect of cerebral diseases is examined regarding several critical driving performance measures, in **rural and urban areas** and **low and high traffic volumes**.

The sample scheme is divided in four categories:

» **Controls** **34 Healthy Controls** (age>55 years old)
» **MCI** **43 patients with MCI** (age>55 years old)
» **AD** **28 patients with AD** (age>55 years old)
» **PD** **20 patients with PD** (age>55 years old)

Furthermore, the effect of the in-vehicle distraction is examined. Thus, there are three distraction conditions: **no distraction, conversation with passenger, and conversation through hand-held mobile phone.**

For each driving measure there are **2 driving areas** (rural/urban), **2 traffic environments** (low/high) and **3 distraction conditions** (no distraction, conversation with passenger and conversation through hand-held mobile phone) for the 4 examined groups of older drivers (**12 Figures** for each driving measure in total). **Dark green color** corresponds to rural area, no distraction condition, **green** corresponds to rural area, conversation with passenger, **light green** corresponds to rural area, mobile phone conversation condition, **dark blue** color corresponds to urban area, no distraction condition, **blue** corresponds to urban area, conversation with passenger, **light blue** corresponds to urban area, mobile phone conversation condition. In order to better understand and more easily detect the differences between the results of all examined conditions, all Figures are presented below (Figures 5.9 - 5.15) and then a discussion will follow.

Figure 5.9. Mean speed boxplots

Figure 5.10. Time headway boxplots

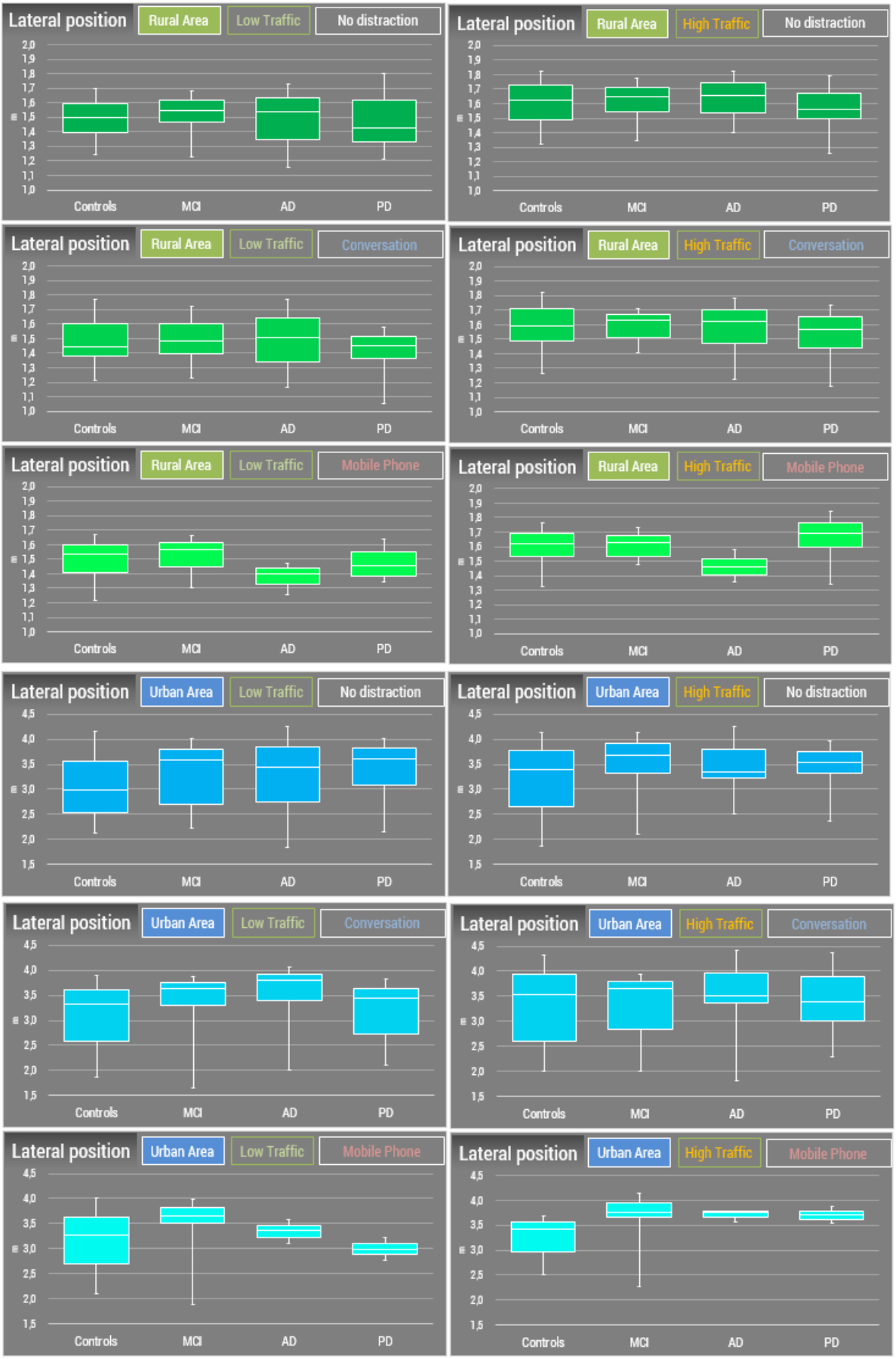


Figure 5.11. Lateral position boxplots

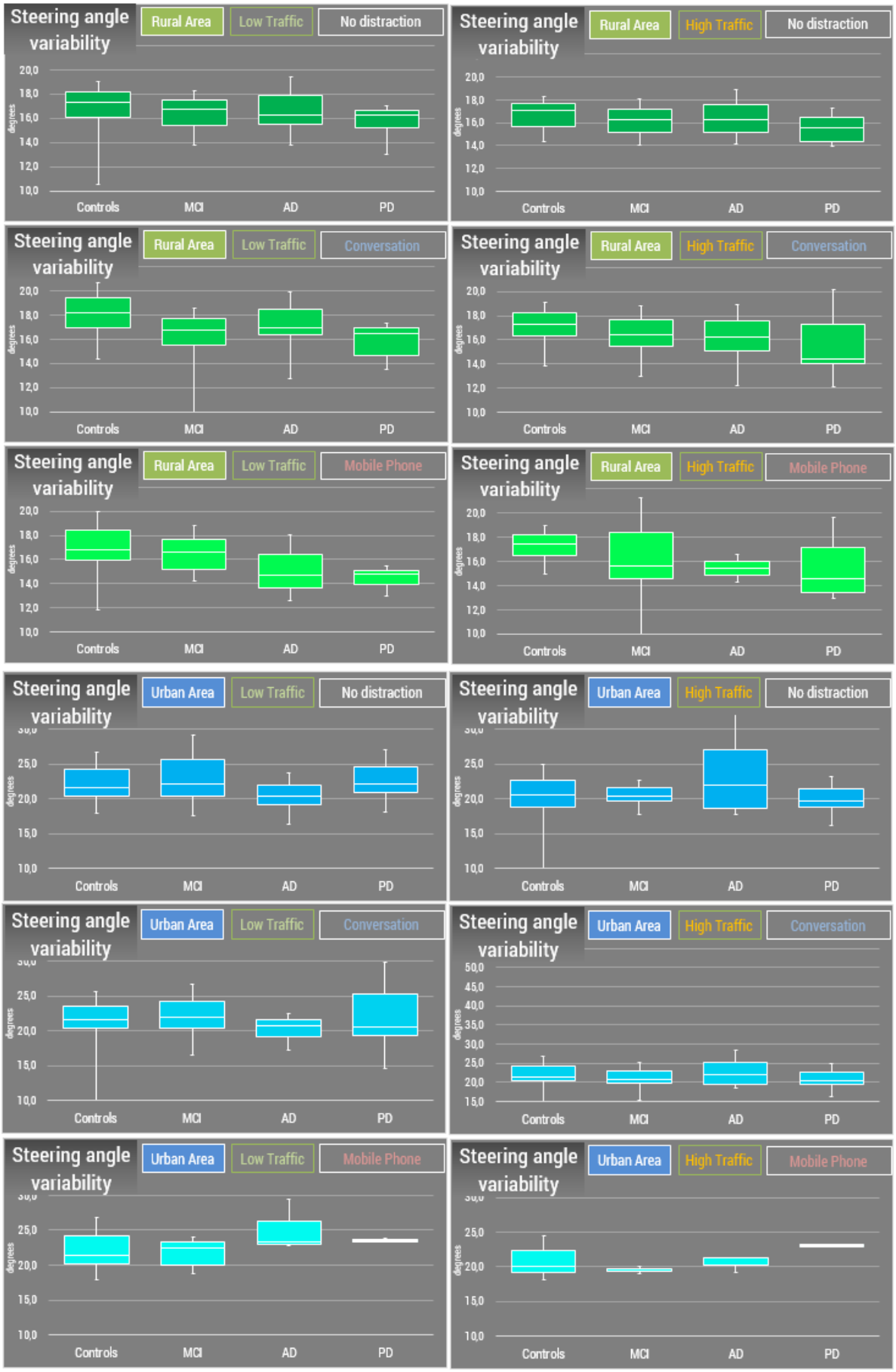


Figure 5.12. Steering angle variability boxplots

Figure 5.13. Reaction time boxplots

Figure 5.14. Accident probability histograms

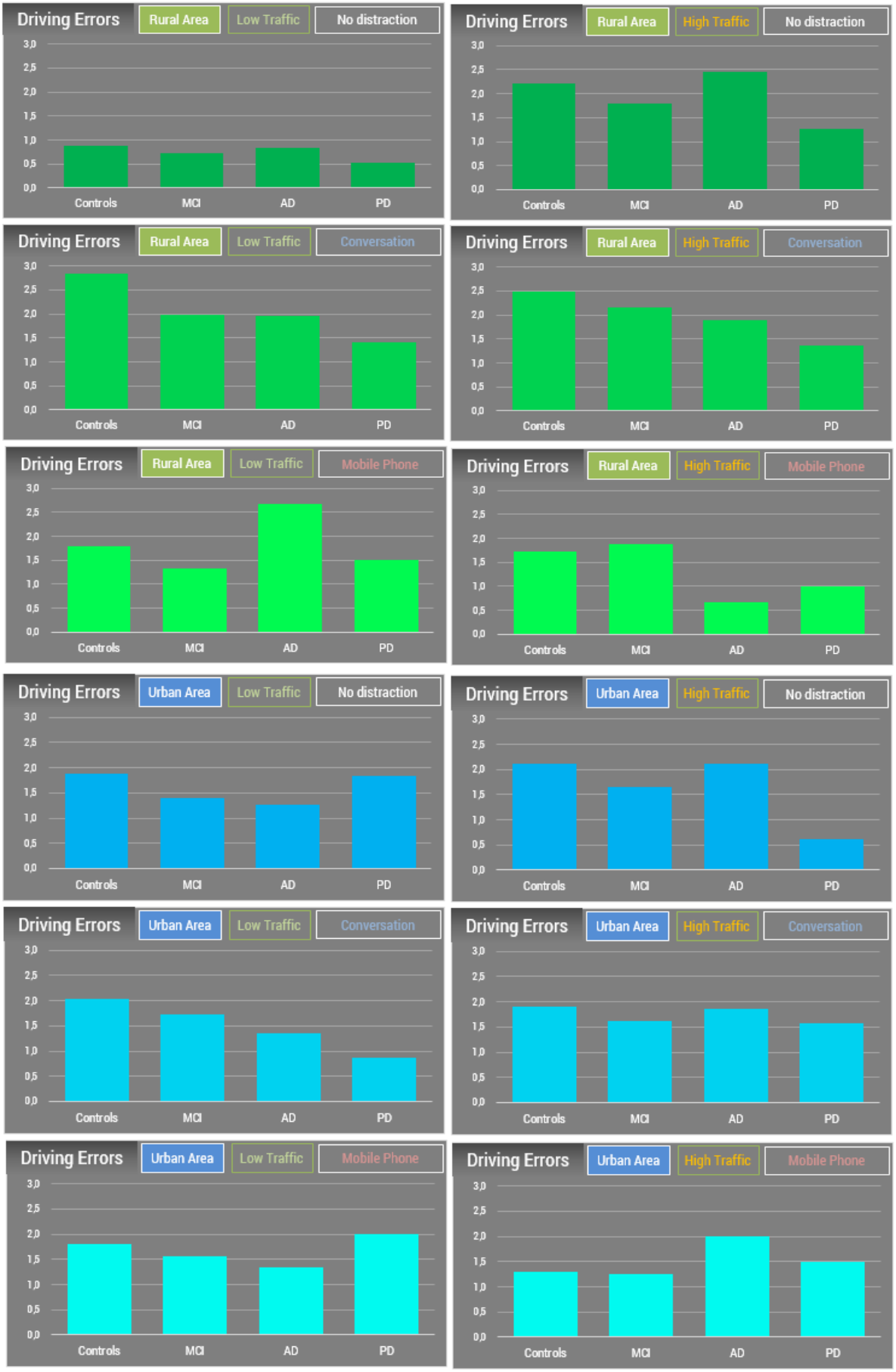


Figure 5.15. Driving errors histograms

To begin with **mean speed** (Figure 5.9) of older drivers, regarding neurological disease affecting cognitive functions, it seems that all 3 cerebral pathologies lead to lower driving speeds in all examined conditions. Especially, AD group, overall, has the lowest mean speeds among the other participants in almost every condition. AD group has at least 20% lower speed compared to their healthy controls counterparts. Moreover, the in-vehicle distraction and the traffic volume seem to have no effect in mean speed of all examined groups. Finally, the urban area leads to lower speeds for all participants.

Moving on to another longitudinal control measure, namely **time headway** (Figure 5.10), we can detect differences of similar characteristics with the mean speed profiles between the groups. More specifically, overall all groups of patients keep larger headways compared to healthy controls of similar age. AD participants keep the largest headways among all four groups, which was expected as they have the lowest mean speeds. Regarding the effect of distraction, we can identify that the mobile phone use leads to larger headways for the AD group, whereas the other three groups seem to stay unaffected by the distraction conditions regarding the headway they keep. Moreover, the high traffic volume has an obvious impact on headways of all participants. Finally, the urban area constitutes a more complex environment and for that reason we can detect that headways for all examined groups are lower by at least 35%.

Regarding **lateral position** (Figure 5.11) of participants, and after highlighting that positive values mean driving more closely to the right border of the road, in rural road the AD group in distraction condition of mobile phone tends to move the vehicle more closely to the left border of the lane. No other differences are easily detectable by this descriptive analysis regarding lateral position and further statistical analyses are required in order to result in specific conclusions.

Another important lateral control measure is the **variability of the steering angle** (Figure 5.12). In rural road patients with neurological diseases affecting cognitive functions seem to have lower variability of their wheeling angle, whereas in urban area this difference is not so pronounced. AD group in urban area with low traffic volume when using the mobile phone have higher variability in steering angle. Overall, only slight differences can be identified and further statistical analyses are needed in order to result in specific conclusions regarding both lateral control measures (lateral position and variability of steering angle).

Moving on to the safety measures, namely **reaction time**, accident probability and driving errors, some more pronounced results appear. It was observed that controls have the best reaction times (Figure 5.13) overall in rural area, whereas AD and PD groups have the worst reaction times (more than 40% worse reaction times than the control group). Then, the mobile phone use has a significant effect on reaction time for AD and PD groups. Finally, conversing with passenger doesn't seem to have an important effect on reaction time in all examined groups.

On the other hand, in urban area the differences in reaction times between the groups are less pronounced, yet detectable. It seems that the conversation with passenger distraction task has an effect in all groups. AD participants seem to have the worst reaction times in urban area. Finally, AD and PD sample in mobile phone use in urban areas was very small (less than 5 participants-due to simulator sickness issues), thus the mobile phone use results for these two groups are not significant. It is important to mention that the reaction times in urban area cannot be compared to the ones in rural area, because of the fact that the incidents are totally different between the two driving environments and because of the fact that urban session was always second for representativeness reasons (thus it is obvious that the reaction times are getting better through driving time for the majority of the participants). Finally, traffic volume, has a little impact on reaction times of all examined groups.

Regarding **accident probability** (Figure 5.14), it is observed that, overall, patients have a higher accident probability compared to the group of controls in both rural and urban driving environments. It is easily detectable that AD drivers have, in all conditions, the higher accident probability, and especially when conversing on the mobile phone. In that case their accident probability is climbing to more than 60%. Participants with PD have also a significantly higher accident probability when using the mobile phone. In rural road environment, it seems that conversation with passenger doesn't increase the possibility of causing an accident for all examined groups. In urban area the differences between the groups are approximately the same with the rural area. Controls have the lowest accident probability overall and conversation with passenger doesn't seem to have any impact on it. Finally, traffic volume, has a little impact on reaction times of all examined groups.

Last but not least, we examined the **driving errors** of participants (Figure 5.15) and interesting results showed up. Overall, patients with MCI, AD or PD seem to make the same or even less driving errors than healthy controls. Then, high traffic volume leads

to more mistakes for all participants, as it is a more complex environment. AD group in rural area seem to get affected by the mobile phone distraction condition and, compared to the undistracted condition, they make more than double driving errors. Overall, the differences are not easily detectable by descriptive statistics and deeper statistical analyses are required.

5.1.3. Individual driving measures of patients with MCI, AD and PD

This descriptive analysis aims to **compare the individual driving performance measures of patients of MCI, AD and PD** to the typical values of healthy controls. The sample scheme used is the same with the previous chapter (125 older drivers). For each driver, the following driving performance measures are calculated and examined: a) mean speed, b) mean speed variability, c) time headway, d) time headway variability, e) lateral position, f) lateral position variability, and g) reaction time at incidents. All these driving indexes **are compared to the range of "typical" values of the respective distribution of healthy drivers:** control groups' mean values minus one standard deviation and plus one standard deviation include 68.26% of the values of healthy controls (according to the normal distribution). For the purpose of this study, this area is defined by our research team as the "typical area" (Figure 5.16). The individual driving indexes of all participants with cerebral diseases were compared to the "typical area" of the control group, in rural and urban driving environment and the results are presented in the next sections.

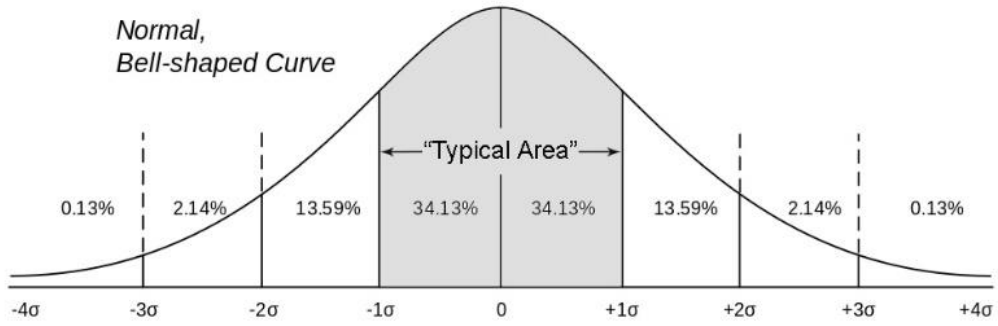


Figure 5.16. Normal distribution - "typical area" of this analysis:
Control groups' mean values minus one standard deviation and plus one standard deviation

5.1.3.1. Mean speed

In Figures 5.17 and 5.18, the mean speed profiles and the mean speed variability profiles of patients with neurological diseases affecting cognitive functions are compared to the

control's "typical area" (blue box represents the "typical area" in the rural area, whereas the brown box represents the "typical area" in the urban area) and several significant results are extracted; overall, **51% of the patients had extremely low mean speeds** (below the lower limit of the control's "typical area"). Especially **the group of AD patients drove significantly slower than the controls at the 68% of the cases**. As expected, the speed was lower in urban area for all participants. Then, only 6% of the patients with neurological diseases affecting cognitive functions drove too fast, compared to the healthy controls. Regarding the mean speed of the PD and AD group, only the 35% of these drivers were inside the "typical area". Finally, **drivers with a brain pathology had significantly lower speed variability** (43% of the cases) than the group of controls. It is notable that 11% of PD drivers had significantly high speed variability in rural area.

Mean Speed		below lower limit	inside the "typical area"	higher than upper limit
Rural Area	PD	57%	36%	7%
	AD	67%	33%	0%
	MCI	43%	54%	3%
Urban Area	PD	43%	46%	11%
	AD	69%	25%	6%
	MCI	27%	64%	9%

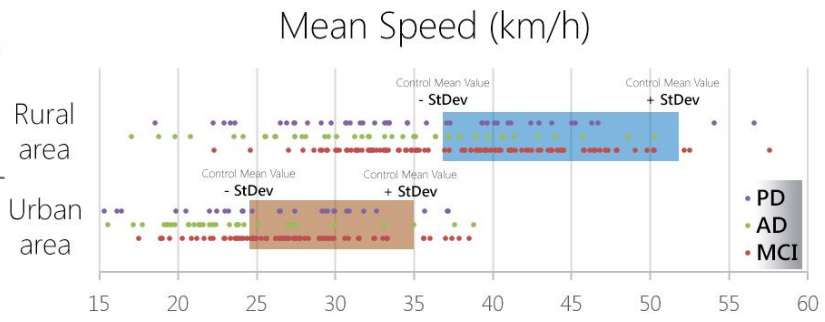


Figure 5.17. Mean speed individual profiles of patients compared to healthy controls

StDev of Mean Speed		below lower limit	inside the "typical area"	higher than upper limit
Rural Area	PD	50%	39%	11%
	AD	49%	42%	9%
	MCI	37%	55%	8%
Urban Area	PD	32%	61%	7%
	AD	59%	38%	3%
	MCI	32%	65%	3%

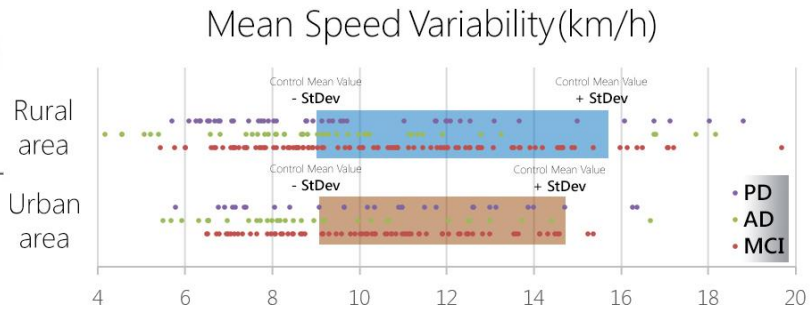


Figure 5.18. Mean speed variability individual profiles of patients compared to healthy controls

5.1.3.2. Time headway

In Figures 5.19 and 5.20, the time headway and the time headway variability profiles of patients with neurological diseases affecting cognitive functions are compared to the control's "typical area" (blue box represents the "typical area" in the rural area, whereas the brown box represents the "typical area" in the urban area) and several significant results were extracted; **44% of the drivers with a brain pathology in rural area have kept very large time headways**, but in urban area this percentage was significantly

lower (12%). No AD or PD patient kept a headway which was below the lower limit of the "typical area". Also, **20% of the patients had very large variability in their time headways whereas 12% of drivers with a brain pathology had significantly lower**. It is important to mention, though, that regarding the variability of time headway in all groups of patients, at least 6 drivers out of 10 were inside the "typical area".

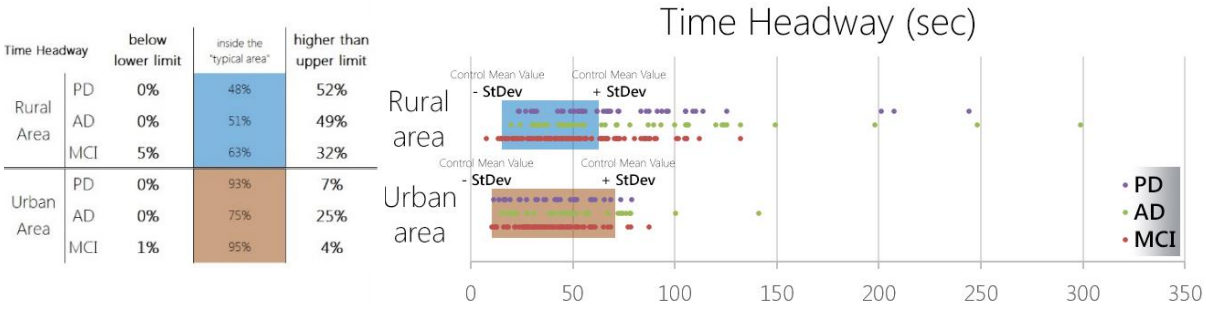


Figure 5.19. Time headway individual profiles of patients compared to healthy controls

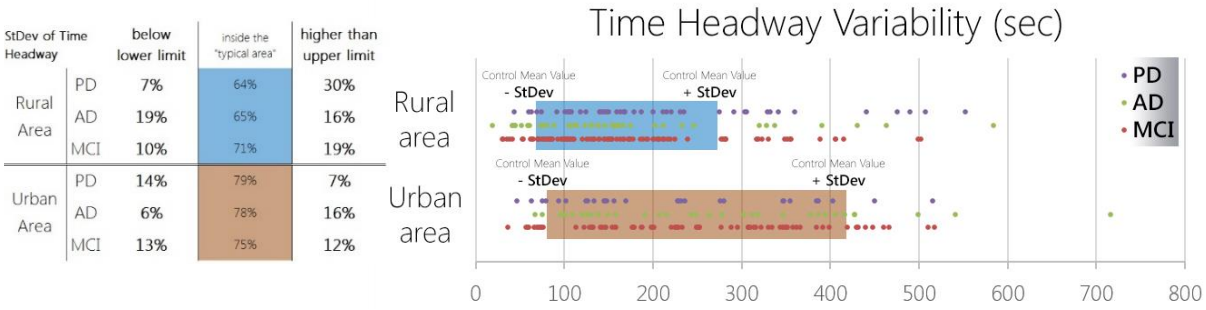


Figure 5.20. Time headway variability individual profiles of patients compared to healthy controls

5.1.3.3. Lateral position

In Figures 5.21 and 5.22, the lateral position and the lateral position variability profiles of patients with neurological diseases affecting cognitive functions are compared to the control's "typical area" (blue box represents the "typical area" in the rural area, whereas the brown box represents the "typical area" in the urban area) and several significant results were extracted; **32% of patients in urban area drove closer to the right border of the road** (positive lateral position values indicate longer distance from the central axis of the road). Overall, 40% of drivers with cerebral disease were out of the "typical area", regarding the lateral position of the vehicle. Also, **more than 1 out of 5 patients had very high variability in their lateral position**. Especially for the group of AD in rural roads, 30% of this particular group had extremely high lateral position variability, despite the fact that the lane was narrow in rural area. It is important to mention that the rural route was single carriageway and the lane width was 3m, whereas the urban

route was (at its bigger part) dual carriageway, and the lane width is 3.5m. Thus, the positioning of the vehicle cannot be compared between the two road environments. Overall, at least 30% of the patients group were outside the "typical area" regarding lateral position variability.

Lateral Position		below lower limit	inside the "typical area"	higher than upper limit
Rural Area	PD	30%	61%	9%
	AD	14%	67%	19%
	MCI	15%	66%	19%
Urban Area	PD	14%	57%	29%
	AD	3%	69%	28%
	MCI	8%	52%	40%

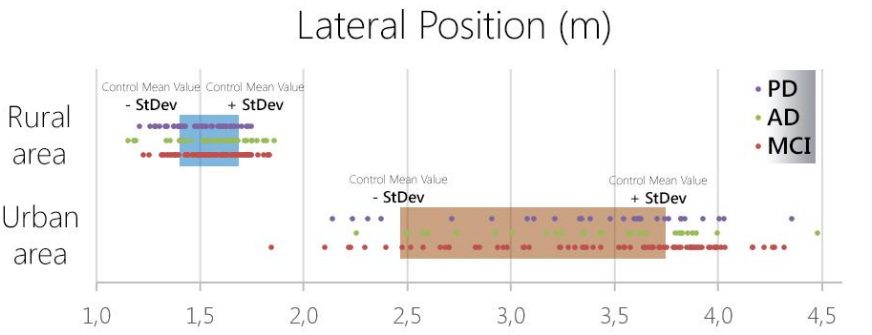


Figure 5.21. Lateral position individual profiles of patients compared to healthy controls

StDev of Lateral Position		below lower limit	inside the "typical area"	higher than upper limit
Rural Area	PD	7%	77%	16%
	AD	7%	63%	30%
	MCI	7%	81%	12%
Urban Area	PD	14%	57%	29%
	AD	9%	75%	16%
	MCI	8%	71%	21%

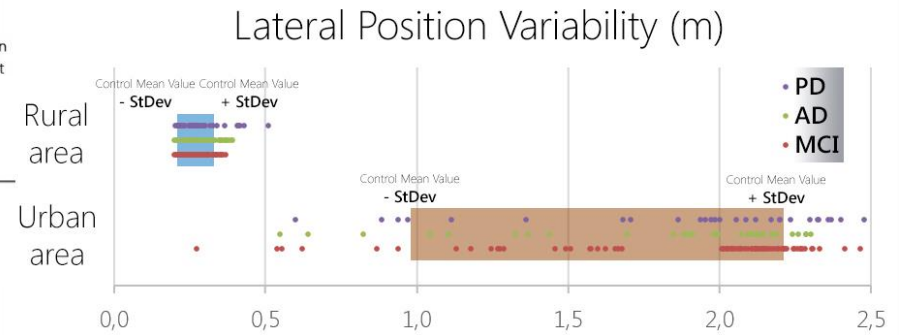
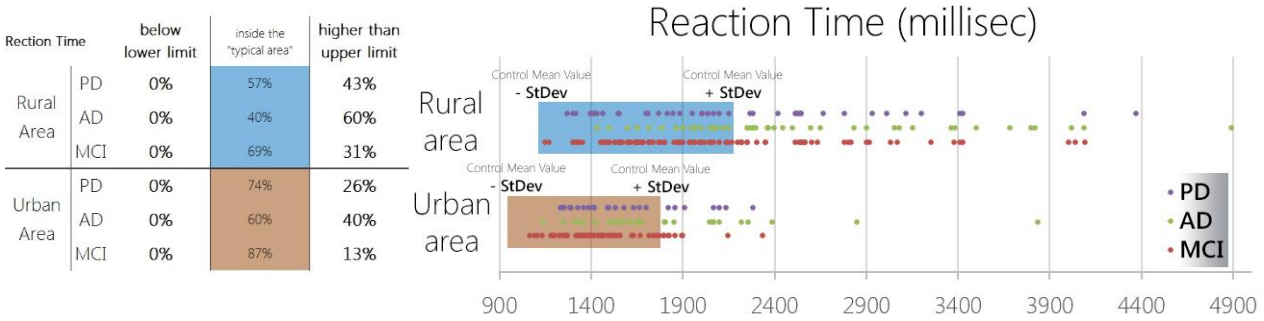


Figure 5.22. Lateral position variability individual profiles of patients compared to healthy controls

5.1.3.4. Reaction time

In Figure 5.23, the reaction time profiles of patients with neurological diseases affecting cognitive functions are compared to the control's "typical area" (blue box represents the "typical area" in the rural area, whereas the brown box represents the "typical area" in the urban area) and several significant results were extracted; the group of patients significantly deviated from the reaction time of the control group. **More than 50% of participants with a brain pathology in rural area and 26% in urban area had significantly larger reaction times than the control group**. In rural area 70% of the patients with neurological diseases affecting cognitive functions had reaction times larger than 2 seconds. Especially for the **AD and the PD groups, the 42% of these participants were above the upper limit of the "typical area" in both rural and urban driving environments**. It is important to mention that the reaction times of the rural area cannot be compared of the reaction times in urban area because all participants drove firstly in rural area and then in urban area for reasons that we

presented in chapter 3. Finally, no patient was below the lower limit of the "typical area", regarding the reaction time.



Rection Time		below lower limit	inside the "typical area"	higher than upper limit
Rural Area	PD	0%	57%	43%
	AD	0%	40%	60%
	MCI	0%	69%	31%
Urban Area	PD	0%	74%	26%
	AD	0%	60%	40%
	MCI	0%	87%	13%

Figure 5.23. Reaction time individual profiles of patients compared to healthy controls

5.1.4. Correlation Table

Before proceeding to the main statistical analysis steps, **a correlation Table was developed in order to investigate any of a broad class of statistical relationships between driving simulator variables**. For this purpose, a Pearson's correlation coefficient table was developed and presented in Table 5.1 regarding all continuous variables extracted from the driving simulator. Pearson's correlation coefficient (r) is a measure of the strength of the association between the two variables. Positive correlation indicates that both variables increase or decrease together, whereas negative correlation indicates that as one variable increases, so the other decreases, and vice versa.

Table 5.1. Correlation Table

Pearson's correlation coefficients

	Speed	Lateral Position	Braking	Gear Use	Rpm	Space Headway	Steering angle	Time Headway	Time to lane change	Time to collision	Reaction Time	Accident Probability
Speed	1,000											
Lateral Position	-0,587	1,000										
Braking	0,050	0,388	1,000									
Gear Use	0,730	-0,478	-0,068	1,000								
Rpm	0,559	-0,375	0,025	-0,071	1,000							
Space Headway	0,093	-0,626	-0,530	0,113	0,143	1,000						
Steering angle	-0,565	0,863	0,521	-0,464	-0,392	-0,657	1,000					
Time Headway	-0,338	-0,161	-0,294	-0,244	-0,128	0,643	-0,142	1,000				
Time to lane change	-0,509	0,672	0,411	-0,409	-0,355	-0,532	0,679	-0,081	1,000			
Time to collision	-0,587	0,558	0,132	-0,423	-0,395	-0,234	0,607	0,185	0,459	1,000		
Reaction Time	-0,210	-0,215	-0,321	-0,142	-0,001	0,442	-0,250	0,372	-0,219	-0,070	1,000	
Accident Probability	-0,029	0,004	-0,059	-0,042	0,028	0,060	-0,030	0,076	-0,014	-0,023	0,324	1,000

Table 5.1 determines the relationships between 12 driving performance variables. Results indicate that that the highest correlation is between average speed and average gear (0,730) as expected. Furthermore, average speed is highly correlated with the lateral position of the vehicle. On the other hand, the reaction time of drivers at unexpected incidents and the accident probability have low correlation coefficients with the variables indicating that there is not a strength correlation between these pairs of variables.

It should be noted that a correlation can only indicate the presence or absence of a relationship, not the nature of the relationship. Correlation is not causation. For this purpose several types of analysis are implemented in the next steps in order to deeply investigate the relationship of these driving performance variables.

5.2. Analysis of variance

In this chapter two analyses of variance (ANOVA) are presented regarding significant differences in the **driving performance indexes extracted from the driving simulator assessment and in the answers extracted from the behaviour questionnaires**, between two groups: groups of healthy controls and patients with neurological diseases affecting cognitive functions.

More specifically, the "old" group (125 participants) is isolated (for representativeness reasons the young group, the middle aged group and the patients of "other" neurological diseases are eliminated from the analysis) and the effect of neurological disease affecting cognitive functions is examined regarding several critical driving performance measures, in rural and urban areas.

The sample scheme is divided in two categories:

» **Controls** **34 Healthy Controls** (age>55 years old)
» **Patients** **91 patients with AD, MCI or PD** (age>55 years old)

5.2.1. Driving simulator measures

In the present section, analysis of variance is implemented in order to identify several differences between the group of patients and the group of controls regarding the driving simulator measures (Table 5.2).

Table 5.2. ANOVA - driving simulator indexes - controls vs patients

ANOVA Controls vs Patients	Rural Area					Urban Area				
	Sum of Squares	df	Mean Square	F	Sig.	Sum of Squares	df	Mean Square	F	Sig.
Average Speed	1869,2	1	1869,2	27,3	,000	1493,0	1	1493,0	29,9	,000
Average Speed Variability	154,1	1	154,1	12,4	,001	99,7	1	99,7	10,2	,002
Lateral Position	0,0	1	0,0	0,1	,709	0,0	1	0,0	0,2	,628
Lateral Position Variability	0,0	1	0,0	0,3	,561	0,0	1	0,0	1,6	,210
Steering Angle	1,7	1	1,7	2,4	,126	0,1	1	0,1	0,2	,645
Steering Angle Variability	8,2	1	8,2	2,2	,144	13,2	1	13,2	5,4	,022
Time Headway	25474,5	1	25474,5	14,8	,000	12176,3	1	12176,3	15,0	,000
Time Headway Variability	17456,0	1	17456,0	1,3	,262	1455,0	1	1455,0	0,3	,562
Time to lane crossing	863,1	1	863,1	3,0	,086	128,0	1	128,0	0,5	,501
Time to lane crossing	35207,9	1	35207,9	5,2	,024	671,8	1	671,8	0,1	,771
Time to collision	36,8	1	36,8	15,2	,000	4,5	1	4,5	3,3	,069
Time to collision Variability	1,8	1	1,8	4,5	,036	12,6	1	12,6	8,8	,004
Reaction Time	9288892,5	1	9288892,5	24,5	,000	10064007,7	1	10064007,7	19,3	,000
Accident Probability	0,0	1	0,0	0,5	,484	0,4	1	0,4	6,7	,011
Errors	0,9	1	0,9	0,5	,492	3,5	1	3,5	0,7	,416

The analysis of variance indicated that the presence of a neurological disease affecting cognitive functions was found to significantly affect mean speed, mean speed variability, time headway, time to collision variability and reaction time in both road environments. The two examined groups have statistically significant differences in time to line crossing and time to collision in rural area, whereas the two groups had differences in steering angle variability and accident probability only in urban areas.

5.2.2. Stated behaviour

All 125 older drivers who participated in our study were requested to fill in a questionnaire about their **driving habits** and their **driving behaviour**. The questions were chosen carefully on the basis of the existing literature on drivers' self-reported behaviour. The sections of the questionnaire were:

» Driving experience - car use
» Self -assessment of the older driver
» Distraction-related driving habits
» Emotions and behaviour of the driver
» Anger expression inventory during driving
» History of accidents, near misses, and traffic violations

The sample scheme is divided in two categories:

» **Controls** **34 Healthy Controls** (age>55 years old)
» **Patients** **91 patients with AD, MCI or PD** (age>55 years old)

The 125 questionnaires were collected and analyzed through Analysis of Variance techniques. Statistically significant differences between the control group and the group of patients with cerebral diseases were found in 33 questions (Table 5.3.):

Table 5.3. Questions in which control group had statistically significant differences with the group of patients

ANOVA Controls vs Patients		Sum of Squares	df	Mean Square	F	Sig.
Q1.11.1	During the last 6 months how often did you drive at night?	10,6	1	10,6	5,0	,027
Q1.11.2	During the last 6 months how often did you drive at rush hours?	31,3	1	31,3	15,7	,000
Q1.11.4	During the last 6 months how often did you drive at motorways?	15,7	1	15,7	8,2	,005
Q1.11.5	During the last 6 months how often did you drive at unknown areas?	4,4	1	4,4	4,0	,049
Q1.11.7	During the last 6 months how often did you drive at urban area?	19,3	1	19,3	11,0	,001
Q1.12	During the last 6 months how often did avoid driving because you were afraid of your driving performance?	2,7	1	2,7	4,6	,035
Q1.14	How would you assess your driving performance in comparison with 5 years ago?	7,2	1	7,2	10,5	,002
Q1.15.1	How would you assess your driving performance in comparison with 5 years ago in low traffic in quiet road?	0,6	1	0,6	5,3	,024
Q1.15.2	How would you assess your driving performance in comparison with 5 years ago in urban area with high traffic?	0,7	1	0,7	4,0	,048
Q1.15.8	How would you assess your driving performance in comparison with 5 years ago in a road with many turns?	1,3	1	1,3	5,2	,025
Q1.15.9	How would you assess your driving performance in comparison with 5 years ago in an unknown area?	2,4	1	2,4	6,6	,012

Q1.15.10	How would you assess your driving performance in comparison with 5 years ago regarding lane changing?	0,6	1	0,6	4,4	,039
Q1.15.12	How would you assess your driving performance in comparison with 5 years ago regarding left turns?	0,9	1	0,9	8,4	,005
Q1.15.14	How would you assess your driving performance in comparison with 5 years ago regarding driving alone?	0,9	1	0,9	4,7	,033
Q1.15.18	How would you assess your driving performance in comparison with 5 years ago regarding overtaking?	1,7	1	1,7	6,9	,010
Q1.16.7	Do you avoid driving in wet road?	3,0	1	3,0	4,6	,034
Q1.16.15	Do you avoid conversing with passenger while driving?	3,6	1	3,6	4,5	,036
Q1.18.1	Do you have divided attention difficulties while driving?	5,3	1	5,3	7,3	,008
Q1.18.3	Do you have difficulties in perceiving other vehicles or pedestrians that suddenly getting close to your vehicle?	4,1	1	4,1	6,4	,013
Q1.18.6	Do you think you have reaction time in unexpected incidents difficulties?	2,3	1	2,3	4,5	,036
Q1.19.1	How dangerous do you think it is to converse with a passenger while driving in urban area with high traffic volume?	24,5	1	24,5	25,1	,000
Q1.19.2	How dangerous do you think it is to converse with a passenger while driving in urban area with low traffic volume?	6,9	1	6,9	8,3	,005
Q1.19.3	How dangerous do you think it is to converse with a passenger while driving in rural area with high traffic volume?	15,8	1	15,8	13,4	,000
Q1.19.4	How dangerous do you think it is to converse with a passenger while driving in rural area with low traffic volume?	7,7	1	7,7	8,1	,006
Q1.21	During the last month how often do you converse with a passenger while driving?	2,9	1	2,9	4,3	,040
Q1.22	During the last month how often do you converse through your mobile phone while driving?	20,8	1	20,8	23,6	,000
Q1.23.1	When conversing with passenger I slow down and drive more carefully	8,6	1	8,6	5,0	,028
Q1.23.2	When conversing with passenger I increase my headway distance	17,5	1	17,5	9,3	,003
Q1.23.3	When conversing with passenger I drive to the right border	21,4	1	21,4	11,2	,001
Q1.32.6	How often do you think that the other drivers shouldn't be permitted to drive while driving?	4,4	1	4,4	5,5	,021
Q1.32.20	How often do you slow down in order to irritate other drivers while driving?	0,9	1	0,9	6,8	,011
Q1.32.29	How often do you think that there is no point to get involved in an argument with some other driver while driving?	5,6	1	5,6	6,0	,016
Q1.32.30	How often do you just try to admit that there are bad drivers in the streets while driving?	3,5	1	3,5	4,0	,048

Before analyzing and discussing the results, for a more distinct picture, mean values of the answers were extracted in order to identify the differences between control group and patients' group in the specific questions that the analysis indicated statistical differences (Table 5.4.).

Table 5.4. Questions in which control group had statistically significant differences with the group of patients

ANOVA Controls vs Patients		Answers – Mean values			Possible answers					
		Controls		Patients	1	2	3	4	5	6
Q1.11.1	During the last 6 months how often did you drive at night?	4,05	>	3,40	Not at all	once in two months	once in a month	once a week	twice a week	four times a week
Q1.11.2	During the last 6 months how often did you drive at rush hours?	4,70	>	3,58	Not at all	once in two months	once in a month	once a week	twice a week	four times a week
Q1.11.4	During the last 6 months how often did you drive at motorways?	3,83	>	3,02	Not at all	once in two months	once in a month	once a week	twice a week	four times a week
Q1.11.5	During the last 6 months how often did you drive at unknown areas?	2,23	>	1,80	Not at all	once in two months	once in a month	once a week	twice a week	four times a week
Q1.11.7	During the last 6 months how often did you drive at urban area?	5,47	>	4,59	Not at all	once in two months	once in a month	once a week	twice a week	four times a week
Q1.12	During the last 6 months how often did avoid driving because you were afraid of your driving performance?	1,20	<	1,53	Never	Rarely	Sometimes	Many times		
Q1.14	How would you assess your driving performance in comparison with 5 years ago?	3,29	>	2,75	Quite worse	A little worse	No difference	A little better	Better	
Q1.15.1	How would you assess your driving performance in comparison with 5 years ago in low traffic in quiet road?	2,98	>	2,82	Quite worse	A little worse	No difference			
Q1.15.2	How would you assess your driving performance in comparison with 5 years ago in urban area with high traffic?	2,88	>	2,72	Quite worse	A little worse	No difference			
Q1.15.8	How would you assess your driving performance in comparison with 5 years ago in a road with many turns?	2,88	>	2,65	Quite worse	A little worse	No difference			
Q1.15.9	How would you assess your driving performance in comparison with 5 years ago in an unknown area?	2,78	>	2,47	Quite worse	A little worse	No difference			
Q1.15.10	How would you assess your driving performance in comparison with 5 years ago regarding lane changing?	2,95	>	2,80	Quite worse	A little worse	No difference			
Q1.15.12	How would you assess your driving performance in comparison with 5 years ago regarding left turns?	2,98	>	2,78	Quite worse	A little worse	No difference			
Q1.15.14	How would you assess your driving performance in comparison with 5 years ago regarding driving alone?	2,93	>	2,73	Quite worse	A little worse	No difference			
Q1.15.18	How would you assess your driving performance in comparison with 5 years ago regarding overtaking?	2,91	>	2,63	Quite worse	A little worse	No difference			
Q1.16.7	Do you avoid driving in wet road?	3,59	>	3,23	Always	Often	Sometimes	Never		
Q1.16.15	Do you avoid conversing with passenger while driving?	3,58	>	3,17	Always	Often	Sometimes	Never		
Q1.18.1	Do you have divided attention difficulties while driving?	1,69	<	2,19	Never	Rarely	Sometimes	Many times	Always	
Q1.18.3	Do you have difficulties in perceiving other vehicles or pedestrians that suddenly getting close to your vehicle?	1,45	<	1,87	Never	Rarely	Sometimes	Many times	Always	
Q1.18.6	Do you think you have reaction time in unexpected incidents difficulties?	1,47	<	1,80	Never	Rarely	Sometimes	Many times	Always	
Q1.19.1	How dangerous do you think it is to converse with a passenger while driving in urban area with high traffic volume?	1,98	<	2,97	Not at all	A little	Quite	A lot		
Q1.19.2	How dangerous do you think it is to converse with a passenger while driving in urban area with low traffic volume?	1,79	<	2,32	Not at all	A little	Quite	A lot		
Q1.19.3	How dangerous do you think it is to converse with a passenger while driving in rural area with high traffic volume?	2,14	<	2,93	Not at all	A little	Quite	A lot		
Q1.19.4	How dangerous do you think it is to converse with a passenger while driving in rural area with low traffic volume?	1,64	<	2,20	Not at all	A little	Quite	A lot		
Q1.21	During the last month how often do you converse with a passenger while driving?	3,19	>	2,85	Never	Rarely	Sometimes	Often		
Q1.22	During the last month how often do you converse through your mobile phone while driving?	2,56	>	1,64	Never	Rarely	Sometimes	Often		
Q1.23.1	When conversing with passenger I slow down and drive more carefully	2,72	<	3,32	Never	Rarely	Sometimes	Often	Always	
Q1.23.2	When conversing with passenger I increase my headway distance	3,05	<	3,92	Never	Rarely	Sometimes	Often	Always	

Q1.23.3	When conversing with passenger I drive to the right border	2,55	<	3,50	Never	Rarely	Sometimes	Often	Always	
Q1.32.6	How often do you think that the other drivers shouldn't be permitted to drive while driving?	1,71	<	2,14	Never	Rarely	Many times	Always		
Q1.32.20	How often do you slow down in order to irritate other drivers while driving?	1,24	>	1,05	Never	Rarely	Many times	Always		
Q1.32.29	How often do you think that there is no point to get involved in an argument with some other driver while driving?	3,60	>	3,12	Never	Rarely	Many times	Always		
Q1.32.30	How often do you just try to admit that there are bad drivers in the streets while driving?	3,55	>	3,17	Never	Rarely	Many times	Always		

ANOVA indicated several interesting results in which patients with neurological diseases affecting cognitive functions have statistically significant differences in their answers compared to the healthy control group:

» Patients with neurological diseases affecting cognitive functions **avoid driving at night, at rush hours, at motorways, at unknown areas and at urban areas** in a significant level compared to healthy controls of similar demographics.
» Patients admit that during the last 6 months they **avoid driving because they are afraid of their driving performance**.
» Patients **self-assess their driving performance as worse**, than 5 years, in a lot more driving occasions compared to healthy controls.
» Patients **avoid driving in wet roads and avoid conversing with a co-passenger** while driving.
» Patients **admit having difficulties in their reaction time, in divided attention conditions, and in perceiving other vehicles or pedestrians** that suddenly getting close to their vehicle.
» Moreover, patients think that **conversing with a passenger while driving is a quite dangerous condition** and they avoid doing so. In the case they doing so, they try to drive more carefully, drive to the right border of the road, try to increase their headway.
» Patients with MCI, AD or PD, **rarely converse through their mobile phone** while driving.
» Finally, control group, as they report, they seems to be a little angrier while driving than the group of patients. The self-awareness of the patients about their cognitive declines may force them to be more calm and focused on the task of driving.

Summarizing the results regarding the usual driving routines of the participants, the self-assessment about their driving frequency, their driving performance, and their possible avoidance of driving, several interesting comments could be extracted; patients self-reported, that they are likely to avoid using their vehicle because they are afraid of their driving abilities which they admit that have been deteriorated over the years. This awareness of deteriorated driving performance due to brain pathologies is of notable

significance; it means that this group of drivers tries to self-regulate their driving. This is a quite interesting finding as it is not clear in the literature that at least AD patients have self-awareness of their deterioration of their driving performance.

Moving on to the results regarding their opinion about in-vehicle driver distraction (conversation with passenger or mobile phone use) and how they deal with it, patients believe that conversing with passenger is dangerous and they avoid to do so. Patients claim that conversing with a co-passenger is at least a quite dangerous action regarding road safety. Additionally, they self-report that when conversing with passenger while driving, they speed down, keep larger headways, and drive to the "right" border of the road in order to compensate their driving behaviour. The control group, on the contrary, claim that this kind of distraction is a little or no dangerous at all.

The take-home message of the current analysis is that drivers with brain pathologies are aware of their deterioration of their driving performance, and they try to compensate their driving behaviour by either conservative driving, or even they avoid driving. They consider in-vehicle distraction as quite dangerous and taking into account that they are aware about their cognitive decline, they avoid such driving conditions or they follow compensatory patterns.

5.3. Regression analyses

5.3.1. Driving performance measures of patients

In the present section, linear regression analysis is implemented in order to identify several sets of explanatory variables that covary with specific driving performance measures of the driving simulator dataset.

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.

For the purposes of this analysis, the "old" group (125 participants) is isolated (for representativeness reasons the young group, the middle aged group and the patients of "other" neurological diseases are eliminated from the analysis) and the effect of neurological disease affecting cognitive functions is examined regarding several critical driving performance measures, in **rural and urban areas** and **low and high traffic volumes**. The sample scheme is divided in four categories:

» **Controls** **34 Healthy Controls** (age>55 years old)
» **MCI** **43 patients with MCI** (age>55 years old)
» **AD** **28 patients with AD** (age>55 years old)
» **PD** **20 patients with PD** (age>55 years old)

Only undistracted driving is under examination within the framework of this analysis regarding the following driving performance measures:

» **Mean speed**
» **Time headway**
» **Lateral position**
» **Steering angle variability**
» **Reaction time at unexpected incidents**
» **Accident probability**
» **Driving errors**

5.3.1.1. Mean 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 Figure 5.24 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the **mean speed** in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Disease, No distraction Condition

Rural Area

Parameter	Low Traffic					High Traffic				
	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	44,8	1,2	1508,3	1	0,000	42,1	1,0	1942,3	1	0,000
MCI	-5,3	1,7	9,2	1	,002	-5,0	1,5	11,8	1	,001
AD	-10,8	2,0	28,2	1	,000	-8,4	1,7	25,8	1	,000
PD	-9,3	2,1	19,6	1	,000	-8,3	1,8	20,2	1	,000
Controls	0[a]					0[a]				
(Scale)	63,808[b]	7,9				47,559[b]	5,8			

Urban Area

Parameter										
	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	30,1	0,9	1047,4	1	0,000	27,8	0,7	1417,1	1	0,000
MCI	-2,0	1,4	2,0	1	,160	-2,3	1,1	4,5	1	,034
AD	-4,3	1,6	7,0	1	,008	-4,2	1,3	10,4	1	,001
PD	-3,8	1,9	4,1	1	,042	-3,1	1,4	4,7	1	,030
Controls	0[a]					0[a]				
(Scale)	33,815[b]	4,7				19,695[b]	2,8			

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

Figure 5.24. GLM - Mean Speed/undistracted driving

In all four models statistically significant differences are detected. More analytically, all three group of **patients drive significantly slower than the controls** in all examined conditions (except for the MCI group in low traffic volume in urban area). Cerebral diseases appear to have a significant effect on driver mean speed in rural driving environment. AD drivers' speed was the lowest among all groups of patients in all conditions. It seems that traffic volume and rural or urban area doesn't affect significantly the speed of any examined group.

5.3.1.2. Time 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 Figure 5.25 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the **time headway** in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM
Dependent variable: Time Headway (sec)
Model: (Intercept), Disease, No distraction Condition

Rural Area

Parameter	Low Traffic					High Traffic				
	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	51,9	5,7	84,2	1	0,000	30,4	3,8	65,1	1	0,000
MCI	11,9	8,6	1,9	1	,164	9,0	5,8	2,4	1	,120
AD	41,5	9,9	17,4	1	,000	29,6	6,5	20,5	1	,000
PD	45,7	10,3	19,9	1	,000	27,2	7,3	13,9	1	,000
Controls	0[a]					0[a]				
(Scale)	1536,083[b]	191,3				739,891[b]	89,7			

Urban Area

Parameter	Low Traffic					High Traffic				
	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	51,5	4,3	144,2	1	0,000	27,2	2,6	110,1	1	0,000
MCI	-4,4	6,4	0,5	1	,499	3,5	3,8	0,9	1	,354
AD	5,4	7,5	0,5	1	,469	8,1	4,6	3,1	1	,078
PD	-2,1	8,6	0,1	1	,809	8,2	5,0	2,7	1	,102
Controls	0[a]					0[a]				
(Scale)	716,512[b]	100,3				242,606[b]	34,8			

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

Figure 5.25. GLM - Time headway/undistracted driving

The examined neurological diseases affecting cognitive functions appear to have a significant effect on mean headway in **rural roads** but only for AD and PD patients: they **had significantly larger mean headway compared to healthy drivers** at both traffic environments (they keep approximately double headway than healthy controls). This was observed for MCI drivers too, but the confidence level was not significant. AD and PD drivers had much longer mean headway compared with the MCI drivers. These results are intuitive, given that lower speeds naturally result in larger headways, for a given distribution of ambient traffic on the road network. It is also noted that headways at low traffic volumes were longer for all driver groups, which is also intuitive. Cerebral

diseases appear **not to have a significant effect on mean headway in urban roads** though. Patients' time headways are not so far from the headways the controls keep. Of course traffic volume has a significant effect on headways of all examined groups as expected.

5.3.1.3. 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 Figure 5.26 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the **lateral position** in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM
Dependent variable: Lateral Position (m)
Model: (Intercept), Disease, No distraction Condition

	Low Traffic					High Traffic					
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	
(Intercept)	1,49	0,0	5778,6	1	0,000	1,61	0,0	7726,5	1	0,000	Rural Area
MCI	0,04	0,0	2,0	1	,158	0,03	0,0	0,9	1	,336	
AD	-0,01	0,0	0,1	1	,745	0,04	0,0	1,2	1	,267	
PD	-0,03	0,0	0,5	1	,479	-0,05	0,0	2,2	1	,142	
Controls	0[a]					0[a]					
(Scale)	,018[b]	0,0				,017[b]	0,0				
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	
(Intercept)	3,09	0,1	923,9	1	0,000	3,28	0,1	1316,8	1	0,000	Urban Area
MCI	0,26	0,2	3,0	1	,086	0,31	0,1	5,5	1	,019	
AD	0,20	0,2	1,3	1	,257	0,14	0,2	0,8	1	,382	
PD	0,31	0,2	2,3	1	,128	0,22	0,2	1,6	1	,200	
Controls	0[a]					0[a]					
(Scale)	,402[b]	0,1				,294[b]	0,0				

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

Figure 5.26. GLM - Lateral Position/undistracted driving

Regarding vehicle lateral position in rural area, it is reminded that the width of the driving lane was 3m (quite narrow), so the drivers didn't have so much flexibility in positioning their vehicle on the lane. Thus, there were no significant differences in lateral position for the drivers. Positive values indicate driving more closely to the right border of the road.

Regarding lateral position in urban area, MCI patients appeared to drive at longer distance from the central road axis compared to healthy drivers, both at high and at low traffic volumes (statistically significant at 95% confidence level for high traffic volume and 90% for low traffic volume). This was observed only in urban road environment; the width of the driving lane was 3,5m, there were 2 lanes in most part of the route, so there were opportunities for overtaking and there were choices in positioning the vehicle on the road. It seems that urban area constitutes a more complex driving environment for the patients and leads them to drive more closely to the right border of the road, this was significant only for the MCI group though.

5.3.1.4. Steering angle variability

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 Figure 5.27 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the **steering angle variability** in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM

Dependent variable: Steering Angle Variability (degrees)

Model: (Intercept), Disease, No distraction Condition

Rural Area

	Low Traffic					High Traffic				
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	17,21	0,3	3830,5	1	0,000	16,90	0,2	6298,7	1	0,000
MCI	-0,56	0,4	1,7	1	,186	-0,56	0,3	3,0	1	,083
AD	-0,23	0,5	0,2	1	,645	-0,41	0,4	1,2	1	,271
PD	-0,78	0,5	2,4	1	,120	-1,12	0,4	7,4	1	,007
Controls	0[a]					0[a]				
(Scale)	3,709[b]	0,5				2,357[b]	0,3			

Urban Area

	Low Traffic					High Traffic				
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	23,95	1,2	414,8	1	0,000	21,63	1,5	221,6	1	0,000
MCI	0,47	1,8	0,1	1	,789	2,26	2,1	1,1	1	,290
AD	-0,18	2,1	0,0	1	,931	3,53	2,6	1,9	1	,169
PD	-0,94	2,4	0,2	1	,689	-1,55	2,8	0,3	1	,583
Controls	0[a]					0[a]				
(Scale)	53,917[b]	7,5				76,037[b]	10,9			

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

Figure 5.27. GLM - Steering angle variability/undistracted driving

Overall, the only statistically significant difference was detected for PD drivers in high traffic area with high traffic volume. In particular, **PD drivers have restricted steering angle variability** in this driving condition and this is maybe a compensatory behaviour.

5.3.1.5. 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 Figure 5.28 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the **reaction time** in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM

Dependent variable: Reaction Time (millisec)

Model: (Intercept), Disease, No distraction Condition

Rural Area

Parameter	Low Traffic					High Traffic				
	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1625,9	86,3	354,7	1	0,000	1752,7	98,4	316,9	1	0,000
MCI	379,7	130,1	8,5	1	,004	439,9	150,4	8,6	1	,003
AD	829,7	150,6	30,4	1	,000	748,6	170,5	19,3	1	,000
PD	584,0	158,0	13,7	1	,000	552,6	194,1	8,1	1	,004
Controls	0[a]					0[a]				
(Scale)	350248,06[b]	43953,0				503994,57[b]	61344,3			

Urban Area

Parameter										
	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1385,8	69,9	392,7	1	0,000	1323,6	55,1	577,1	1	0,000
MCI	51,1	102,1	0,3	1	,617	175,9	82,0	4,6	1	,032
AD	476,8	118,9	16,1	1	,000	361,3	99,6	13,2	1	,000
PD	232,5	133,0	3,1	1	,080	265,1	107,9	6,0	1	,014
Controls	0[a]					0[a]				
(Scale)	166258,12[b]	24123,3				103214,49[b]	15472,5			

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Figure 5.28. GLM - Reaction time/undistracted driving

Significant differences in the driving behaviour of healthy drivers and patients were also identified as regards the drivers' reaction time at unexpected incidents in rural roads. In both traffic conditions all group of patients had at least 0.4 sec longer reaction times than the healthy ones. This difference was found to be statistically significant at 95% confidence level for all patient groups and both traffic volumes. Especially for the **AD group who has the significantly worst reaction times among all groups**, they had more than 0.7 sec larger reaction times than control ones. Then, regarding the reaction times in urban road, they appeared to be improved for the MCI, AD and PD drivers compared to the rural road. They were more closely to the reaction times of the control group, yet they are significantly worse than that of controls. Once again, AD group had the worse reaction times overall. Finally, the traffic volume doesn't seem to have a significant effect on reaction time.

5.3.1.6. Accident probability

The next regression analysis regards the accident probability in unexpected incident. The accident probability constitutes the most significant road safety measure. In Figure 5.29 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the **accident probability** in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Disease, No distraction Condition

	Low Traffic					High Traffic					
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	
(Intercept)	0,13	0,0	11,2	1	0,001	0,04	0,0	1,4	1	0,238	Rural Area
MCI	-0,01	0,1	0,0	1	,916	0,09	0,0	3,2	1	,072	
AD	0,15	0,1	5,4	1	,020	0,19	0,1	11,6	1	,001	
PD	-0,03	0,1	0,2	1	,691	0,04	0,1	0,4	1	,521	
Controls	0[a]					0[a]					
(Scale)	,068[b]	0,0				,055[b]	0,0				
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	
(Intercept)	0,07	0,0	2,8	1	0,095	0,10	0,0	4,7	1	0,030	Urban Area
MCI	0,16	0,1	6,2	1	,013	0,15	0,1	4,4	1	,037	
AD	0,23	0,1	9,6	1	,002	0,20	0,1	5,3	1	,021	
PD	0,12	0,1	2,0	1	,156	0,19	0,1	4,2	1	,042	
Controls	0[a]					0[a]					
(Scale)	,066[b]	0,0				,076[b]	0,0				

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

Figure 5.29. GLM - Accident probability/undistracted driving

Several interesting results were extracted from this regression analysis. Firstly, AD participants in all 4 driving conditions **had significantly higher accident probability by 15%-23% compared to healthy controls** of similar demographics. Then, PD participants had significantly worse accident probability than the controls only in urban

area in high traffic volume (the most complex driving environment of all four). MCI patients didn't have significant differences with the control group in rural road, but on the other hand they had higher accident probability in urban driving environment. This is an important finding as MCI group is characterized clinically only by memory impairment with well reserved every day and professional functioning.

5.3.1.7. Driving Errors

In Figure 5.30 the parameter estimates of four generalized linear models (GLM), on the dependent variable of the **driving errors** (hits of sidebars + outside road lines + speed limit violations) in: a) low traffic volume rural area, b) low traffic volume urban area, c) high traffic volume rural area and d) high traffic volume urban area is presented.

Parameter Estimates of the GLM
Dependent variable: Driving Errors
Model: (Intercept), Disease, No distraction Condition

	Low Traffic					High Traffic					
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	
(Intercept)	0,88	0,2	20,2	1	0,000	2,21	0,3	50,0	1	0,000	Rural Area
MCI	-0,15	0,3	0,2	1	,623	-0,42	0,5	0,8	1	,383	
AD	-0,05	0,3	0,0	1	,886	0,25	0,5	0,2	1	,644	
PD	-0,35	0,4	1,0	1	,320	-0,95	0,6	2,5	1	,117	
Controls	0[a]					0[a]					
(Scale)	1,822[b]	0,2				5,082[b]	0,6				
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.	
(Intercept)	0,31	0,1	12,9	1	0,000	0,14	0,1	4,1	1	0,043	Urban Area
MCI	-0,11	0,1	0,8	1	,376	0,02	0,1	0,0	1	,824	
AD	0,06	0,1	0,2	1	,685	0,10	0,1	0,6	1	,427	
PD	-0,15	0,2	0,8	1	,370	-0,06	0,1	0,2	1	,642	
Controls	0[a]					0[a]					
(Scale)	,287[b]	0,0				,170[b]	0,0				

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

Figure 5.30. GLM - Driving errors/undistracted driving

No statistically significant differences were detected in this regression analysis between any of the patients' groups and the heathy group.

5.3.2. Patients with neurological diseases affecting cognitive functions and distraction

In the present section, the effect of in-vehicle distraction is examined regarding the driving performance measures of the three clinical groups (MCI, AD, and PD) and the control group through GLM techniques.

The sample scheme is the following:

» **Controls** **34 Healthy Controls** (age>55 years old)
» **MCI** **43 patients with MCI** (age>55 years old)
» **AD** **28 patients with AD** (age>55 years old)
» **PD** **20 patients with PD** (age>55 years old)

No distraction condition, conversation with passenger and conversation through handheld mobile phone are examined within the framework of this regression analysis regarding the following driving performance measures in rural and urban areas:

» **Mean speed**
» **Time headway**
» **Lateral position**
» **Steering angle variability**
» **Reaction time at unexpected incidents**
» **Accident probability**

The aim of this regression analyses is to examine the effect of in-vehicle distraction in the three clinical groups with cerebral diseases and the control group, regarding the driving performance measures in which they have significant differences with their undistracted driving.

5.3.2.1. Control group

In Figures 5.31-5.36 the parameter estimates of twelve generalized linear models (GLM), on the 6 dependent driving performance variables regarding the group of controls in: a) rural area and b) urban area, are presented.

Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

Control group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	44,43	0,7	4117,9	1	0,000
Conversation	0,11	1,0	0,0	1	,910
Mobile phone	-2,01	1,2	2,9	1	,088
No distraction	0[a]				
(Scale)	53,681[b]	4,6			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	29,90	0,5	3020,5	1	0,000
Conversation	-0,42	0,8	0,3	1	,593
Mobile phone	0,15	1,0	0,0	1	,878
No distraction	0[a]				
(Scale)	25,758[b]	2,5			

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

Figure 5.31. GLM - Effect of distraction - Mean speed of the Control group of older

Parameter Estimates of the GLM
Dependent variable: Time headway (sec)
Model: (Intercept), Distractor

Control group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	38,80	2,5	236,1	1	0,000
Conversation	-1,21	3,6	0,1	1	,740
Mobile phone	9,47	4,3	4,9	1	,028
No distraction	0[a]				
(Scale)	714,303[b]	60,8			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	40,44	3,4	138,7	1	0,000
Conversation	-1,82	4,9	0,1	1	,713
Mobile phone	8,34	6,1	1,9	1	,173
No distraction	0[a]				
(Scale)	1025,814[b]	100,6			

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

Figure 5.32. GLM - Effect of distraction - Time headway of the Control group of older drivers

Parameter Estimates of the GLM
Dependent variable: Lateral Position (m)
Model: (Intercept), Distractor

Control group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1,54	0,0	12708,0	1	0,000
Conversation	-0,02	0,0	0,8	1	,359
Mobile phone	0,01	0,0	0,2	1	,698
No distraction	0[a]				
(Scale)	,021[b]	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	3,14	0,1	2100,7	1	0,000
Conversation	0,05	0,1	0,2	1	,633
Mobile phone	0,12	0,1	1,0	1	,311
No distraction	0[a]				
(Scale)	,407[b]	0,0			

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

Figure 5.33. GLM - Effect of distraction - Lateral position of the Control group of older

Parameter Estimates of the GLM
Dependent variable: Steering Angle Variability (degrees)
Model: (Intercept), Distractor

Control group

Rural Area

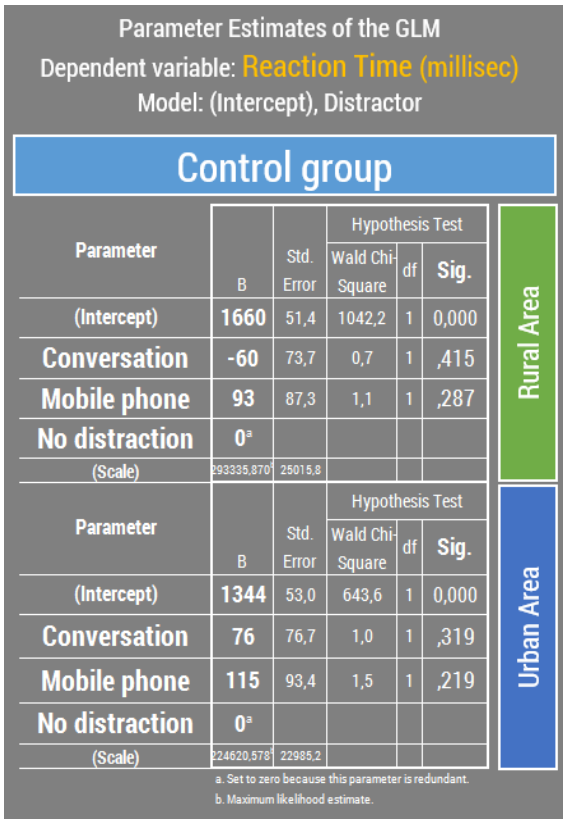
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	17,23	0,2	11131,3	1	0,000
Conversation	0,65	0,2	7,7	1	,006
Mobile phone	0,33	0,3	1,4	1	,237
No distraction	0[a]				
(Scale)	2,989[b]	0,3			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	22,66	0,6	1628,6	1	0,000
Conversation	-0,15	0,8	0,0	1	,855
Mobile phone	-1,07	1,0	1,1	1	,287
No distraction	0[a]				
(Scale)	27,442[b]	2,7			

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

Figure 5.34. GLM - Effect of distraction - Steering angle variability of the Control group



Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

Control group

Rural Area

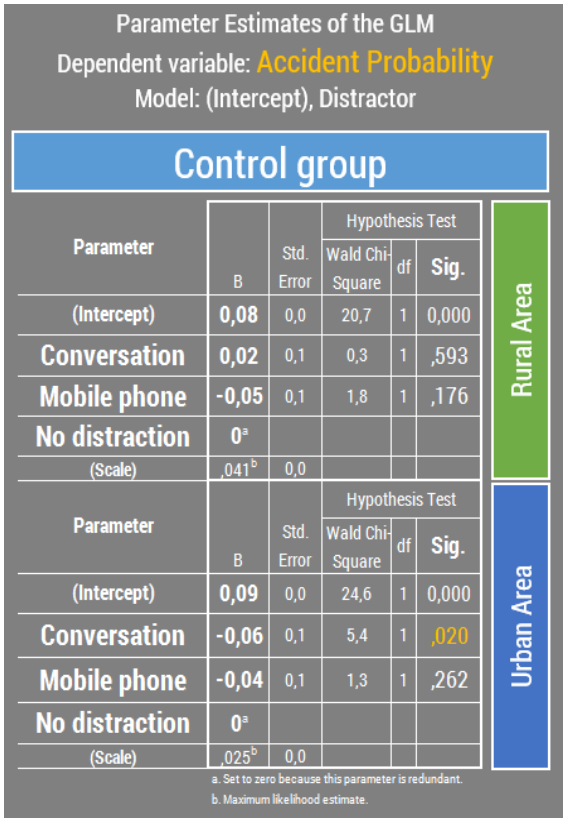
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1660	51,4	1042,2	1	0,000
Conversation	-60	73,7	0,7	1	,415
Mobile phone	93	87,3	1,1	1	,287
No distraction	0[a]				
(Scale)	293335,870[1]	25015,8			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1344	53,0	643,6	1	0,000
Conversation	76	76,7	1,0	1	,319
Mobile phone	115	93,4	1,5	1	,219
No distraction	0[a]				
(Scale)	224620,578[1]	22985,2			

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

Figure 5.35. GLM - Effect of distraction - Reaction time of the Control group of older



Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

Control group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,08	0,0	20,7	1	0,000
Conversation	0,02	0,1	0,3	1	,593
Mobile phone	-0,05	0,1	1,8	1	,176
No distraction	0[a]				
(Scale)	,041[b]	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,09	0,0	24,6	1	0,000
Conversation	-0,06	0,1	5,4	1	,020
Mobile phone	-0,04	0,1	1,3	1	,262
No distraction	0[a]				
(Scale)	,025[b]	0,0			

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

Figure 5.36. GLM - Effect of distraction - Accident probability of the Control group of

Investigating the **effect of distraction in the group of healthy controls of similar demographics with the groups of patients**, only in three conditions significant differences were detected: The mobile phone use lead to larger headways in rural roads, and the conversation with passenger lead to higher steering angle variability on rural roads and slightly lower accident probability in urban area.

It appears that the distraction conditions (even the mobile phone use while driving) don't have any significant impact on several driving performance measures in the group of controls overall, in contrast with the findings extracted from the patients' groups regression analyses in whom the impact of distraction and especially the mobile phone use, was detrimental.

5.3.2.2. MCI group

In Figures 5.37-5.42 the parameter estimates of twelve generalized linear models (GLM), on the 6 dependent driving performance variables regarding the MCI group in: a) rural area and b) urban area, are presented.

Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

MCI group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	38,20	0,8	2144,2	1	0,000
Conversation	-1,20	1,2	1,1	1	,304
Mobile phone	-2,95	1,5	3,7	1	,056
No distraction	0[a]				
(Scale)	55,815[b]	5,6			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	26,76	0,6	2144,0	1	0,000
Conversation	-0,37	0,8	0,2	1	,660
Mobile phone	0,91	1,3	0,5	1	,475
No distraction	0[a]				
(Scale)	22,041[b]	2,6			

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

Figure 5.37. GLM - Effect of distraction - Mean speed of the MCI group

Parameter Estimates of the GLM
Dependent variable: Time Headway (sec)
Model: (Intercept), Distractor

MCI group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	51,99	3,7	193,3	1	0,000
Conversation	6,02	5,3	1,3	1	,253
Mobile phone	18,41	7,0	7,0	1	,008
No distraction	0[a]				
(Scale)	1146,470[b]	115,2			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	39,91	2,8	196,5	1	0,000
Conversation	0,08	4,1	0,0	1	,984
Mobile phone	9,90	6,3	2,5	1	,115
No distraction	0[a]				
(Scale)	535,093[b]	63,1			

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

Figure 5.38. GLM - Effect of distraction - Time headway of the MCI group

Parameter Estimates of the GLM
Dependent variable: Lateral Position (m)
Model: (Intercept), Distractor

MCI group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1,58	0,0	11397,4	1	0,000
Conversation	-0,03	0,0	1,8	1	,176
Mobile phone	0,00	0,0	0,0	1	,904
No distraction	0[a]				
(Scale)	,018[b]	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	3,48	0,1	2339,3	1	0,000
Conversation	-0,08	0,1	0,6	1	,436
Mobile phone	0,03	0,2	0,0	1	,855
No distraction	0[a]				
(Scale)	,342[b]	0,0			

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

Figure 5.39. GLM - Effect of distraction - Lateral position of the MCI group

Parameter Estimates of the GLM
Dependent variable: Steering Angle Variability (degrees)
Model: (Intercept), Distractor

MCI group

Rural Area

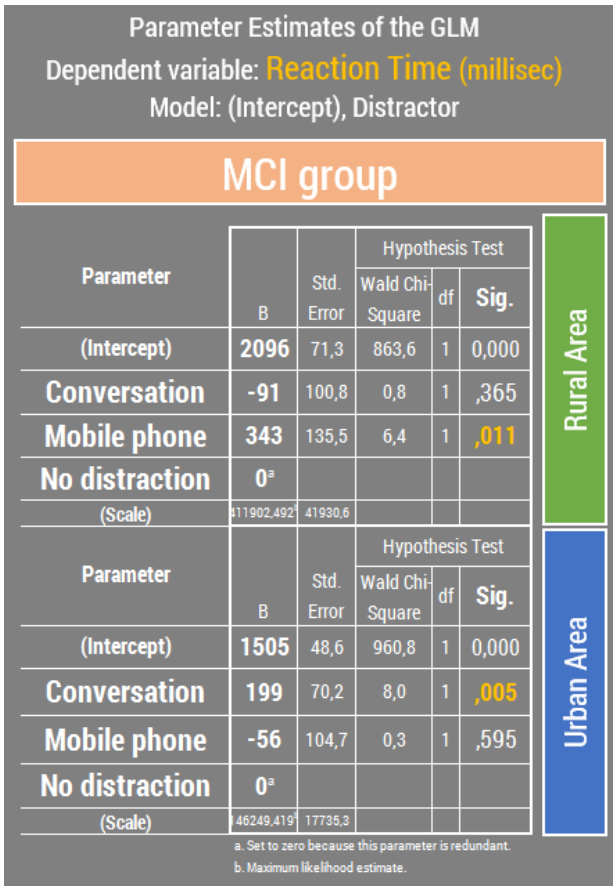
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	16,44	0,2	4523,7	1	0,000
Conversation	0,11	0,3	0,1	1	,758
Mobile phone	-0,30	0,5	0,4	1	,505
No distraction	0[a]				
(Scale)	4,897[b]	0,5			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	24,34	0,9	679,0	1	0,000
Conversation	-1,16	1,3	0,7	1	,391
Mobile phone	-3,58	2,1	3,0	1	,083
No distraction	0[a]				
(Scale)	57,596[b]	6,8			

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

Figure 5.40. GLM - Effect of distraction - Steering angle variability of the MCI group



Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

MCI group

Rural Area

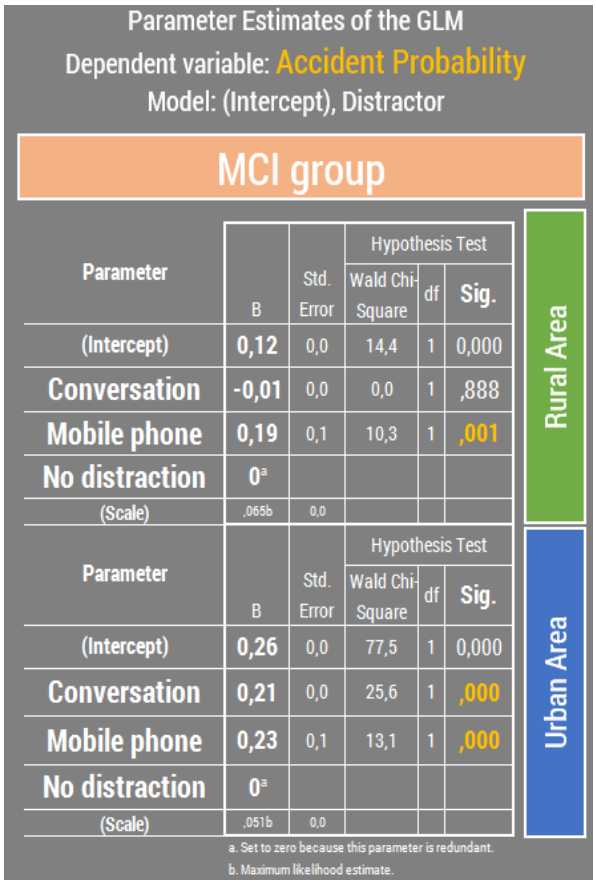
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	2096	71,3	863,6	1	0,000
Conversation	-91	100,8	0,8	1	,365
Mobile phone	343	135,5	6,4	1	,011
No distraction	0[a]				
(Scale)	411902,492[b]	41930,6			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1505	48,6	960,8	1	0,000
Conversation	199	70,2	8,0	1	,005
Mobile phone	-56	104,7	0,3	1	,595
No distraction	0[a]				
(Scale)	46249,419[b]	17735,3			

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

Figure 5.41. GLM - Effect of distraction - Reaction time of the MCI group



Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

MCI group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,12	0,0	14,4	1	0,000
Conversation	-0,01	0,0	0,0	1	,888
Mobile phone	0,19	0,1	10,3	1	,001
No distraction	0[a]				
(Scale)	,065[b]	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,26	0,0	77,5	1	0,000
Conversation	0,21	0,0	25,6	1	,000
Mobile phone	0,23	0,1	13,1	1	,000
No distraction	0[a]				
(Scale)	,051[b]	0,0			

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

Figure 5.42. GLM - Effect of distraction - Accident probability of the MCI group

Investigating the **effect of distraction in the group of MCI** several interesting results are extracted. Mobile phone use has a significant impact on mean speed, time headway, steering angle variability, reaction time and accident probability of MCI drivers. More specifically, in rural area mobile phone use leads to lower speed and larger headways, leads to decreased steering angle variability in urban area, to larger reaction time and higher accident probability in a significant level. On the other hand, the effect of conversation with passenger isn't that detrimental as it leads to larger reaction time and higher accident risk in urban driving environment only.

5.3.2.3. AD group

In Figures 5.43-5.48 the parameter estimates of twelve generalized linear models (GLM), on the 6 dependent driving performance variables regarding the AD group in: a) rural area and b) urban area, are presented.

Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

AD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	33,89	1,2	864,0	1	0,000
Conversation	0,06	1,6	0,0	1	,969
Mobile phone	-3,82	3,4	1,2	1	,265
No distraction	0[a]				
(Scale)	62,480[b]	8,8			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	24,80	0,9	772,7	1	0,000
Conversation	-1,06	1,4	0,6	1	,440
Mobile phone	-0,11	2,4	0,0	1	,962
No distraction	0[a]				
(Scale)	28,655[b]	4,9			

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

Figure 5.43. GLM - Effect of distraction - Mean speed of the AD group

Parameter Estimates of the GLM
Dependent variable: Time Headway (sec)
Model: (Intercept), Distractor

AD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	75,47	9,4	63,8	1	0,000
Conversation	5,05	13,4	0,1	1	,706
Mobile phone	22,72	28,1	0,7	1	,418
No distraction	0[a]				
(Scale)	195,098	593,3			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	46,70	4,0	139,4	1	0,000
Conversation	-1,80	6,1	0,1	1	,768
Mobile phone	12,28	10,5	1,4	1	,241
No distraction	0[a]				
(Scale)	563,018[b]	96,6			

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

Figure 5.44. GLM - Effect of distraction - Time headway of the AD group

Parameter Estimates of the GLM
Dependent variable: Lateral Position (m)
Model: (Intercept), Distractor

AD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1,56	0,0	3680,8	1	0,000
Conversation	-0,03	0,0	0,5	1	,464
Mobile phone	-0,14	0,1	3,3	1	,071
No distraction	0[a]				
(Scale)	,031[b]	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	3,35	0,1	1126,0	1	0,000
Conversation	0,14	0,2	0,8	1	,370
Mobile phone	0,17	0,3	0,4	1	,512
No distraction	0[a]				
(Scale)	,358[b]	0,1			

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

Figure 5.45. GLM - Effect of distraction - Lateral position of the AD group

Parameter Estimates of the GLM
Dependent variable: Steering Angle Variability (degrees)
Model: (Intercept), Distractor

AD group

Rural Area

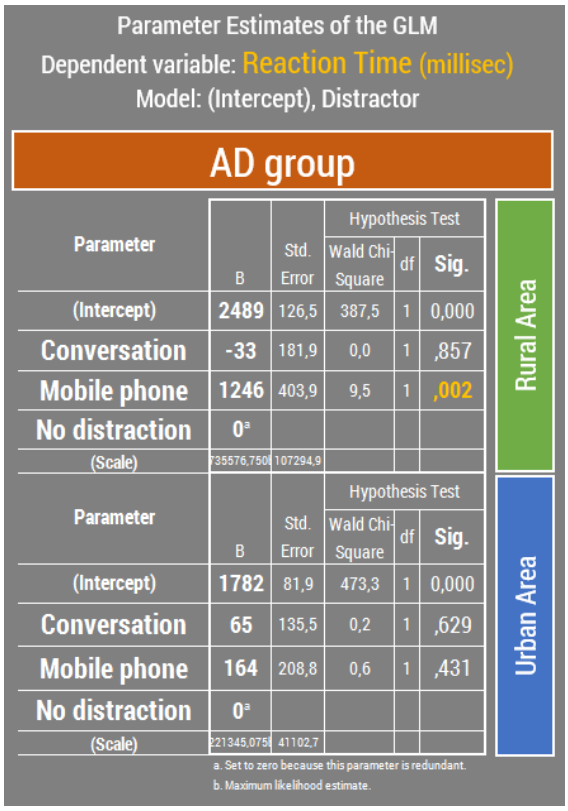
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	16,79	0,4	1494,6	1	0,000
Conversation	0,41	0,6	0,4	1	,505
Mobile phone	-1,51	1,3	1,4	1	,242
No distraction	0[a]				
(Scale)	8,867[b]	1,3			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	24,43	1,5	261,1	1	0,000
Conversation	-1,59	2,3	0,5	1	,495
Mobile phone	-1,20	4,0	0,1	1	,764
No distraction	0[a]				
(Scale)	82,252[b]	14,1			

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

Figure 5.46. GLM - Effect of distraction - Steering angle variability of the AD group



Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

AD group

Rural Area

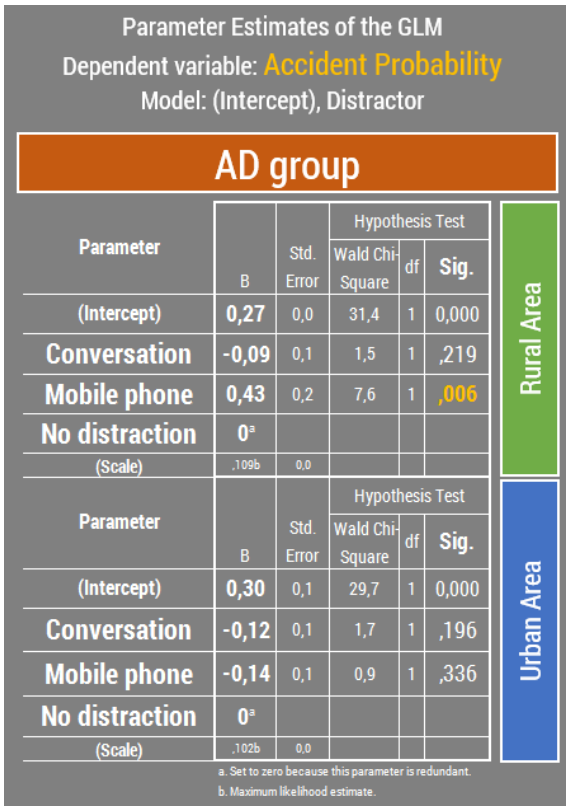
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	2489	126,5	387,5	1	0,000
Conversation	-33	181,9	0,0	1	,857
Mobile phone	1246	403,9	9,5	1	,002
No distraction	0[a]				
(Scale)	735576,750	107294,9			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1782	81,9	473,3	1	0,000
Conversation	65	135,5	0,2	1	,629
Mobile phone	164	208,8	0,6	1	,431
No distraction	0[a]				
(Scale)	221345,075	41102,7			

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

Figure 5.47. GLM - Effect of distraction - Reaction time of the AD group



Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

AD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,27	0,0	31,4	1	0,000
Conversation	-0,09	0,1	1,5	1	,219
Mobile phone	0,43	0,2	7,6	1	,006
No distraction	0[a]				
(Scale)	,109[b]	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,30	0,1	29,7	1	0,000
Conversation	-0,12	0,1	1,7	1	,196
Mobile phone	-0,14	0,1	0,9	1	,336
No distraction	0[a]				
(Scale)	,102[b]	0,0			

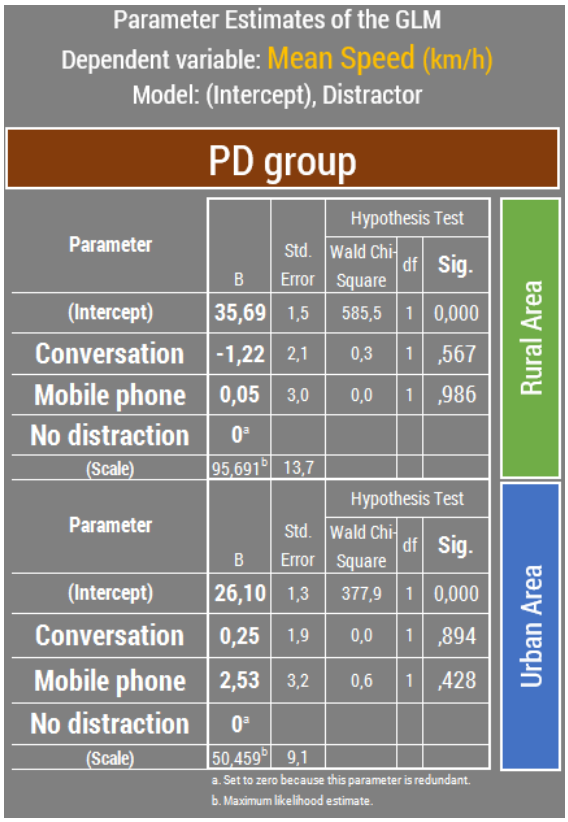
a. Set to zero because this parameter is redundant.
b. Maximum likelihood estimate.

Figure 5.48. GLM - Effect of distraction - Accident probability of the AD group

Investigating the **effect of distraction in the group of AD** several interesting results are extracted but much less than of the MCI group. More specifically, significant differences were detected only in rural area, where AD patients when using the mobile phone while driving they tend to drive more closely to the left border of the road, compared to the undistracted condition, in a significant level of 90%, and they have significantly larger reaction time and higher accident probability in mobile phone condition compared to the undistracted driving.

5.3.2.4. PD group

In Figures 5.49-5.54 the parameter estimates of twelve generalized linear models (GLM), on the 6 dependent driving performance variables regarding the PD group in: a) rural area and b) urban area, are presented.



Parameter Estimates of the GLM
Dependent variable: Mean Speed (km/h)
Model: (Intercept), Distractor

PD group

Rural Area

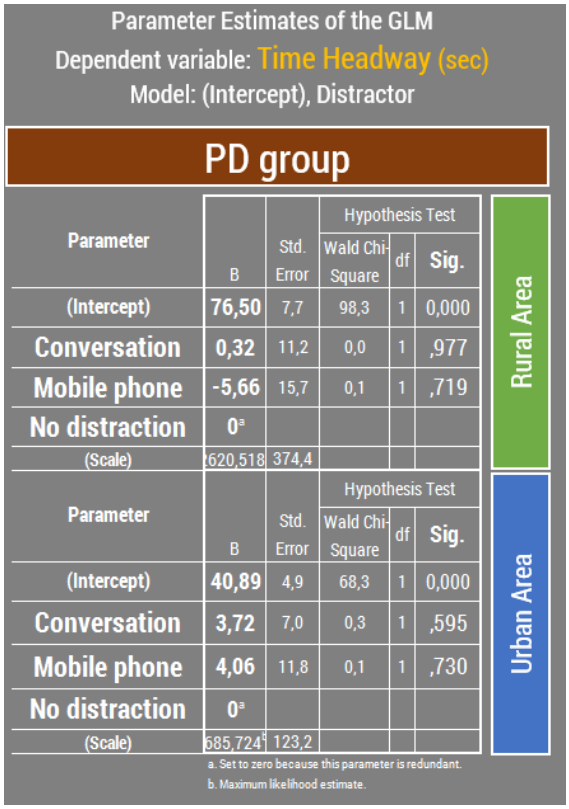
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	35,69	1,5	585,5	1	0,000
Conversation	-1,22	2,1	0,3	1	,567
Mobile phone	0,05	3,0	0,0	1	,986
No distraction	0[a]				
(Scale)	95,691[b]	13,7			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	26,10	1,3	377,9	1	0,000
Conversation	0,25	1,9	0,0	1	,894
Mobile phone	2,53	3,2	0,6	1	,428
No distraction	0[a]				
(Scale)	50,459[b]	9,1			

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

Figure 5.49. GLM - Effect of distraction - Mean speed of the PD group



Parameter Estimates of the GLM
Dependent variable: Time Headway (sec)
Model: (Intercept), Distractor

PD group

Rural Area

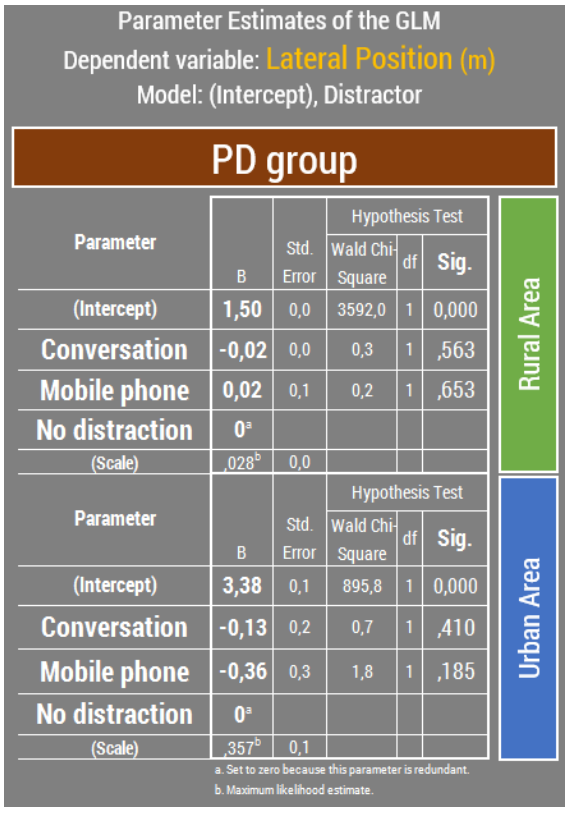
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	76,50	7,7	98,3	1	0,000
Conversation	0,32	11,2	0,0	1	,977
Mobile phone	-5,66	15,7	0,1	1	,719
No distraction	0[a]				
(Scale)	620,518	374,4			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	40,89	4,9	68,3	1	0,000
Conversation	3,72	7,0	0,3	1	,595
Mobile phone	4,06	11,8	0,1	1	,730
No distraction	0[a]				
(Scale)	685,724[b]	123,2			

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

Figure 5.50. GLM - Effect of distraction - Time headway of the PD group



Parameter Estimates of the GLM
Dependent variable: Lateral Position (m)
Model: (Intercept), Distractor

PD group

Rural Area

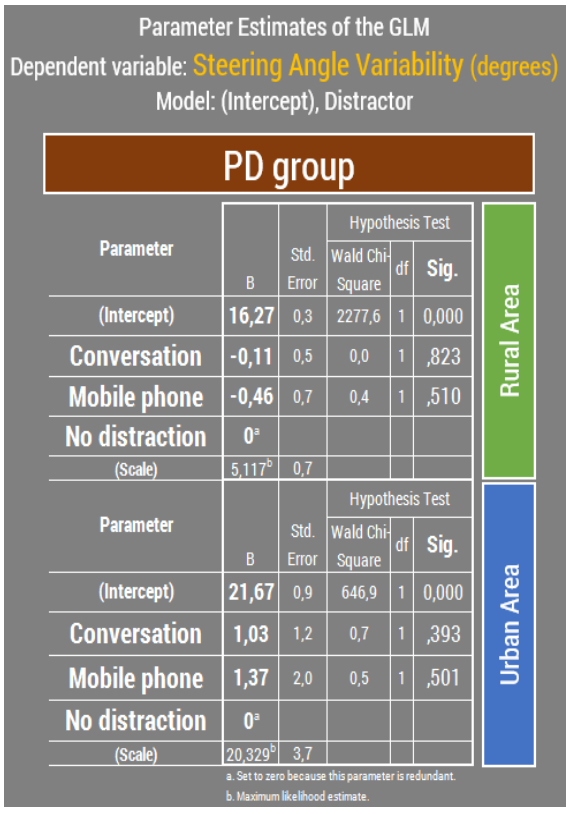
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1,50	0,0	3592,0	1	0,000
Conversation	-0,02	0,0	0,3	1	,563
Mobile phone	0,02	0,1	0,2	1	,653
No distraction	0[a]				
(Scale)	,028[b]	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	3,38	0,1	895,8	1	0,000
Conversation	-0,13	0,2	0,7	1	,410
Mobile phone	-0,36	0,3	1,8	1	,185
No distraction	0[a]				
(Scale)	,357[b]	0,1			

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

Figure 5.51. GLM - Effect of distraction - Lateral position of the PD group



Parameter Estimates of the GLM
Dependent variable: Steering Angle Variability (degrees)
Model: (Intercept), Distractor

PD group

Rural Area

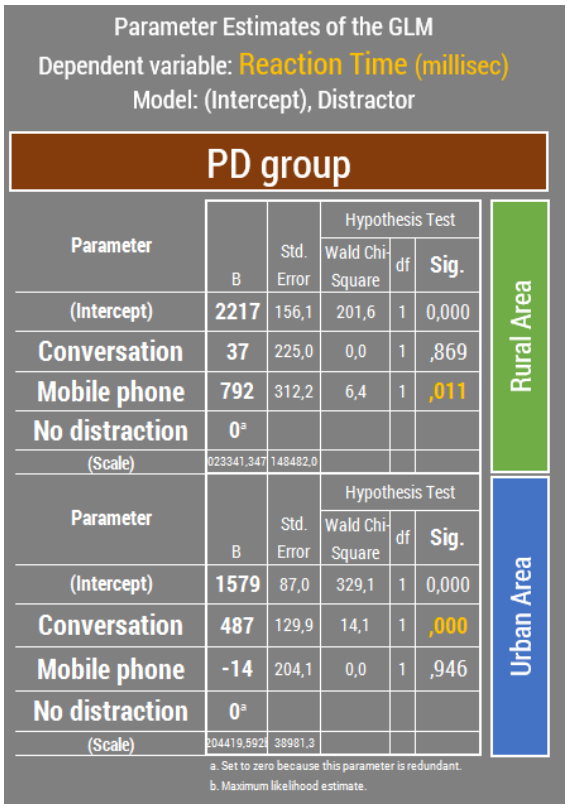
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	16,27	0,3	2277,6	1	0,000
Conversation	-0,11	0,5	0,0	1	,823
Mobile phone	-0,46	0,7	0,4	1	,510
No distraction	0[a]				
(Scale)	5,117[b]	0,7			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	21,67	0,9	646,9	1	0,000
Conversation	1,03	1,2	0,7	1	,393
Mobile phone	1,37	2,0	0,5	1	,501
No distraction	0[a]				
(Scale)	20,329[b]	3,7			

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

Figure 5.52. GLM - Effect of distraction - Steering angle variability of the PD group



Parameter Estimates of the GLM
Dependent variable: Reaction Time (millisec)
Model: (Intercept), Distractor

PD group

Rural Area

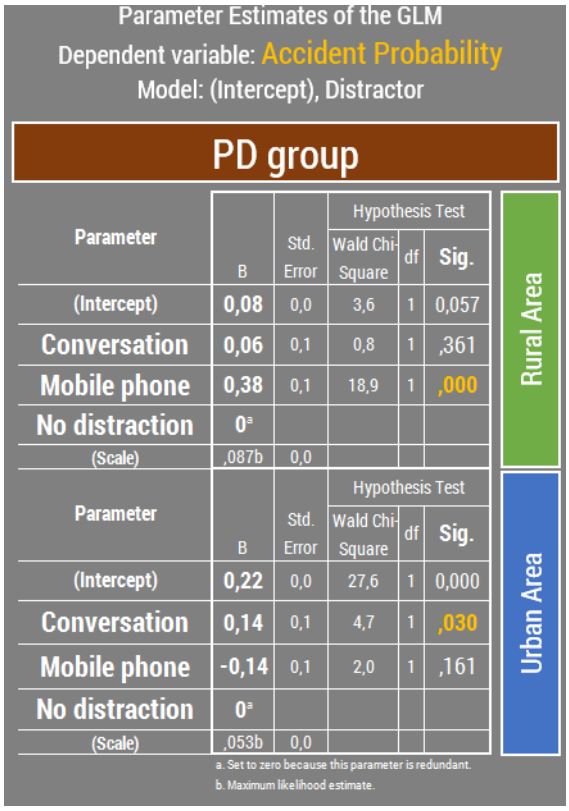
Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	2217	156,1	201,6	1	0,000
Conversation	37	225,0	0,0	1	,869
Mobile phone	792	312,2	6,4	1	,011
No distraction	0[a]				
(Scale)	023341,347	148482,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	1579	87,0	329,1	1	0,000
Conversation	487	129,9	14,1	1	,000
Mobile phone	-14	204,1	0,0	1	,946
No distraction	0[a]				
(Scale)	204419,592	38981,3			

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

Figure 5.53. GLM - Effect of distraction - Reaction time of the PD group



Parameter Estimates of the GLM
Dependent variable: Accident Probability
Model: (Intercept), Distractor

PD group

Rural Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,08	0,0	3,6	1	0,057
Conversation	0,06	0,1	0,8	1	,361
Mobile phone	0,38	0,1	18,9	1	,000
No distraction	0[a]				
(Scale)	,087b	0,0			

Urban Area

Parameter	B	Std. Error	Hypothesis Test: Wald Chi-Square	df	Sig.
(Intercept)	0,22	0,0	27,6	1	0,000
Conversation	0,14	0,1	4,7	1	,030
Mobile phone	-0,14	0,1	2,0	1	,161
No distraction	0[a]				
(Scale)	,053b	0,0			

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

Figure 5.54. GLM - Effect of distraction - Accident probability of the PD group

Investigating the **effect of distraction in the group of PD** significant differences were detected only in two variables, namely the reaction time and the accident probability; More specifically, PD patients in rural area when using the mobile phone while driving they have significantly larger reaction time and higher accident probability compared to the undistracted driving. Finally, in urban area, when conversing with passenger, they have significantly longer reaction time and higher accident probability compared to the undistracted driving, but not when using their mobile phone.

5.4. Principal Component Analysis

A distinct part of the analysis is devoted to the estimation of **driving performance and driving error factors** using the variables that are recorder from the driving simulator experiments, and the **neurological and the neuropsychological state** using the variables derived from the neurological and neuropsychological databases respectively.

In statistics, an exploratory **Principal Component Analysis** (PCA) is used in the early investigation of a set of multivariate data to determine whether the factor analysis model is useful in providing a parsimonious way of describing and accounting for the relationships between the observed variables. For the purpose of this study, this type of analysis will determine which observed variables are **most highly correlated** with the common factors and how many common factors are needed to give an adequate description of the data. As described in the database characteristics, the driving simulator dataset consists of different types of variables. In this dissertation, in the fourth step of the statistical analysis, PCA analysis is implemented aiming to estimate the key measures that underline driving performance, driving errors, neurological state and neuropsychological state.

In all PCA analyses a common method of varimax rotation was used. Varimax rotation is an orthogonal rotation of the factor axes to maximize the variance of the squared loadings of a factor (column) on all the variables (rows) in a factor matrix, which has the effect of differentiating the original variables by extracted factor.

5.4.1. Driving performance principal component analysis

Firstly, a PCA is performed to investigate which observed continuous variables from the driving simulator experiment are most correlated with the common factors that underline driving performance. In addition, it allows us to determine how many common factors are needed to obtain an adequate description of the data.

In this PCA analysis 21 variables are included in the driving simulator database under consideration. Table 5.5 presents a matrix of loadings for each of the variables. The factors presented in the Table indicate how much the variable explains its corresponding factor. It should be noted that small loadings (<0.500) are conventionally not printed (replaced by spaces), to draw attention to the pattern of the larger loadings. Moreover, all variables have been sorted regarding the loadings.

Table 5.5. Driving simulator variables PCA loadings

Driving Performance Variables (simulator)

Rotated Component Matrix[a]

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

	Factor 1	Factor 2	Factor 3
StdLateralPosition	**,923**		
TTLAverage	**,905**		
StdWheelAverage	**,900**		
WheelAverage	,845		
LateralPositionAverage	,835		
HWayAverage	-,738		
StdHWayAverage	-,708		
StdTTLAverage	,666		
StdTTCAverage	,631		
TTCAverage	,623		
BrakeAverage	,553		
StdBrakeAverage	,553		
AverageSpeed		**,776**	
TheadAverage		-,697	
RalphaAverage		,677	
StdRalphaAverage		,669	
StdevAverageSpeed		,637	
GearAverage			**,753**
StdGearAverage			,751
StdRpmAverage			,664
RpmAverage			,573

a. Rotation converged in 6 iterations.

Total Variance Explained

	Rotation Sums of Squared Loadings		
Component	1	2	3
Total	8,5	5,7	2,2
% of Variance	38,5	25,7	10,1
Cumulative %	38,5	64,2	74,3

Results from the first PCA analysis indicate that three factors are best fitted regarding this specific database extracted from the simulator experiment. These three factors represent 74.3% of the overall database.

Regarding the first factor (representing the 38.5% of the overall database), lateral position variability, time to line crossing and steering angle variability have the three highest loadings amongst all variables. This reveals that the first factor represents lateral control measures which indicates how well drivers maintain their vehicle position. In the

second factor (representing the 25.7% of the overall database), average speed has the highest loading indicating that the second factor represents the longitudinal measure of speed. In the third factor (representing the 10.1% of the overall database), average gear has the highest loading, and with the other three loadings of variability of gear use, rounds per minutes and variability of rounds per minute indicating that the third factor represents the use of the gearbox.

The present PCA analysis investigated which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the driving performance data extracted from the simulator experiment. In the next step, in order to implement structural equation models on the specific database only one latent variable will be developed to estimate the overall driving performance. The variables which are selected to be included in the latent analysis and underline the latent variable "driving performance" are **the three variables with the highest loadings of the first factor** which represents the 38,5% of the dataset (variability of the lateral position, time to line crossing and variability of the steering angle), and **the variables with the highest loadings of the next two factors** (average speed and average gear use) which represent 25,7% and 10,1% of the dataset respectively. Thus, the variable "driving performance" could be adequately described by the aforementioned 5 variables **covering the 74.3% of the driving simulator database**.

5.4.2. Driving errors principal component analysis

Driving error has long been a focus of road safety research. As a result, a range of methods have been developed to specifically measure this concept, including the Driver Behaviour Questionnaire (Reason, 1990). Estimates suggest that driving error is a causal factor in 75% (Hankey et al., 1999), and even up to 95% (Rumar, 1990) of road accidents and, thus, is a significant contributor to road accident.

The objective of this explanatory PCA on driving errors is to estimate which variables obtained from the driving simulator experiments have the bigger estimate on driving error. For this purpose, a PCA analysis was implemented in which six driving performance variables consisted the respective database. In Table 5.6 the loadings of the respective variables are recorded indicating how much each variable explains the factor. It should be noted that small loadings (<0.500) are conventionally not printed (replaced by spaces), since the focus is drawn to the pattern of the larger loadings.

Table 5.6. Driving error PCA loadings

Driving Errors Variables (simulator)

Rotated Component Matrix[a]

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

	Factor 1	Factor 2
HitOfSideBars	**,763**	
OutsideRoadLines	**,717**	
HighRoundsPerMinute	,550	
SuddenBrakes		**,706**
SpeedLimitViolation		**,679**
EngineStops		-,546

a. Rotation converged in 3 iterations.

Total Variance Explained

Rotation Sums of Squared Loadings		
Component	1	2
Total	2,1	1,2
% of Variance	35,6	20,8
Cumulative %	35,6	56,4

Results from the second PCA analysis indicate that two factors are best fitted regarding this specific database extracted from the simulator experiment. These two factors represent 56.4% of the overall database. Regarding the first factor (representing the 35.6% of the overall database), hits of sidebars and outside road lines have the two highest loadings amongst all variables. In the second factor (representing the 20.8% of the overall database), sudden brakes and speed limit violations have the two highest loadings.

The present PCA analysis investigated which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the driving errors data extracted from the simulator experiment. In the next step, in order to implement structural equation models on the specific database only one latent variable will be developed to estimate the overall driving errors. The variables which are selected to be included in the latent analysis and underline the latent variable "driving errors" are **the two variables with the highest loadings of the first factor** which represents the 35,6% of the dataset (hits of sidebars and outside road lines), and **the two variables with the highest loadings of the second factor** which represents the 20.8% of the dataset (sudden brakes and speed limit violations). Thus, the variable "driving errors" could be adequately described by the 4 aforementioned variables **covering the 56.4% of the database**.

5.4.3. Neurological assessment principal component analysis

The scope of the present PCA analysis is to explore the capacity of various neurologically-related measures to predict the driving behaviour of individuals with common neurological disorders, such as AD, PD and MCI. The neurologically-related measures that were elected as potential predictors of driving behaviour covered a broad range of areas that included measures of functionality, neuropsychiatric symptoms, depressive symptoms, disease severity, sleeping abnormalities and cognitive status. In this PCA analysis 19 variables extracted from the neurological assessment are under consideration. Table 5.7 presents a matrix of loadings for each of the variables. The factors presented in the Table indicate how much the variable explains its corresponding factor. It should be noted that small loadings (<0.500) are conventionally not printed (replaced by spaces), to draw attention to the pattern of the larger loadings. Moreover, all variables have been sorted regarding the loadings.

Table 5.7. Neurological PCA loadings

Neurological Variables

Rotated Component Matrix[a]

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
EvalF_Tapping_Errors	**,838**					
Evalsc_FBItot	,698					
Evalsc_CDRtot	,672					
Evalsc_NPItot	,649					
IADLBothGenders	,647					
Evalsc_MMSEtot	-,443					
EvalPHQ_Nine		**,865**				
Evalsc_GerDeprScale		,849				
EvalAthens_In_Scale		,656				
EvalTandemWalking_Errors			**,882**			
EvalTandemWalking_RNC_Errors			,859			
EvalTandemWalking_RNC_Time			,530			
EvalTandemWalking_Time				**,874**		
EvalR_P_Walk				,693		
EvalF_Tapping_Time				,591		
Evalsc_Hachinski_score					,771	
EvalEpworth_S_Sc					-,535	
EvalH_T_Rotation_Right						,816
EvalH_T_Rotation_Left						,607

a. Rotation converged in 11 iterations.

Total Variance Explained

	Rotation Sums of Squared Loadings					
Component	1	2	3	4	5	6
Total	3,1	2,7	2,5	1,9	1,7	1,6
% of Variance	16,3	14,2	13,3	9,8	9,1	8,6
Cumulative %	16,3	30,5	43,8	53,6	62,7	71,4

Results from the third PCA analysis indicate that six factors are best fitted regarding this specific database. These six factors represent 71.4% of the overall neurological database. Regarding the first factor (representing the 16.3% of the overall database), the variable "foot taping errors" has the highest loadings amongst all variables. In the second factor (representing the 14.2% of the overall database), patients health questionnaire 9 has the highest loadings amongst all variables. In the third and fourth factors (representing the 13.3% and 9.8% respectively of the overall database) tandem errors and tandem walking time have the highest loadings amongst all variables.

The present PCA analysis investigated which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the neurological state and the neurological data. In the next step, in order to implement structural equation models on the overall database, only one latent variable will be developed to estimate the overall neurological status. The variables which are selected to be included in the latent analysis and underline the latent variable "neurological state" are **the first variables with the highest loadings of the first four factors which represent the 53.6% of the dataset** (foot tapping errors, patients health questionnaire 9, tandem walking errors and tandem walking time). Thus, the variable "neurological state" could be adequately described by the aforementioned 4 variables covering the fields of emotional state and motor abilities: balance, movement coordination, mistakes and time of execution.

5.4.4. Neuropsychological assessment principal component analysis

The scope of the present PCA analysis is to explore the capacity of various neuropsychologically-related measures to predict the driving behaviour of individuals with common neurological disorders, such as AD, PD and MCI. The neuropsychologically-related measures that were elected as potential predictors of driving behaviour covered a broad range of areas that included measures of Verbal Memory and Learning, Verbal Working Memory, Visual Scanning/Memory and Learning, Spatial Memory and Learning, Visuospatial Perception, Visuospatial Working Memory, Constructional ability, Attention/Information Processing Speed/Perception, Selective and Divided Attention, Executive Functions, and Psychomotor vigilance.

In this PCA analysis 32 variables extracted from the neuropsychological assessment are under consideration. Table 5.8 presents a matrix of loadings for each of the variables. The factors presented in the Table indicate how much the variable explains its

corresponding factor. It should be noted that small loadings (<0.500) are conventionally not printed (replaced by spaces), to draw attention to the pattern of the larger loadings. Moreover, all variables have been sorted regarding the loadings.

Table 5.8. Neurological PCA loadings

Neuropsychological Variables

Rotated Component Matrix[a]

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
EvalCTMT_1	**-,805**				
EvalCTMT_3	-,794				
EvalCTMT_2	-,773				
EvalTMT_A	-,752				
EvalCTMT_4	-,743				
EvalVigilanceTest	-,717				
EvalUFV_2	-,651				
EvalCTMT_5	-,569				
EvalTMT_B	-,557				
Evalsc_Ver_Fluency_Letter	,542				
Evalsc_VER_FLUEN_ANIMALS	,524				
EvalUFV_3	-,503				
EvalBVMTTotal		**,850**			
EvalBVMT2Trial		,841			
EvalBVMT3Trial		,812			
EvalBVMT1Trial		,792			
EvalBVMTDelayed		,784			
EvalBVMTRI		,596			
EvalHopkinsRI			**,827**		
EvalHopkinsTotal			,760		
EvalHopkins2Trial			,749		
EvalHopkinsRecognition			,747		
EvalHopkinsDelayed			,724		
EvalHopkins3Trial			,721		
EvalHopkins1Trial			,668		
EvalEmbeddedTest				**,794**	
EvalSpatialSpan_For				,683	
EvalSpatialSpan_Back				,617	
EvalSDMT_Written				,559	
EvalSDMT_Oral				,555	
EvalSpatialAddition				,551	
EvalBVMTRecognition					,843

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 7 iterations.

Total Variance Explained

	Rotation Sums of Squared Loadings				
	1	2	3	4	5
Total	7,8	7,1	6,3	4,8	1,4
% of Variance	22,2	20,4	18,0	13,7	3,9
Cumulative %	22,2	42,6	60,5	74,3	78,2

Results from the fourth PCA analysis indicate that five factors are best fitted regarding this specific database. These five factors represent 78.2% of the overall neuropsychological database. Regarding the first factor (representing the 22.2% of the overall database), the variable "Comprehensive trail making test 1" has the highest loadings amongst all variables. In the second factor (representing the 20.4% of the overall database), brief visuospatial memory test has the highest loadings amongst all variables. In the third and fourth factors (representing the 18% and 13.7% respectively of the overall database) Hopkins verbal learning test - RI and Witkin's embedded figure test have the highest loadings amongst all variables.

The present PCA analysis investigated which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the cognitive functions and the neuropsychological data. In the next step, in order to implement structural equation models on the overall database, only one latent variable will be developed to estimate the overall neuropsychological status. The variables which are selected to be included in the latent analysis and underline the latent variable "neuropsychological state" are **the first variables with the highest loadings of the first four factors which represent the 74.3% of the dataset** (comprehensive trails making test, brief visuospatial memory test, Hopkins verbal learning test - RI, and Witkin's embedded figure test). Thus, the variable "neuropsychological state" could be adequately described by the aforementioned 4 variables covering the fields of verbal memory learning, spatial memory learning, processing speed, visual scanning and attention.

5.5. Structural Equation Modeling

For the purposes of this chapter which is the **core of the statistical modeling** of this PhD dissertation, the whole sample scheme was included in the analysis (Figure 5.55). **Four latent variables were developed** namely, "driving performance", "driving errors", "neurological state" and "neuropsychological state" in order to **implement four Structural Equation Models (SEMs)**. The four latent variables were developed using the most critical indexes (neurological,

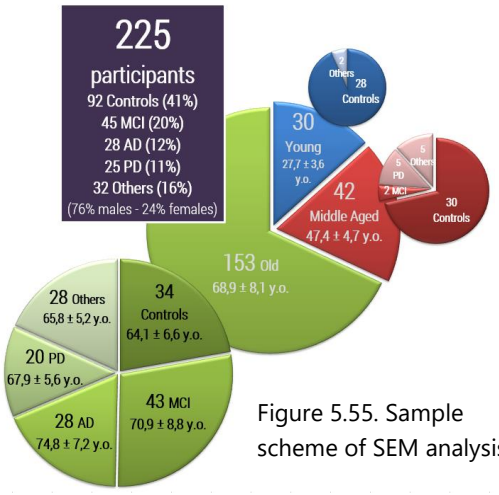


Figure 5.55. Sample scheme of SEM analysis

neuropsychological, and driving measures) extracted from the PCA analyses of the previous chapter and thoroughly discussed.

The exploratory PCA analysis was performed for investigating which driving simulator indexes had the most important contribution on explaining the higher order factor "**driving performance**" (Figure 5.56), and was described in the previous section. Based on the factor loadings that were extracted, the following five driving measures (out of a set of 21 variables assessing driving behaviour) had the highest loadings in their factors and were placed under the factor that was considered to reflect driving performance: **a) average speed, b) lateral position variability, c) steering angle variability, d) average gear, and e) time to line crossing,** covering the 74.3% of the driving simulator database.

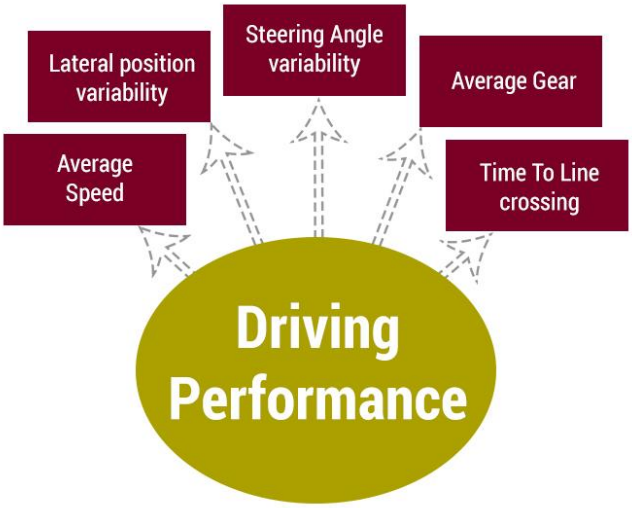


Figure 5.56. Latent variable - driving performance

In addition, an exploratory PCA analysis was performed for investigating which driving simulator indexes had the most important contribution on explaining the higher order factor "**driving errors**" (Figure 5.57). Based on the factor loadings that were extracted, the following four driving measures (out of a set of 6 variables assessing driving errors) had the highest loadings and were placed under the factor that was considered to reflect driving errors: **a) speed limit violations, b) hits of sidebars, c) outside road lines and d) sudden brakes,** covering the 56.4% of the database.

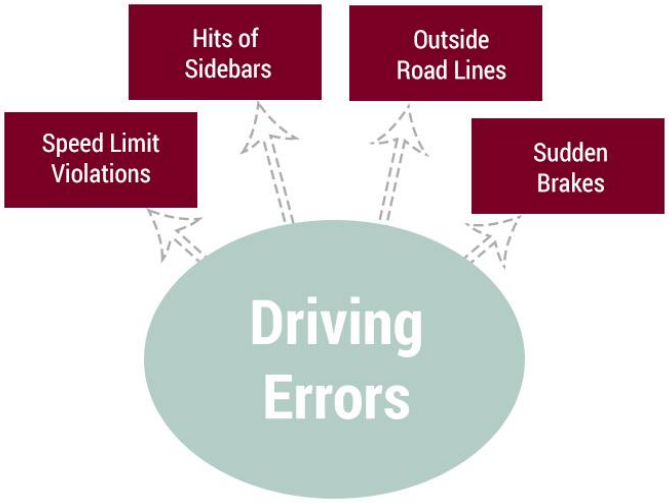


Figure 5.57. Latent variable - driving errors

Based on the same approach, exploratory PCA analysis was performed for investigating which neurological measures had the most important contribution on explaining the higher order factor "**neurological state**" (Figure 5.58). The factor loadings that were extracted, indicated that the four following neurological measures (out of a set of 19 neurological tasks) had the highest loadings in their factors and could describe sufficiently the factor that was considered to reflect neurological state: **a) Tandem Walking Errors, b) Tandem Walking Time, c) Patient Health Questionnaire (PHQ-9) and d) Foot Tapping Errors,** covering the 53.6% of the neurological database.

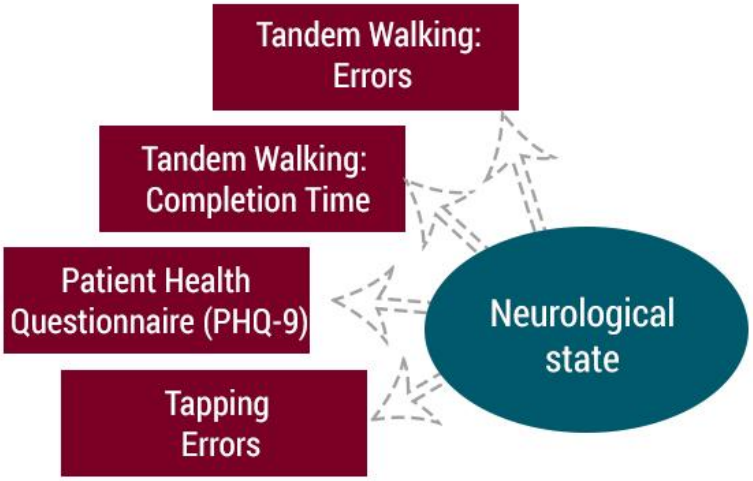


Figure 5.59. Latent variable - neurological state

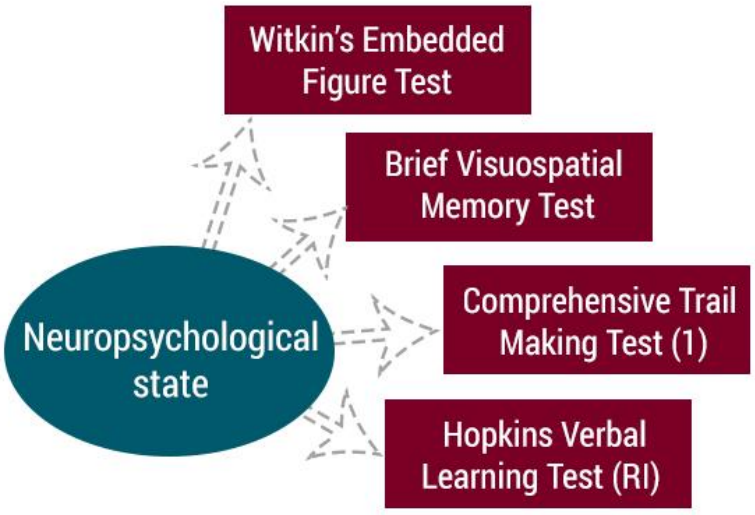


Figure 5.58. Latent variable - neuropsychological state

Finally, an exploratory PCA analysis was performed for investigating which neuropsychological tests assessing aspects of motor fitness had the most important contribution on explaining the higher order factor "**neuropsychological state**" (Figure 5.59). Based on the factor loadings that were extracted, the following four neuropsychological tests (out of a set of 32 variables assessing cognitive fitness) were placed under the factor that was considered to reflect neurological state: **a) Witkin's Embedded Figure Test, b) Brief Visuospatial Memory Test, c) Comprehensive Trail Making Test - 1, and d) Hopkins Verbal Learning Test,** covering the 74.3% of the neuropsychological database.

The **main statistical analysis contribution of this PhD dissertation is the implementation of the four SEMs**, since SEMs have never been utilized before in the scientific field of neurological diseases affecting cognitive functions and driving. SEMs allow both response and explanatory latent variables to be linked by a series of linear equations. The goal of structural equation models is used essentially in order to explain the correlations or covariances of the observed variables in terms of the relationships these variables have with the assumed underlying latent variables and the relationships postulated between the latent variables themselves.

In the first SEM, the objective is the quantification of the impact of neurological diseases affecting cognitive functions, distraction, age and road and traffic environment on the observed variable "**reaction time**". Additionally, the quantified impact of two latent variables regarding neurological state and neuropsychological state of the drivers on the observed variable "reaction time" is analyzed.

In the second SEM, the objective is the quantification of the impact of neurological diseases affecting cognitive functions, distraction, age and road and traffic environment on the observed variable "**accident probability**". Additionally, the quantified impact of two latent variables regarding neurological state and neuropsychological state of the drivers on the observed variable "accident probability" is analyzed.

In the third SEM, the key latent variable reflects the underlying "**driving errors**" and the objective is the quantification of the impact of neurological disease affecting cognitive functions, distraction, driver characteristics and road and traffic environment on driving errors. Additionally, the quantified impact of two latent variables regarding neurological state and neuropsychological state of the drivers on the latent variable "driving errors" is analyzed.

In the fourth SEM, the key latent variable reflects the underlying "**driving performance**" and the objective is the quantification of the impact of neurological disease affecting cognitive functions, distraction, driver characteristics and road and traffic environment on driving performance. Additionally, the quantified impact of two latent variables regarding neurological state and neuropsychological state of the drivers on the latent variable "driving performance" is analyzed.

The four different structural equation models are developed as described graphically in the next Figure (Figure 5.60) and explained below:

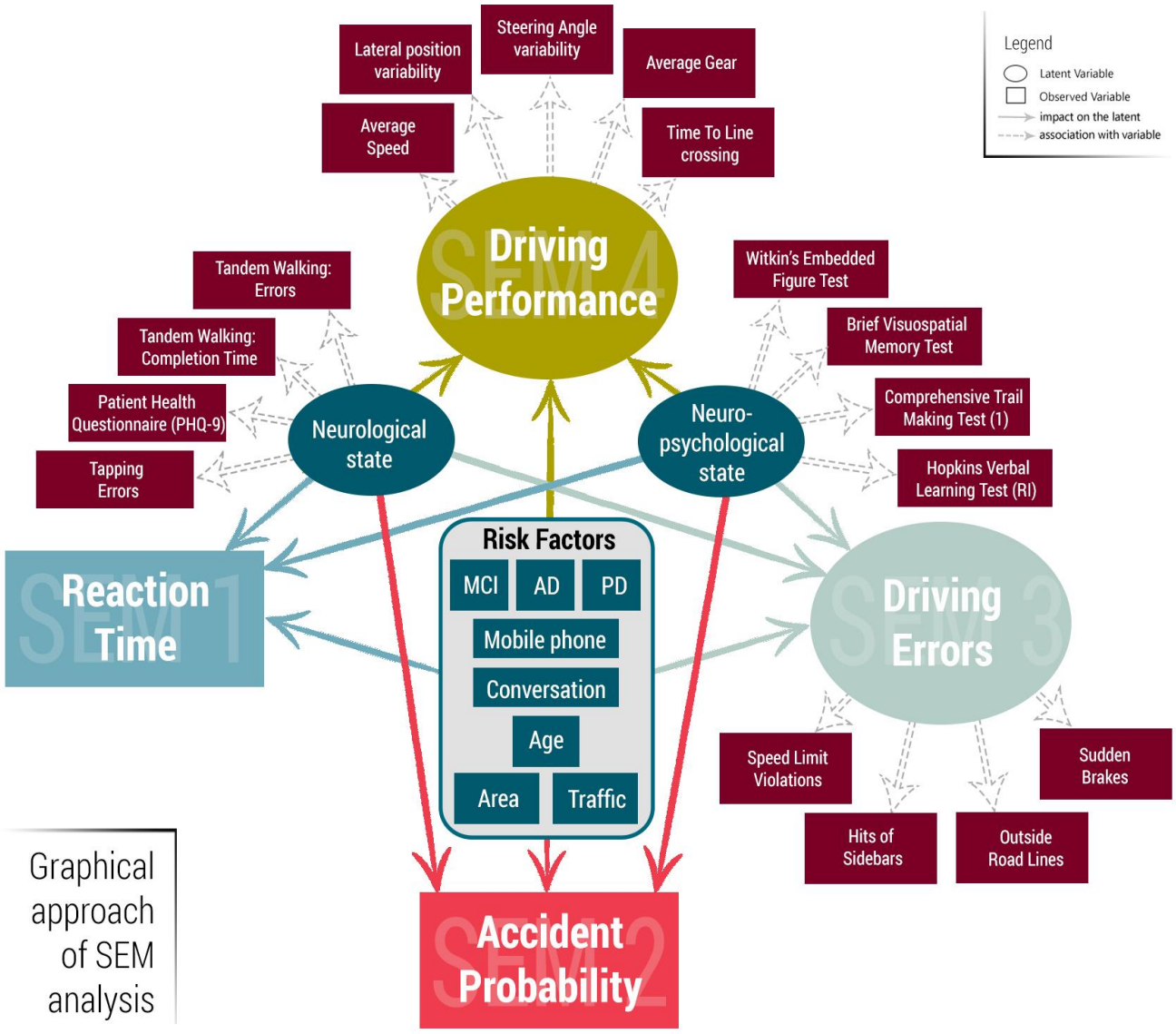


Figure 5.60. Structural Equation Models

The overall aim of the present analysis is to investigate all the critical factors that affect reaction time, accident probability, driving errors and driving performance. **The structure of the presentation for each individual SEM** is the following:

In the beginning, the description of the structural equation model is presented including all the variables in both steps of the model. This is followed by a first graphical approach, which helps to better understand the objective of this specific analysis. Then, a summary Table including all parameter estimates is presented. More specifically, in the upper part of the Table the variables that create the new latent (unobserved) variable are recorder with the respective parameters (estimate, Standard error, t-statistic, probability). In the

lower part of the Table, the second phase of the SEM is presented including the regression analysis parameter estimates.
In order to evaluate the overall suitability of the whole SEM four summary goodness-of-fit measures are reported:

» Standardized Root Average Square Residual (SRMR)
» Root Average Square Error of Approximation (RMSEA)
» Comparative Fit Index (CFI)
» Tucker Lewis Index (TLI)

All the goodness-of-fit measures were further analyzed in previous sections. It is noted that values of the SRMR range between zero and one, with well-fitting models having values less than 0.08. The appropriate acceptable cut-off point for the RMSEA has been a topic of debate, but in general it lies within 0.06 and 0.08, while 0.07 is often considered as having the general consensus. For the final two goodness of fit measures, the Comparative Fit Index (CFI) and the Tucker Lewis Index (TLI) values larger of 0.90 or even 0.95 are advised.

Then, the path diagram of the model is presented. Path analysis was introduced by Wright (1934) as a method for studying the direct and indirect effects of variables. The quintessential feature of path analysis is a diagram showing how a set of explanatory variables can influence a dependent variable under consideration. How the paths are drawn determines whether the explanatory variables are correlated causes, mediated causes, or independent causes.

It is worth mentioning that each latent variable is an unobserved variable that has no established unit of measurement. Therefore, in order to define the unit of measurement of each latent variable, a non-zero coefficient (usually one) is given to one of its observed variables as an indicator (i.e., reference variable). Finally, model results are discussed and specific conclusions are extracted regarding each Structural Equation Model.

5.5.1. SEM regarding reaction time

In the first SEM we explored the impact of various latent and observed variables on reaction time. More specifically, the objective is the quantification of the impact of neurological diseases affecting cognitive functions, distraction, age, road and traffic

environment, neurological state and neuropsychological state on the observed variable "**reaction time**" (Figure 5.61).

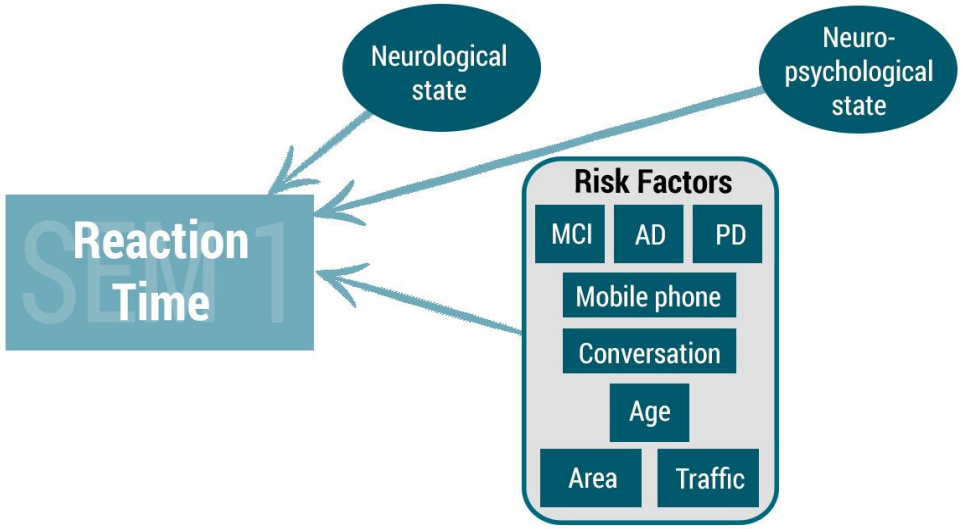


Figure 5.61. Structure of Reaction time SEM

After the initial SEM analysis approaches, the traffic flow was not found to affect significantly the dependent variable and for that reason this variable was eliminated from the final SEM. The following predictors were included in the analysis:

» **Disease - MCI**
  → drivers with Mild Cognitive Impairment
» **Disease - AD**
  → drivers with Alzheimer's disease
» **Disease - PD**
  → drivers with Parkinson's disease
» **Area - Urban**
  → an urban route at its bigger part dual carriageway, separated by guardrails, lane width is 3.5m, narrow sidewalks, commercial uses and parking are available at the roadsides
» **Age - Old**
  → (drivers older than 55 years of age)
» **Distraction - Conversation**
  → distraction task: conversation with passenger, while driving
» **Distraction - Mobile phone**
  → distraction task: conversation through a hand-held mobile phone, while driving
» **Neuropsychological state *(Latent)***
  » *Witkin's Embedded Figure Test*
  » *Brief Visuospatial Memory Test*
  » *Comprehensive Trail Making Test (1)*
  » *Hopkins Verbal Learning Test (RI)*
» **Neurological state *(Latent)***
  » *Tandem Walking: Errors*

- » *Tandem Walking: Completion Time*
- » *Patient Health Questionnaire (PHQ-9)*
- » *Foot taping errors*

The estimation results are presented in Table 5.9.

Table 5.9. Estimation results of the reaction time SEM

Latent variables	Est.	Std.err	Z-value	P(>|z|)
Neuropsychological State *(latent 1)*				
Witkin's Embedded Figure Test	1.000			
Brief Visuospatial Memory Test	1.962	0.048	40.927	**<.001**
Comprehensive Trail Making Test (1)	-6.752	0.405	-16.685	**<.001**
Hopkins Verbal Learning Test (RI)	0.415	0.020	20.818	**<.001**
Neurological State *(latent 2)*				
Tandem Walking: Errors	1.000			
Tandem Walking: Completion Time	5.557	0.873	6.364	**<.001**
Patient Health Questionnaire (PHQ-9)	9.956	2.416	4.120	**<.001**
Foot taping errors	0.829	0.170	4.885	**<.001**

Regressions	Est.	Std.err	Z-value	P(>|z|)
Reaction Time				
Disease - MCI	103.575	52.205	1.984	**.047**
Disease - AD	327.075	87.927	3.492	**<.001**
Disease - PD	381.056	88.544	4.304	**<.001**
Urban Area	-345.309	33.260	-10.382	**<.001**
Advanced Age	190.137	43.877	4.333	**<.001**
Distraction - Conversation	80.614	37.769	2.134	**.033**
Distraction - Mobile Phone	225.921	54.088	4.177	**<.001**
Neuropsychological State *(latent)*	-20.899	6.464	-3.233	**<.001**
Neurological State *(latent)*	-789.943	226.670	-3.485	**<.001**

Summary statistics	ML
Minimum Function Test Statistic	1928.87
Degrees of freedom	81

Goodness of fit	
SRMR	0.138
RMSEA	0.132
CFI	0.722
TLI	0.702

A critical finding that supports the validity of the overall SEM is that the contribution of the observed variables on the construction of the latent variables (neuropsychological state and neurological state) was in all cases statistically significant. Also, regarding the regression analysis, all predictors had a significant contribution on the prediction of the reaction time. Finally, the obtained goodness-of-fit measures are generally close to the respective limits.

In this SEM, reaction time is the dependent observed variable while the independent variables include a diagnosis of a cerebral disorder (AD, PD or MCI), neuropsychological state, neurological state, driver distraction, area type, and drivers' age. Regarding the effect of cerebral disorders on reaction time, it was found that the presence of MCI, AD or PD had a significant negative impact on reaction time. Concerning the effect of age, young and middle-aged drivers were found to outperformed older drivers in term of reaction time.

Moreover, neuropsychological state and neurological state that are commonly impaired in patients with cerebral disorders had a significant unique contribution on predicting better reaction times. Regarding the effect of in-vehicle distraction, both distractors were found to have a statistically significant negative effect on reaction time. Finally, regarding area and traffic characteristics, the results indicate that area type is a critical factor affecting drivers' reaction time as in urban areas reaction time was significantly affected in a positive way. On the other hand, traffic conditions didn't appear to influence reaction time significantly.

The respective path diagram of the SEM is presented in Figure 5.62. Blue lines express a significant impact on better reaction time, red lines express a significant impact on worse reaction time and grey lines express the absence of a statistically significant association (grey lines correspond to variables that are not included in the model). Furthermore, dashed lines indicate which variables create the latent ones, while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the parameter estimates.

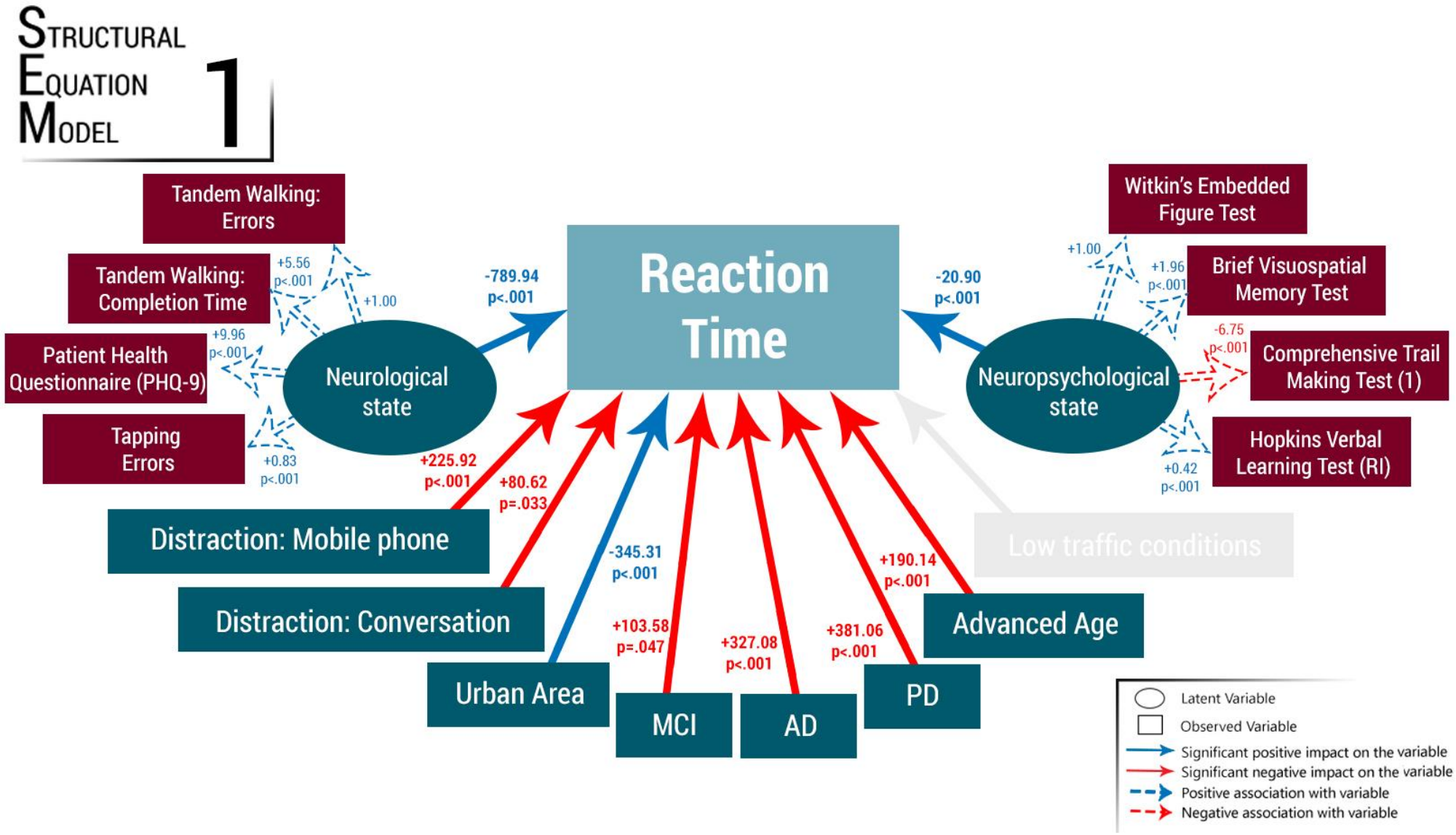


Figure 5.62. Path diagram of the reaction time SEM

5.5.2. SEM regarding accident probability

In the second SEM we explored the impact of various latent and observed variables on accident probability. More specifically, the objective is the quantification of the impact of neurological diseases affecting cognitive functions, distraction, age, road and traffic environment, neurological state and neuropsychological state on the observed variable "**accident probability**" (Figure 5.63).

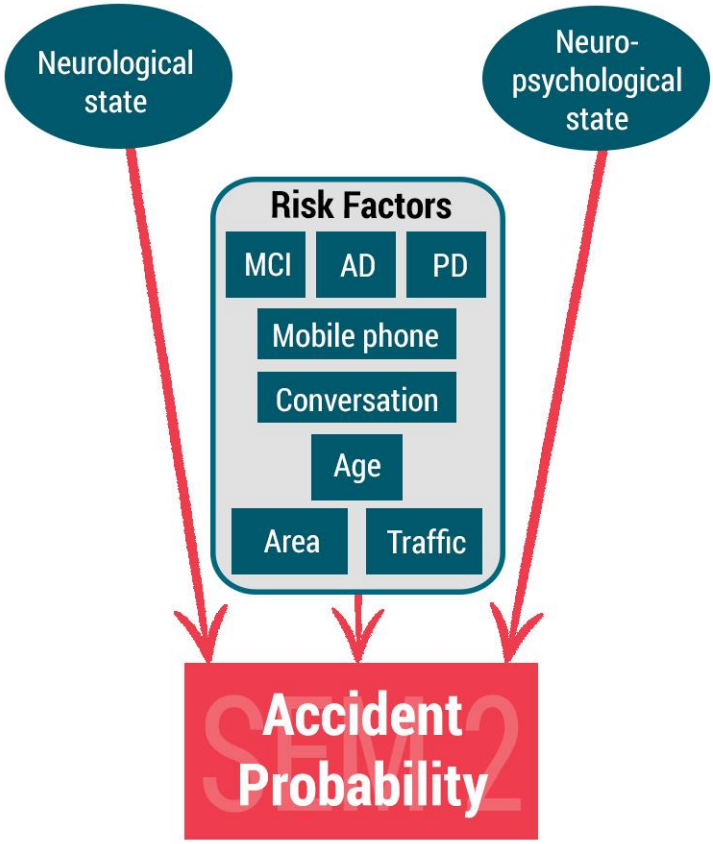


Figure 5.63. Structure of Accident Probability SEM

After the initial SEM analysis approaches, the distractor "conversation with passenger", the traffic flow, the presence of MCI, the age and the latent variable "neurological state" were not found to affect significantly the dependent variable and for that reason they were eliminated from the final SEM. The following predictors were included in the analysis:

- **Disease - AD**
- **Disease - PD**
- **Area - Urban**
- **Distraction - Mobile phone**
- **Neuropsychological state *(Latent)***
  - *Witkin's Embedded Figure Test*

- *Brief Visuospatial Memory Test*
- *Comprehensive Trail Making Test (1)*
- *Hopkins Verbal Learning Test (RI)*

The estimation results are presented in Table 5.10.

Table 5.10. Estimation results of the accident probability SEM

Latent variables	Est.	Std.err	Z-value	P(>|z|)
Neuropsychological State *(latent 1)*				
Witkin's Embedded Figure Test	1.000			
Brief Visuospatial Memory Test	1.989	0.047	42.238	**<.001**
Comprehensive Trail Making Test (1)	-7.022	0.375	-18.740	**<.001**
Hopkins Verbal Learning Test (RI)	0.421	0.018	23.199	**<.001**

Regressions	Est.	Std.err	Z-value	P(>|z|)
Accident Probability				
Disease - AD	0.162	0.062	2.146	**.032**
Disease - PD	0.104	0.060	2.017	**.041**
Urban Area	-0.063	0.027	-2.306	**.021**
Distraction - Mobile Phone	0.054	0.036	1.909	**.049**
Neuropsychological State *(latent)*	-0.023	0.004	-5.612	**<.001**

Summary statistics	ML
Minimum Function Test Statistic	711.78
Degrees of freedom	21

Goodness of fit	
SRMR	0.125
RMSEA	0.135
CFI	0.699
TLI	0.659

A critical finding that supports the validity of the overall SEM is that the contribution of the observed variables on the construction of the neuropsychological state was statistically significant. Regarding the regression analysis, 5 predictors had a significant contribution on the prediction of the accident probability. The neurological state didn't have a critical contribution on the dependent variable of accident probability and for that reason it was eliminated from the model. Finally, the obtained goodness-of-fit measures are in general terms close to the respective limits.

In this SEM, accident probability is the dependent observed variable while the independent variables include a diagnosis of a cerebral disorder (AD and PD), neuropsychological state, driver distraction through mobile phone, and area type. Regarding the effect of cerebral disorders on accident probability, it was found that the presence of AD or PD had a significant negative impact on accident probability (no significant effect was found for the group of MCI). Concerning the effect of age, young and middle-aged drivers were not found to have any significant difference with the older drivers concerning the accident probability.

Moreover, neuropsychological state (but not neurological state) that are commonly impaired in patients with cerebral disorders had a significant unique contribution on predicting lower accident probability. Regarding the effect of in-vehicle distraction, although conversation with passenger didn't have any significant influence on accident probability, the mobile phone use appeared to have a negative impact on having more accidents.

Finally, regarding traffic and area characteristics, the results indicate that traffic volume is not a critical factor affecting drivers' accident probability as in low traffic volumes the accident probability wasn't significantly affected. On the other hand, it seems that the rural area lead to more addidents than urban area.

The respective path diagram of the SEM is presented in Figure 5.64. Blue lines express a significant positive impact on accident probability (lower accident probability), red lines express a significant negative impact on accident probability (higher accident probability) and grey lines express the absence of a statistically significant association (grey lines correspond to variables that are not included in the model). Furthermore, dashed lines indicate which variables create the latent ones, while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the parameter estimates.

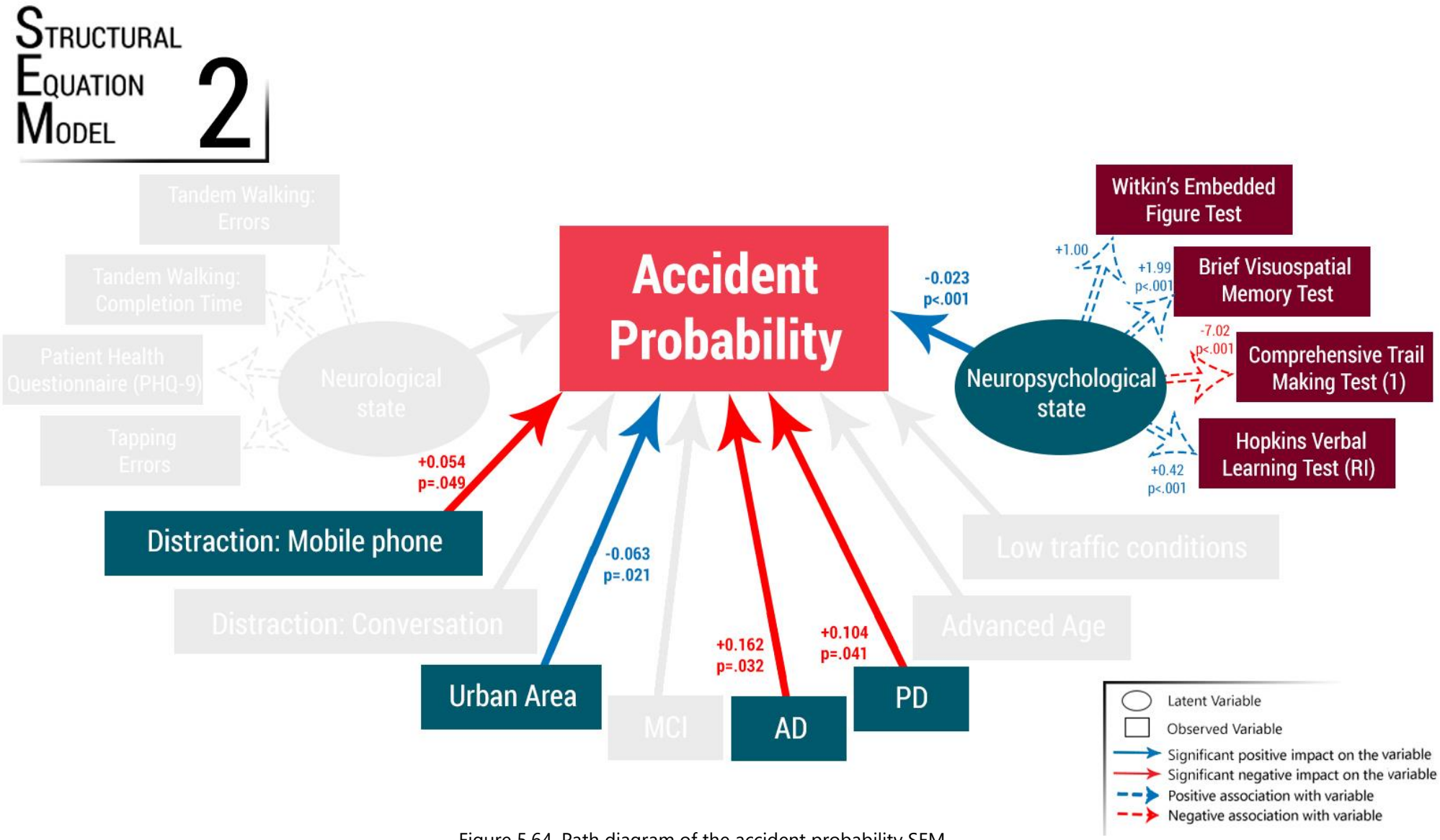


Figure 5.64. Path diagram of the accident probability SEM

5.5.3. SEM regarding driving errors

As presented in the methodological chapter, several driving measures exist for the evaluation of driving errors, the selection of which should be guided by a number of general rules related to the nature of the task examined as well as the specific research questions. In this section, latent variable "driving errors" is defined as a new, unobserved variable, within the framework of latent analysis. Consequently, the effect of cerebral disorders such as AD, PD or MCI, as well as the role of in vehicle distraction (conversation with passenger or conversation through mobile phone), traffic load (low traffic volume or high traffic volume), road environment (rural area or urban area) and the age of the participants, is estimated directly on the latent variable "driving errors" (instead of being estimated on individual driving error measures) (Figure 5.65).

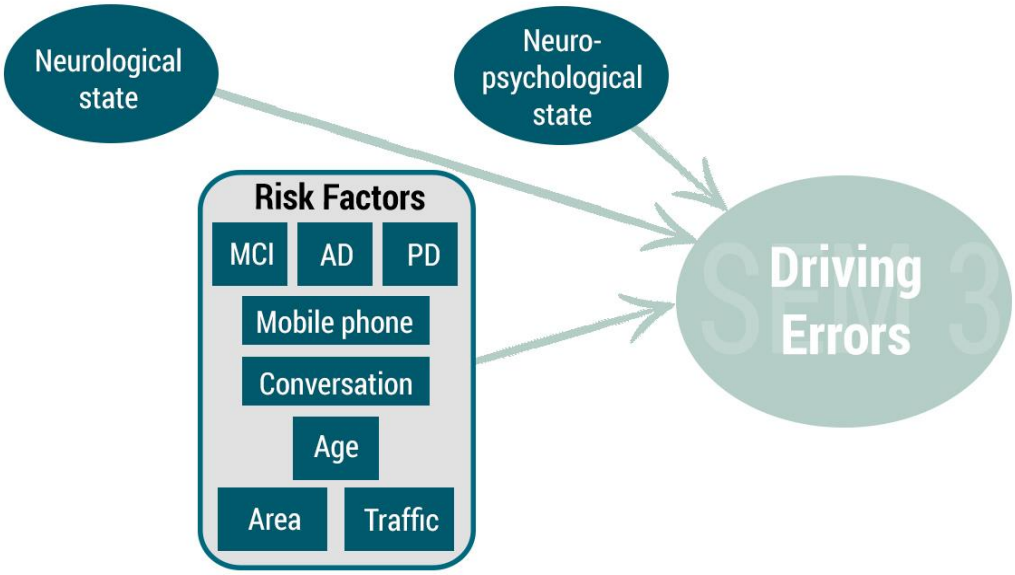


Figure 5.65. Structure of Driving Errors SEM

More specifically, in this third SEM the latent variable reflects the underlying driving errors of the participants and is based on driving errors variables extracted from the PCA analysis of the previous section:

» **Speed limit violations**
→ how many times per trial, the driver extended the speed limit

» **Hits of sidebars**
→ how many times per trial, the vehicle hit the sidebars in the right

» **Outside road lines**
→ how many times per trial, the vehicle crossed over road lines

» **Sudden brakes**
→ how many times per trial, the driver suddenly used the brake for no reason

In the second part of the SEM, driving errors is the dependent variable while the independent variables include a broad set of predictors. After the initial SEM analysis approaches, distractor "conversation with passenger", distractor "mobile phone", the traffic flow, and the presence of all three examined neurological diseases affecting cognitive functions, were not found to affect significantly the dependent variable and for that reason they were eliminated from the final SEM. The following predictors were included in the analysis:

- **Area - Urban**
- **Age - Old**
- **Neuropsychological state *(Latent)***
  - *Witkin's Embedded Figure Test*
  - *Brief Visuospatial Memory Test*
  - *Comprehensive Trail Making Test (1)*
  - *Hopkins Verbal Learning Test (RI)*
- **Neurological state *(Latent)***
  - *Tandem Walking: Errors*
  - *Tandem Walking: Completion Time*
  - *Patient Health Questionnaire (PHQ-9)*
  - *Foot taping errors*

The estimation results are presented in Table 5.11.

Table 5.11. Estimation results of the driving errors SEM

Latent variables	Est.	Std.err	Z-value	P(>|z|)
Driving Errors *(latent 1)*				
Speed Limit Violations	1.000			
Hits of Sidebars	1.000	0.421	2.374	**.018**
Outside Road Lines	0.059	0.034	1.961	**.048**
Sudden Brakes	7.731	2.339	3.306	**<.001**
Neuropsychological State *(latent 2)*				
Witkin's Embedded Figure Test	1.000			
Brief Visuospatial Memory Test	1.955	0.046	42.238	**<.001**
Comprehensive Trail Making Test (1)	-6.799	0.391	-17.385	**<.001**
Hopkins Verbal Learning Test (RI)	0.416	0.019	21.553	**<.001**
Neurological State *(latent 3)*				
Tandem Walking: Errors	1.000			
Tandem Walking: Completion Time	5.537	0.875	6.326	**<.001**
Patient Health Questionnaire (PHQ-9)	9.128	2.127	4.292	**<.001**

Foot taping errors	0.748	0.144	5.191	**<.001**

Regressions	Est.	Std.err	Z-value	P(>|z|)
Driving Errors				
Urban Area	-0.027	0.015	-1.960	**.047**
Advanced Age	0.106	0.033	3.230	**<.001**
Neuropsychological State *(latent)*	-0,005	0.002	-2.236	**.025**
Neurological State *(latent)*	-0.113	0.064	-1.992	**.048**

Summary statistics	ML
Minimum Function Test Statistic	1445.72
Degrees of freedom	73

Goodness of fit	
SRMR	0.118
RMSEA	0.125
CFI	0.720
TLI	0.669

A critical finding that supports the validity of the overall SEM is that the contribution of the observed variables on the construction of the latent variables (driving errors, neuropsychological state and neurological state) was in all cases statistically significant. Also, regarding the regression analysis, only four predictors had a significant contribution on the prediction of the latent variable "driving errors". Finally, the obtained goodness-of-fit measures are generally close to the respective limits.

In the first part of the model, increased driving errors (the latent variable) are positively associated with hits of sidebars, outside road lines, and high rounds per minute. It should be kept in mind that the selected driving errors measures which create the latent variable have the highest loadings in the respective explanatory factor analysis presented in the previous section.

In the second part of the SEM, "driving errors" is the dependent variable. Regarding the effect of cerebral disorders on driving errors, it was found that the presence of MCI, or AD, or PD is not significantly associated with driving errors. The two latent variables namely the neurological state and the neuropsychological state, as predictors, appeared to reduce, in a significant way, the driving errors. Regarding the effect of in-vehicle distraction, none of the two distractors was found to have a statistically significant effect on driving errors. Finally, regarding area and traffic characteristics, the results indicate that area type is a critical factor affecting drivers' errors as in the urban area driving

errors were less comon than in the rural driving environment. Age also influence driving errors since advanced age was associated with increased amount of driving errors. Finally, traffic volume didn't have an impact on driving errors.

The respective path diagram of the SEM is presented in Figure 5.66. Blue lines express a significant impact on reducing driving errors, red lines express a significant impact on increasing driving errors and grey lines express the absence of a statistically significant association (grey lines correspond to variables that are not included in the model). Furthermore, dashed lines indicate which variables create the latent ones (first part of the SEM), while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the parameter estimates.

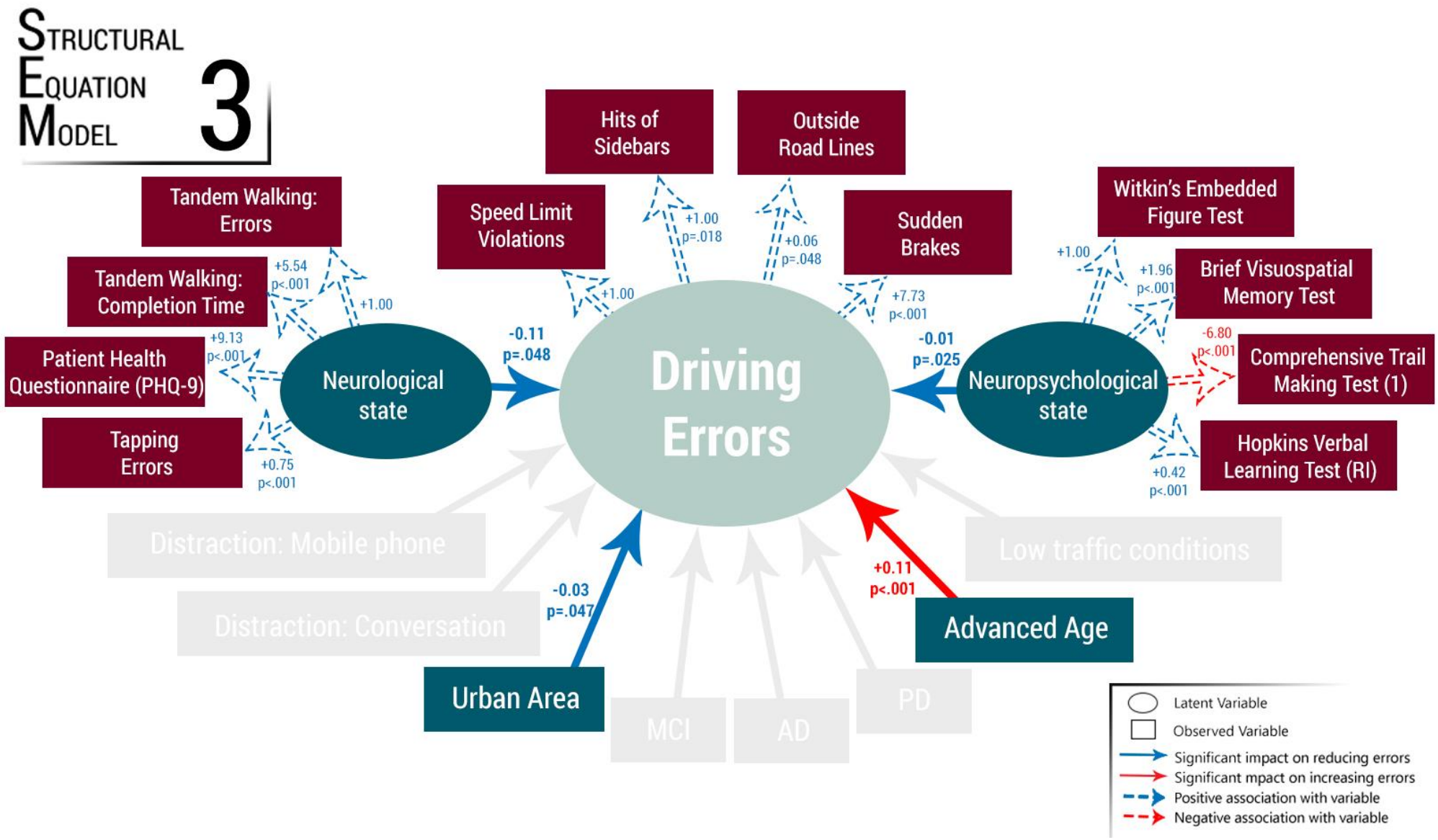


Figure 5.66. Path diagram of the driving errors SEM

5.5.4. SEM regarding driving performance

As presented in the methodological chapter, several driving performance measures exist for the evaluation of driving performance, the selection of which should be guided by a number of general rules related to the nature of the task examined as well as the specific research questions. In this section, driving performance is defined as a new, unobserved variable, within the framework of latent analysis. Consequently, the effect of cerebral disorders such as AD, PD or MCI, as well as the role of in vehicle distraction (conversation with passenger or conversation through mobile phone), traffic load (low traffic volume or high traffic volume), road environment (rural area or urban area) and the age of the participants, is estimated directly on driving performance (instead of being estimated on individual driving performance measures) (Figure 5.67).

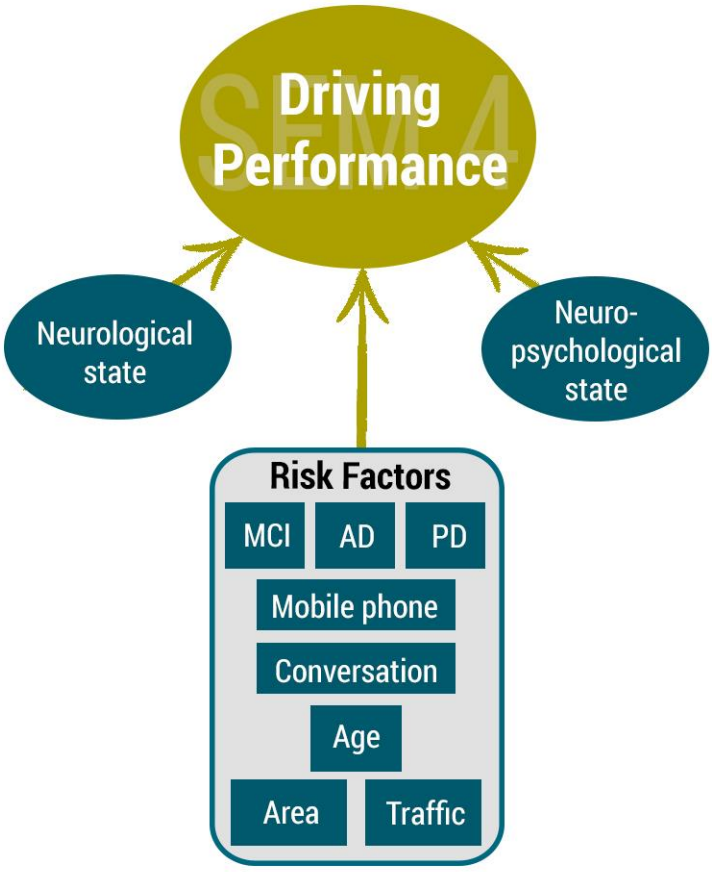


Figure 5.67. Structure of Driving Performance SEM

More specifically, in this first SEM the latent variable reflects the underlying driving performance of the participants and is based on driving performance variables extracted from the factor analysis of the previous section:

» **Average Speed**

→ refers to the mean speed, in km/hr, of the driver along the route, excluding the

small sections in which incidents occurred, and excluding junction areas

» **Lateral Position Variability**
→ refers to the variability (standard deviation) of the lateral position of the vehicle

» **Steering Angle Variability**
→ refers to the variability (standard deviation) of the mean steering angle during the driving in degrees

» **Average Gear**
→ refers to the average chosen gear (0 = idle, 6 = reverse) of the simulator gear-box along the driving route

» **Time to Line Crossing**
→ refers to the time to line crossing, time until the road border line is exceeded, in seconds

In the second part of the SEM, driving performance is the dependent variable while the independent variables include a broad set of predictors. After the initial SEM analysis approaches, distractor "conversation with passenger", was not found to affect significantly the dependent variable and for that reason it was eliminated from the final SEM. The following predictors were included in the analysis:

» **Distraction - Mobile phone**
» **Area - Urban**
» **Traffic - Low**
» **Disease - AD**
» **Disease - PD**
» **Disease - MCI**
» **Age - Old**
» **Neuropsychological state *(Latent)***
  » *Witkin's Embedded Figure Test*
  » *Brief Visuospatial Memory Test*
  » *Comprehensive Trail Making Test (1)*
  » *Hopkins Verbal Learning Test (RI)*
» **Neurological state *(Latent)***
  » *Tandem Walking: Errors*
  » *Tandem Walking: Completion Time*
  » *Patient Health Questionnaire (PHQ-9)*
  » *Foot taping errors*

The estimation results are presented in Table 5.12.

Table 5.12. Estimation results of the driving performance SEM

Latent variables	Est.	Std.err	Z-value	P(>|z|)
Driving Performance *(latent 1)*				
Average Speed	1.000			
Lateral Position Variability	-0.098	0.003	-29.483	**<.001**
Steering Angle Variability	-0.373	0.028	-13.303	**<.001**
Time to Line Crossing	-12.102	0.483	-25.039	**<.001**
Average Gear	0.049	0.002	29.762	**<.001**
Neuropsychological State *(latent 2)*				
Witkin's Embedded Figure Test	1.000			
Brief Visuospatial Memory Test	1.962	0.047	41.964	**<.001**
Comprehensive Trail Making Test (1)	-6.803	0.390	-17.430	**<.001**
Hopkins Verbal Learning Test (RI)	0.416	0.019	21.553	**<.001**
Neurological State *(latent 3)*				
Tandem Walking: Errors	1.000			
Tandem Walking: Completion Time	5.777	0.937	6.166	**<.001**
Patient Health Questionnaire (PHQ-9)	9.101	2.077	4.382	**<.001**
Foot taping errors	0.721	0.134	5.363	**<.001**

Regressions	Est.	Std.err	Z-value	P(>|z|)
Driving Performance				
Disease - MCI	-0.772	0.267	-2.889	**.004**
Disease - AD	-1.066	0.329	-3.237	**<.001**
Disease - PD	-0.705	0.336	-2.100	**.036**
Urban Area	-13.902	0.390	-35.638	**<.001**
Low Traffic Conditions	0.414	0.185	2.245	**.025**
Advanced Age	-1.296	0.235	-5.521	**<.001**
Distraction - Mobile Phone	-0.604	0.223	-2.701	**.007**
Neuropsychological State *(latent)*	0.082	0.026	3.174	**.002**
Neurological State *(latent)*	3.765	0.871	4.320	**<.001**

Summary statistics	ML
Minimum Function Test Statistic	3517.01
Degrees of freedom	146

Goodness of fit	
SRMR	0.122
RMSEA	0.124
CFI	0.755
TLI	0.700

A critical finding that supports the validity of the overall SEM is that the contribution of the observed variables on the construction of the latent variables (driving performance, neuropsychological state and neurological state) was in all cases statistically significant. Also, regarding the regression analysis, all predictors had a significant contribution on the prediction of the latent variable "driving performance". Finally, the obtained goodness-of-fit measures are generally close to the respective limits.

In the first part of the model, driving performance (the latent variable) is positively associated with average speed and average gear and negatively associated with time to line crossing and lateral position variability. It should be kept in mind that the selected driving performance measures which create the latent variable have the highest loadings in the respective explanatory PCA analysis presented in the previous section.

In the second part of the SEM, driving performance is the dependent variable while the independent variables include a diagnosis of a cerebral disorder (AD, PD or MCI), neuropsychological state, neurological state, driver distraction, area type, traffic volume as well as drivers' age. Regarding the effect of cerebral disorders on driving performance, it was found that the presence of MCI, or AD, or PD has a significant negative impact on driving performance. Concerning the effect of age, young and middle-aged drivers were found to outperformed older drivers in term of driving performance.

Moreover, neuropsychological state and neurological state that are commonly impaired in patients with cerebral disorders had a significant unique positive contribution on predicting driving performance. Regarding the effect of in-vehicle distraction, conversation with the passenger was not found to have a statistically significant effect indicating that drivers do not change their driving behaviour while conversing with a passenger compared to undistracted driving. On the other hand, the hand-held mobile phone use had a significant negative association with driving performance. Finally, regarding area and traffic characteristics, the results indicate that area type is a critical factor affecting drivers' performance as in urban areas driving performance was significantly affected in a negative way. Traffic conditions also influence driving performance since the presence of a low traffic volume had a significant positive association with driving performance.

The respective path diagram of the SEM is presented in Figure 5.68. Blue lines express a significant positive impact on driving performance, red lines express a significant

negative one and grey lines express the absence of a statistically significant association (grey lines correspond to variables that are not included in the model). Furthermore, dashed lines indicate which variables create the latent ones (first part of the SEM), while continuous lines indicate which variables exist in the regression part of the SEM. Finally the label values represent the parameter estimates.

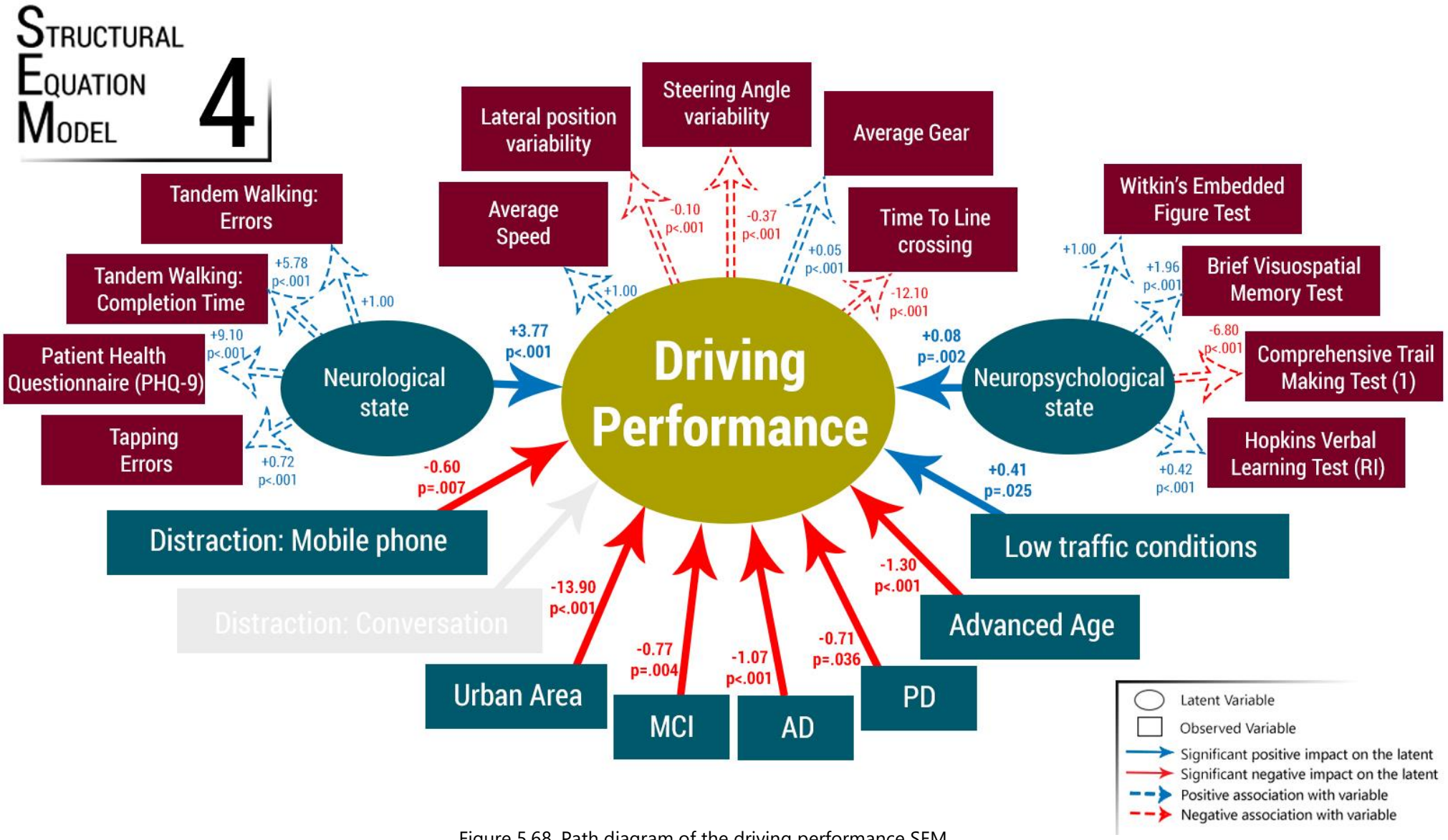


Figure 5.68. Path diagram of the driving performance SEM

5.6. Discussion

In chapter 5 an **innovating statistical analysis** methodology has been developed and presented in order to investigate all the critical parameters that affect driving behaviour and especially reaction time, accident probability, driving performance and driving errors in the final statistical step. The developed methodology consisted of **five individual analyses**:

1. Descriptive analysis
2. Analysis of variance
3. Regression analysis
4. Principal Component Analysis
5. Structural Equation Model analysis

All different statistical analyses provide remarkable findings for this PhD dissertation research, which will be discussed thoroughly in the following sub-chapters.

5.6.1. Discussion of descriptive statistics

Within the framework of **descriptive statistics**, **126 boxplots were developed** correlating mean speed, time headway, lateral position, steering angle variability, reaction time at unexpected incidents, accident probability, and driving errors, with traffic volume, driving area, regarding age and cerebral disease of the participants. The basic conclusions of the descriptive analysis of the large database are presented below.

For the purposes of this first analysis, the control group was isolated and **the effect of age was examined** regarding several critical driving performance measures, in rural and urban areas, low and high traffic volumes, in no distraction condition. The sample scheme was divided in three categories of healthy participants with no brain pathology: 28 Young, 30 Middle Aged, and 34 Older drivers. Several interesting results were extracted from the 28 boxplots of this analysis are the following.

In both rural and urban driving areas the advanced age led to **lower mean driving speeds** - old group had the lowest mean speed in every examined condition, a finding that highlights the conservative driving attitude of older drivers and probable self-regulation. In urban area drivers of all ages were slower than in rural roads. As expected, older drivers in high traffic volume had larger time headways than middle aged and especially young participants who kept at least 15% shorter headways than the other two groups in all driving conditions.

Moving on to the lateral control measures, older drivers **tended to place the vehicle more closely to the right border** of the road, whereas young drivers tend to place the vehicle more closely to the left as expected taking into account their driving aggressiveness compared to the older drivers who tend to be more conservative. Older drivers had little variability in wheeling angle that they used during driving, except for the urban area in low traffic road condition, but more importantly they had **much longer reaction times** than the other two groups (at least 20% larger reaction times in all examined conditions).

Regarding the accident probability, in rural area and in low traffic condition young drivers had an **accident probability of more than 20%**. In urban area though, older drivers appeared to have the higher accident probability in both traffic environments. Finally, regarding driving errors of healthy participants in no distraction condition, it is observed that except rural area and high traffic condition, in all other conditions all control drivers have the same results.

For the purposes of the second part of the descriptive analysis, the "old" group was isolated and **the effect of neurological disease affecting cognitive functions** was examined regarding several critical driving performance measures, in rural and urban areas and low and high traffic volumes. The sample scheme was divided in four categories: 34 Healthy Controls, 43 MCI, 28 AD and 20 PD drivers. Furthermore, the **effect of the in-vehicle distraction** was examined. Thus, there are three distraction conditions: no distraction, conversation with passenger, and conversation through hand-held mobile phone. Several interesting results were extracted from the 84 boxplots of this analysis are the following.

Firstly, all three cerebral pathologies examined led to **lower driving speeds in all examined conditions,** which is in line with the literature (Eby et al., 2012; Uc et al., 2006). Especially, AD group had the lowest mean speeds among the other participants in almost every condition. They also had at least 20% lower speed compared to their healthy controls counterparts. The in-vehicle distraction and the traffic volume appeared to have no effect in mean speed of all examined groups, while the urban area leads to lower speeds for all participants. Additionally, all groups of patients kept larger headways compared to healthy controls, especially for the AD participants who kept the largest headways among all four groups, which was expected as they have the lowest mean speeds.

The **mobile phone use led to larger headways** for the AD group, whereas the other three groups seem to stay unaffected by the distraction conditions regarding the headway they keep. Alongside, the high traffic volume had an obvious impact on headways of all participants. It is notable that urban area, which constitutes a more complex environment, led to lower headways for all examined groups by at least 35%.

As the **lateral measures** are concerned, in rural road, the AD group, in distraction condition of mobile phone tended to move the vehicle more closely to the left border of the lane and at the same time in rural road all patients seemed to have lower variability of their wheeling angle, whereas in urban area this difference was not so pronounced. AD group, in urban area, with low traffic volume, when using the mobile phone had higher variability in steering angle, which means that this group had difficulties on this driving condition.

Regarding the reaction time, **healthy controls had the best reaction times** overall in rural area, whereas AD and PD groups had the worst reaction times (more than 40% worse reaction times than the control group). But even worse the mobile phone use had a significant negative effect on reaction time for AD and PD groups. AD participants seem to have the worst reaction times in urban area. Conversing with passenger, though, didn't appear to have an important effect on reaction time in all examined groups.

Moving on to accident probability, it is observed that, overall, healthy control drivers had a small accident probability compared to the group of patients in both rural and urban driving environments. It is easily detectable that AD drivers had, in all conditions, the higher accident probability, and especially when conversing on the mobile phone, although at the same time, in their everyday lives, they haven't been involved in an accident during the last two years (as self-reported). In that case their accident probability is climbing to more than 60%, which is an impressive finding. PD participants had also a significantly higher accident probability when using the mobile phone. In rural road environment, conversation with passenger didn't increase the possibility of causing an accident for all examined groups. In urban area the differences between the groups are approximately the same with the rural area. Controls had the lowest accident probability overall and conversation with passenger didn't seem to have any impact on it. Finally, traffic volume, has a little impact on reaction times of all examined groups.

Finally, **regarding the driving errors**, namely the hits of sidebars, the speed limit violations and the outside road lines, in general terms, patients with MCI, AD or PD

seemed to make the same or even less driving errors than healthy controls. High traffic volume leads to more mistakes for all participants, as it is a more complex environment. AD group in rural area seem to get affected by the mobile phone distraction condition and, compared to the undistracted condition, they make more than double driving errors.

The third and final descriptive analysis aimed to **compare the individual driving performance measures of patients of MCI, AD and PD** to the typical values of healthy controls and identify the patients who deviate significantly from the general population, regarding their driving performance and safety measures. The sample scheme used was the same with the previous chapter (125 older drivers). For each driver, the following driving performance measures were calculated and examined: a) mean speed, b) mean speed variability, c) time headway, d) time headway variability, e) lateral position, f) lateral position variability, and g) reaction time at incidents. All these driving indexes **were compared to the range of "typical" values of the respective distribution of healthy drivers:** control groups' mean values minus one standard deviation and plus one standard deviation include 68.26% of the values of healthy controls (according to the normal distribution). For the purpose of this study, this area was defined by our research team as the "typical area". The individual driving indexes of all participants with cerebral diseases were compared to the "typical area" of the control group, in rural and urban driving environments.

Highlighting the most important results, regarding the mean speed of the PD and AD group, **only the 35% of these drivers were inside the "typical area"**. Moreover, in line with the previous analyses, patients had significantly lower speed variability (43% of the cases) than the group of controls. Comparing the 3 groups of patients, it seemed that group of MCI drove slightly faster than the other 2 groups of patients. The low mean speed of the group of patients and the low variability of the mean speed, indicates conservative driving behaviour and sometimes self-regulation of their driving behaviour caused by the self-awareness of their degraded driving performance. Overall, 40% of drivers with neurological diseases affecting cognitive functions were out of the "typical area", regarding the lateral position of the vehicle. Also, more than 25% of patients had very large variability in their lateral position (above the upper limit). 30% of the AD group particular group had extremely high lateral position variability, despite the fact that the lane was narrow in this area. It seems that **the more complex the driving environment is, the more the patients have difficulty** in maintaining the position of the vehicle in

the lane. Thus, the variability of the lateral position is considered to be a critical driving performance index.

Analyzing the reaction times of the patients at unexpected incidents, it was observed that participants with neurological diseases affecting cognitive functions **had significantly higher reaction times** in both rural and urban areas in comparison to the control group. Compared with each other, drivers with MCI seemed to have slightly better reaction times than the groups of AD and PD in most cases. It was impressive that in rural area 70% of the patients with neurological diseases affecting cognitive functions had reaction times larger than 2 seconds, and no patient was below the lower limit of the "typical area", whereas 42% of participants with AD or PD were above the upper limit of the "typical area" in both rural and urban driving environments. All these very large reaction times, are findings of great significance if we take into consideration the low mean speeds and low variabilities of the mean speeds that the groups of patients had. The fact that these "not typical" findings that concern reaction time, are combined with "not typical" indexes in the other driving performance measures is of great significance.

In conclusion, the **take-home message of the current analysis** is that quite a large number of the drivers with neurological diseases affecting cognitive functions had serious individual difficulties in their driving performance in comparison with the healthy controls and their driving indexes deviated significantly from the "typical area" of the healthy controls regarding several driving indexes. This finding is of critical importance regarding road safety.

5.6.2. Discussion of ANOVA results

Two analyses of variance (ANOVA) were extracted regarding identification of significant differences in the driving performance indexes extracted from the driving simulator assessment and in the answers extracted from the behaviour questionnaires, between two groups: groups of healthy controls and patients with neurological diseases affecting cognitive functions. The first analysis of variance indicated that the presence of a neurological disease affecting cognitive functions was found **to significantly affect in both road environments**: mean speed, mean speed variability, time headway, time to collision variability, and reaction time. The two examined groups had **statistically significant differences in rural area in**: time to line crossing and time to collision. The two examined groups had **statistically significant differences in urban area in**: steering angle variability and in accident probability.

Moving on to the next ANOVA regarding questionnaire about the driving habits and the driving behaviour, ANOVA indicated several interesting results in which patients with neurological diseases affecting cognitive functions have statistically significant differences in their answers compared to the healthy control group. Drivers with MCI reduce their driving frequency at a faster rate that cognitively intact individuals and they avoid difficult driving situation in a similar patterns as patients diagnosed with dementia (O' Connor 2010; 2013, Keay et al., 2009) and this was revealed by this analysis of this PhD thesis as well. The take-home message of the current analysis is that **drivers with brain pathologies are aware of their deterioration of their driving performance**, and they try to compensate their driving behaviour by either conservative driving, or even they avoid driving. This findings about compensatory mechanisms are quite interesting, as in the literature at least for the AD patients this was not so clear so far. Moreover, patients with neurological diseases affective cognitive functions consider in-vehicle distraction as quite dangerous and taking into account that they are aware about their cognitive decline, they avoid such driving conditions or they follow compensatory patterns.

5.6.3. Discussion of regression results

Within the framework of the regression analyses the effect of the neurological diseases affecting cognitive functions (MCI, AD and PD) on driving performance measures and the effect of the in-vehicle distraction on patients with the examined brain pathologies were examined and several significant results were extracted.

5.6.3.1. Undistracted driving of participants with MCI, AD and PD

For the purposes of this analysis, the "old" group (125 participants) was isolated and the effect of neurological disease affecting cognitive functions is examined regarding several critical driving performance measures, in rural and urban areas and low and high traffic volumes. The sample scheme was divided in four categories: 34 Healthy Controls, 43 MCI, 28 AD and 20 PD drivers. Only undistracted driving is under examination within the framework of this analysis regarding the following driving performance measures: Mean speed, Time headway, Lateral position, Steering angle variability, Reaction time, Accident probability, and Driving errors. Table 5.13 summarizes the results of the **28 regression analyses (GLMs) regarding the effect of MCI, AD and PD on driving performance** measures.

Table 5.13. Results of the GLMs regarding the effect of MCI, AD and PD on driving performance measures

MCI, AD and PD drivers compared to healthy controls			
	Rural	**Urban**	**Comment**
Mean speed	↓	↓	**Lower speed for all groups of patients in all examined contitions**
Time headway	↑	–	**Larger headways for AD and PD group in rural area**
Lateral position	–	→	**More closely to the right border for the MCI group in urban road**
Steering angle variability	↓	–	**Lower variability in steering angle for the PD group in rural area in high traffic**
Reaction time	↑	↑	**Larger reaction times for all groups of patients in all examined contitions**
Accident probability	↑	↑	**Higher accident probability for the AD group in all examined conditions and for the MCI and PD groups in urban area**
Driving errors	–	–	**No significant differences**

Summarizing the results, all three groups of patients were found to drive at significantly lower speeds compared to the healthy control group drivers in rural and urban roads, both at low and 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 in rural roads, but only for AD and PD groups, however in urban environment there were not statistically significant differences.

Analyzing the lateral control measures it was observed that patients with MCI drove more closely to the right border of the road in urban area and in both traffic volumes. Regarding the variability of this measure, in rural area, PD group had low steering variability in high traffic volume that was a result of their low speed, their conservative driving and maybe this is a compensatory behaviour.

Investigating the reaction time of the patients at unexpected incidents, it was observed that drivers with neurological diseases affecting cognitive functions had significantly larger reaction times in all examined conditions compared with the cognitively intact group. More specifically, their reaction times were more than 40% worse than that of the control group. Overall, MCI drivers seemed to have slightly better reaction times than the AD and PD groups in all cases. Moving on to the accident probability, higher accident probability was detected for the AD group in all examined conditions and for the MCI and PD groups only in urban area, although at the same time, in their everyday lives, they haven't been involved in an accident during the last two years (as self-reported). On the other hand patients and controls had not differences in the driving errors they made during the driving session at the driving simulator experiment.

Overall, among the 3 examined groups of patients with neurological diseases affecting cognitive functions, MCI group presented a better driving profile in terms of driving behaviour and road safety, in line with the literature which indicates that MCI patients may experience an increased level of driving difficulties in comparison to their healthy counterparts without, however, being characterized as unsafe drivers (Fritteli et al., 2009; Kawano, et al., 2012; Olsen et al., 2014). Taking into account that the literature investigating driving performance in the MCI population is relatively sparse (O' Connor et al, 2010), the results of this PhD dissertation regarding the MCI population are considerable but should be considered with caution, as MCI patients presented significant difficulties and differences with the healthy control group but not at the same extend as the other two examined groups of patients (AD and PD).

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 thesis as well, as PD drivers had significant differences with the healthy control group of similar demographic characteristics. An individual approach would be ideal for this population as there are many PD drivers who are able to drive.

Regarding the AD group, it could be classified as the worse examined group in terms of road safety and driving behaviour by this PhD dissertation regression analyses, as it had significant differences with their healthy control counterparts in almost every driving measure examined. This was in line with the international literature which connects them with a significant risk to individual and public road safety (Man-Song-Hing et al., 2007; Reger et al., 2004; Lincoln et al., 2009). However, not all AD patients are incapable of driving, especially in the earlier stages of the disease (Perkinson et al., 2005, Trobe et al.,

1995; Carr et al., 2000; Brown & Ott, 2004; Ernst et al., 2010; Withaar et al., 2000) and this was concluded as well by the individual assessment within the framework of this PhD dissertation, which indicated that some AD patients were inside the "typical area" and didn't have significant differences with the control group.

This analysis further demonstrates how the progression of the disease (i.e. from MCI to AD) leads to more pronounced driving impairments in several longitudinal or lateral control measures. While the reduced mean speed, the increased headways and the driving closer to the right road border may be considered beneficial for road safety, as **they reflect a more conservative and cautious driving pattern**, the results regarding reaction time clearly suggest that this driving pattern is not adequate for safe driving. In fact, reaction time at unexpected incidents is significantly impaired for MCI drivers, and even more impaired for AD and PD drivers, especially in unfamiliar driving environments. According to the literature, drivers with MCI maintain a good level of self-awareness as regards driving ability (Okonkwo, 2009), although self-awareness of deficits in MCI patients is controversial (paper accepted for publication, Fragkiadaki et al., 2016). Nonetheless, little is known about self-awareness of patients with AD or PD.

Furthermore, there is clear indication for increasing difficulties in maintaining lane position when cognitive impairment increases and when driving conditions are more demanding. On the basis of the above, it is suggested that the examined cognitive impairments result in driving impairments based on two mechanisms (see Figure 5.69):

» **Development of compensatory driving behaviour**, due to drivers' awareness of own deficits, expressed by reduced speed, increased headways, more conservative vehicle positioning (and as a consequence less manoeuvre and overtaking);

» **Driving impairments related to the disease itself**, due to the decline in various cognitive domains, including neurological state, attention, perception, psychomotor speed and general executive functions, expressed by increased reaction times at incidents, increased steering or lane positioning variability etc.

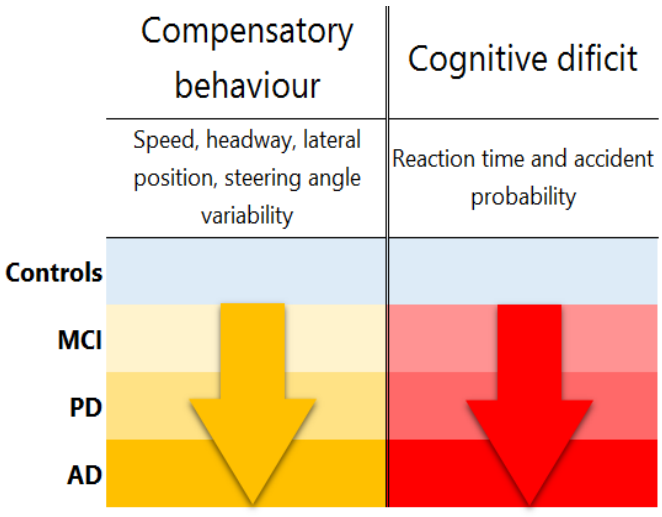


Figure 5.69. Mechanism of cognitively impaired driving

The results of this research suggest that **the latter mechanism is prominent, and the compensatory behaviour of the first mechanism is not sufficient to counterbalance the driving deficits due to cognitive impairments.**

5.6.3.2. Effect of distraction on participants with MCI, AD and PD

Moving towards, the goal of the following regression models is the analysis of the impact of in-vehicle distraction on the driving behaviour of drivers suffering a brain pathology such that of MCI, AD or PD. The sample scheme was divided in four categories of similar demographics: 34 Healthy Controls, 43 MCI, 28 AD and 20 PD drivers. No distraction condition, conversation with passenger and conversation through handheld mobile phone are examined within the framework of this regression analysis regarding the following driving performance measures in rural and urban areas: Mean speed, Time headway, Lateral position, Steering angle variability, Reaction time and Accident probability. Table 5.14 summarizes the results of the next **42 regression analyses (GLMs) regarding the effect of distraction on driving performance of patients** with MCI, AD and PD and controls.

Table 5.14. Results of the GLMs regarding the effect of distraction on driving performance of patients with MCI, AD and PD

MCI, AD and PD drivers compared to their undistracted driving			
	Conversation with passenger	**Mobile phone use**	**Comment**
Mean speed	—	↓	**Lower speed for MCI group in rural road when using mobile phone**
Time headway	—	↑	**Larger headway for MCI group in rural road when using mobile phone**
Lateral position	—	←	**More closely to the left border of the road for the AD group in rural road when using mobile phone**
Steering angle variability	—	—	**No significant impact of distraction in any group**
Reaction time	↑	↑	**Larger reaction time for all groups in all conditions when using mobile phone and for the MCI and PD groups when conversing with passenger in urban road**
Accident probability	↑	↑	**Higher accident probability for all groups in all conditions when using mobile phone and for the MCI and PD groups when conversing with passenger in urban road**

This analysis focused on the effect of distraction on the driving behaviour of patients with neurological diseases affecting cognitive functions, by exploring three distraction conditions, namely driving without distraction, driving while conversing with a co-passenger and driving while conversing through a handheld mobile phone. The **use of mobile phone had the most pronounced negative effect on the driving behaviour of individuals with neurological diseases affecting cognitive functions** as compared to a group of cognitively intact individuals of similar demographics.

Overall, it appears that the distraction conditions don't have such a significant impact on several driving performance measures in the group of controls, in contrast with the findings extracted from the **patients' groups regression analyses in whom the impact of distraction and especially the mobile phone use, was detrimental**.

In particular, the reaction time in unexpected incidents of drivers with brain pathologies increased on more than 30% under the driving condition with the use of mobile phone whereas in the group of cognitively intact drivers the equivalent increase was only 13%. Moreover, the group of drivers with neurological diseases affecting cognitive functions had a striking increase of the risk of being engaged in a car accident when using a mobile phone.

Notably, the aforementioned pattern of findings was observed despite the fact that the drivers with neurological diseases affecting cognitive functions tried to adjust their driving behaviour by reducing at an important extent their driving speed and time headway when using a mobile phone. Also, **the presence of a conversation with a passenger had an impact on the driving performance of the patients, but of a smaller magnitude** as compared to the case of the mobile phone. In particular, under the specific driving condition there was an accentuation of the difference on reaction time and accident probability between group of patients and cognitive intact individuals, but only for the MCI and the PD groups in urban area. Overall, the conversation with passenger didn't seem to have a detrimental effect on the majority of the examined conditions. However the groups of patients self-reported, at the questionnaire assessment, that they consider conversation with passenger as a quite dangerous action and they avoid doing so.

The driving profile of individuals with neurological diseases affecting cognitive functions according to these results **changed radically under the more demanding driving condition that included the use of a hand-held mobile phone**. The detection of this

strong adverse effect of the mobile phone on the driving fitness of individuals with MCI could be explained by their reduced cognitive resources (Aggarwal et al., 2005, Bennett et al., 2002), especially during the performance of divided attention procedures (Okonkwo et al., 2008). Following this perspective, it is suggested that the parallel execution of two tasks, namely of driving and using a hand-held mobile phone, placed the group of drivers with cerebral diseases in a particularly vulnerable position due to the need to effectively divide their attention under this demanding driving condition.

In line with this approach, the driving condition with conversation, that is of intermediate difficulty and also requires by the drivers to divide their attention at a certain level, had an increased negative effect on the driving performance of individuals with AD or PD, but of a smaller extent as compared to the case of the mobile phone. Notably, in the driving condition with the mobile phone, the drivers with MCI, AD and PD **applied again the compensatory strategy** of reducing their speed but in this case the outcome was not successful, as indicated by the pronounced increase of their reaction time and accident risk.

5.6.4. Discussion of PCA results

In the third part of the overall statistical methodology the implementation of **four PCA analyses** was taking place in order to investigate which observed variables are most highly correlated with the common factors of driving performance, driving error, neurological state and neuropsychological state and how many common factors are needed to give an adequate description of the data.

Results from the **driving performance PCA analysis** (including 21 variables extracted from the simulator experiment) indicate that three factors are best fitted regarding this specific database extracted from the simulator experiment (representing 74.3% of the overall database). Regarding the first factor (representing the 38.5% of the overall database), lateral position variability, time to line crossing and steering angle variability have the three highest loadings amongst all variables. This reveals that the first factor represents lateral control measures which indicates how well drivers maintain their vehicle position. In the second factor (representing the 25.7% of the overall database), average speed has the highest loading indicating that the second factor represents the longitudinal measure of speed. In the third factor (representing the 10.1% of the overall database), average gear has the highest loading, and with the other three loadings of

variability of gear use, rounds per minutes and variability of rounds per minute indicating that the third factor represents the use of the gearbox.

Results from the **driving errors PCA analysis** (including 6 variables regarding driving errors from the simulator experiment) indicate that two factors are best fitted regarding this specific database extracted from the simulator experiment. These two factors represent 56.4% of the overall database. Regarding the first factor (representing the 35.6% of the overall database), hits of sidebars and outside road lines have the two highest loadings amongst all variables. In the second factor (representing the 20.8% of the overall database), sudden brakes and speed limit violations have the two highest loadings.

Results from the **neurological PCA analysis** (including 19 variables extracted from the neurological assessment) indicate that six factors are best fitted regarding this specific database. These six factors represent 71.4% of the overall neurological database. Regarding the first factor (representing the 16.3% of the overall database), the variable "foot taping errors" has the highest loadings amongst all variables. In the second factor (representing the 14.2% of the overall database), patients health questionnaire 9 has the highest loadings amongst all variables. In the third and fourth factors (representing the 13.3% and 9.8% respectively of the overall database) tandem errors and tandem walking time have the highest loadings amongst all variables.

Results from the **neuropsychological PCA analysis** (including 32 variables extracted from the neuropsychological assessment) indicate that five factors are best fitted regarding this specific database. These five factors represent 78.2% of the overall neuropsychological database. Regarding the first factor (representing the 22.2% of the overall database), the variable "Comprehensive trail making test 1" has the highest loadings amongst all variables. In the second factor (representing the 20.4% of the overall database), brief visuospatial memory test has the highest loadings amongst all variables. In the third and fourth factors (representing the 18% and 13.7% respectively of the overall database) Hopkin's verbal learning test - RI and Witkin's embedded figure test have the highest loadings amongst all variables.

5.6.5. SEMs discussion

Within the framework of latent analysis, four **Structural Equation Models** were implemented aiming to investigate the impact of common neurological diseases affecting cognitive functions (AD, PD and MCI), on "reaction time", "accident risk", "driving performance" (latent), and "driving errors" (latent). Also, through this analysis, the role of additional potential predictors of driving behaviour was explored. In particular, the following variables were included as well, as predictors in the current analysis:

» Distraction - Mobile phone
» Distraction - Conversation
» Area Type (Urban/Rural)
» Traffic Volume (Low/High)
» Age (≥55 years old/<55 years old)
» Neurological state (latent)
» Neuropsychological state (latent)

For this purpose four latent variables were constructed, namely "driving performance", "driving errors", "neurological state" and "neuropsychological state".

The variables which are selected to be included in the **latent analysis and underline the latent variable "driving performance"** are the three variables with the highest loadings of the first factor which represents the 38,5% of the dataset (variability of the lateral position, time to line crossing and variability of the steering angle), and the variables with the highest loadings of the next two factors (average speed and average gear use) which represent 25,7% and 10,1% of the dataset respectively. Thus, the variable "driving performance" could be adequately described by the aforementioned 5 variables covering the 74.3% of the driving simulator database.

The variables which are selected to be included in the **latent analysis and underline the latent variable "driving errors"** are the two variables with the highest loadings of the first factor which represents the 35.6% of the dataset (hits of sidebars and outside road lines), and the two variables with the highest loadings of the second factor which represents the 20.8% of the dataset (sudden brakes and speed limit violations). Thus, the variable "driving errors" could be adequately described by the 4 aforementioned variables covering the 56.4% of the database.

The variables which are selected to be included in the **latent analysis and underline the latent variable "neurological state"** are the first variables with the highest loadings of the first four factors which represent the 53.6% of the dataset (foot tapping errors, patients' health questionnaire 9, tandem walking errors and tandem walking time). Thus, the variable "neurological state" could be adequately described by the aforementioned 4 variables covering the fields of emotional state and motor abilities: balance, movement coordination, mistakes and time of execution.

The variables which are selected to be included in the **latent analysis and underline the latent variable "neuropsychological state"** are the first variables with the highest loadings of the first four factors which represent the 74.3% of the dataset (comprehensive trails making test, brief visuospatial memory test, Hopkins verbal learning test - RI, and Witkin's embedded figure test). Thus, the variable "neuropsychological state" could be adequately described by the aforementioned 4 variables covering the fields of verbal memory learning, spatial memory learning, processing speed, visual scanning and attention.

Several interesting results were extracted by the implementation of the 4 SEM analyses. Firstly, **regarding neurological diseases affecting cognitive functions** drivers with MCI, AD or PD (as compared with cognitively intact individuals of similar demographics) were associated with significantly lower levels of the latent variable "driving performance" that reflected a broad range of driving indexes and were associated with significantly worse "reaction time". Also, the clinical conditions of AD and PD were associated with a negative impact on accident risk. Finally, none of the clinical groups showed a significantly increased amount of driving errors.

The findings about the **AD and the PD patients were in the expected direction** and are in line with previous research that indicates impairments in driving performance of the two clinical groups both in the case of driving simulator experiments and on-road evaluations (Dubinsky et al., 1991; Man-Son-Hing et al., 2007; Uc & Rizzo, 2008; Uitti 2009). According to previous research, it seems that MCI patients have some driving difficulties, however their driving skills are not consistently worse than that of cognitively intact individuals of similar age and driving experience (Devlin et al., 2012; Frittelli et al., 2009; Kawano et al., 2012). The present analysis by utilizing latent variables that assess a broad range of driving indexes, indicates that patients with MCI had a significantly altered driving performance as compared to healthy controls. It was noted that despite

their worse "reaction times", "driving performance" and their "accident probability", the latent variable "driving errors" were not significantly differ from the healthy controls.

Regarding neuropsychological state and neurological state, latent variable "neuropsychological state" had a significant positive effect on all outcome variables, namely, "driving performance", "driving errors", reaction time and accident risk. The current analysis by applying the SEM methodology indicates the importance of neuropsychological state as a predictor of driving competence that was assessed by the use of latent variables. Apart from the case of cerebral disorders, the role of neuropsychological state on driving behaviour was also evident on the control group of our study, as indicated by the main effect that was observed in all SEM models. Latent variable "neurological state" had a significant positive effect on "driving performance" "driving errors" and reaction time, whereas, its impact on accident risk was not statistically significant. Neurological and neuropsychological state appear to influence driving behaviour as they reflect the level of motor coordination and behavioural stability on one hand and functioning on cognitive domains, such as working memory, information processing speed, and visual attention on the other.

Regarding driver distraction, conversation with the passenger was not found to have a critical impact on driving performance accident probability and driving errors, indicating that drivers don't alter their driving behaviour in an important way under this type of distraction, but they have worse reaction time. On the other hand, mobile phone use had a significant negative effect on "driving performance", "reaction time" and "accident probability" but not on "driving errors". The negative effect of mobile phone on driving behaviour can be probably explained by the accumulating role of two synergistic mechanisms. Firstly, due to the amount of physical and cognitive resources that drivers allocate for performing the distraction task. Secondly, by adopting a compensatory behaviour that however only partially counterbalances the impact of distraction on overall driving behaviour.

Regarding age, it seems that advanced age had a significant negative impact on "driving performance", "driving errors" and reaction time, whereas, its impact on accident risk was not statistically significant. As indicated by the significant main effect that was observed in the three SEM models, the role of advanced age on driving behaviour appears to generalize as well on the control group of our study that included cognitively intact individuals.

Regarding area and traffic characteristics, urban area had a significant negative impact on "driving performance", whereas its impact on "driving errors", reaction time and accident probability was positive. Possibly, the more complex environment of the urban region increased the levels of awareness, thus leading to less driving errors, better reaction time and less accident probability. Low traffic conditions affected positively the "driving performance", whereas it hadn't any significant impact on "driving errors", reaction time and accident probability, which was an intuitive finding. In high traffic, the complicated road environment including a lot of interactions between vehicles has a totally negative effect on driving performance.

Chapter Six
Conclusions

6.1. Overview of the PhD dissertation

This research is an inter-disciplinary effort entering the scientific fields of traffic and safety behaviour of drivers on one hand and neurological disease affecting cognitive functions on the other. The objective of the present inter-disciplinary PhD thesis is **the analysis of traffic and safety behaviour of drivers with neurological diseases affecting cognitive functions**. More specifically, the impact of certain brain pathologies on driving performance, driving errors, reaction time and accident probability is under investigation. The driving behaviour is examined in terms of both traffic and safety behaviour and the neurological diseases affecting cognitive functions concern Alzheimer's disease (AD), Parkinson's disease (PD), and Mild Cognitive Impairment (MCI), in their mild stages.

The central objective of this PhD dissertation was addressed by: a) **designing and implementing** a large driving simulator experiment, b) **developing** an original methodology for the assessment of the impact of drivers' neurological diseases affecting cognitive functions on their driving performance taking also into account their neuropsychological and demographic characteristics as well as the main road safety and traffic characteristics, c) **quantifying the impact** of neurological diseases affecting cognitive functions directly on driving performance, driving errors, reaction time and accident probability, d) **comparing the driving performance** of drivers with different neurological diseases, and e) **examining the impact of distraction** on the performance of drivers with cerebral diseases.

The PhD thesis aims to capture the interaction of neurological diseases affecting cognitive functions, other related parameters (i.e. demographic, medical, and neuropsychological) as well as road and traffic conditions, and driver distraction with respect to driving behaviour. The **combined effect of these key parameters** on driving performance, driving errors, reaction time and accident probability might provide useful insight on driver traffic and safety behaviour analysis.

Given the interaction of several scientific areas in research of impaired driving due to neurological diseases affecting cognitive functions (transportation engineering,

neurology and neuropsychology), this PhD thesis covers a field of research with an **obvious and unique interdisciplinary nature**, which has not been examined in the past. The analysis of the neurological diseases affecting cognitive functions and other demographic and neuropsychological characteristics in combination with the driving performance of the general population, is very crucial domain and a scientific challenge at the same time.

This PhD thesis' goals, despite their high frequency of appearance in the general population and especially in the elderly, haven't been adequately investigated, especially by applying driving simulator experiments.

In order to achieve the objectives of this PhD dissertation, four discrete methodological steps were followed: a) extensive **literature review** (Chapter 2), b) **methodological approach** (Chapter 3), c) design and implementation of a **large driving simulator experiment** (Chapter 4), and d) development and application of an innovative **statistical analysis** (Chapter 5).

The PhD thesis overview is presented in Figure 6.1.

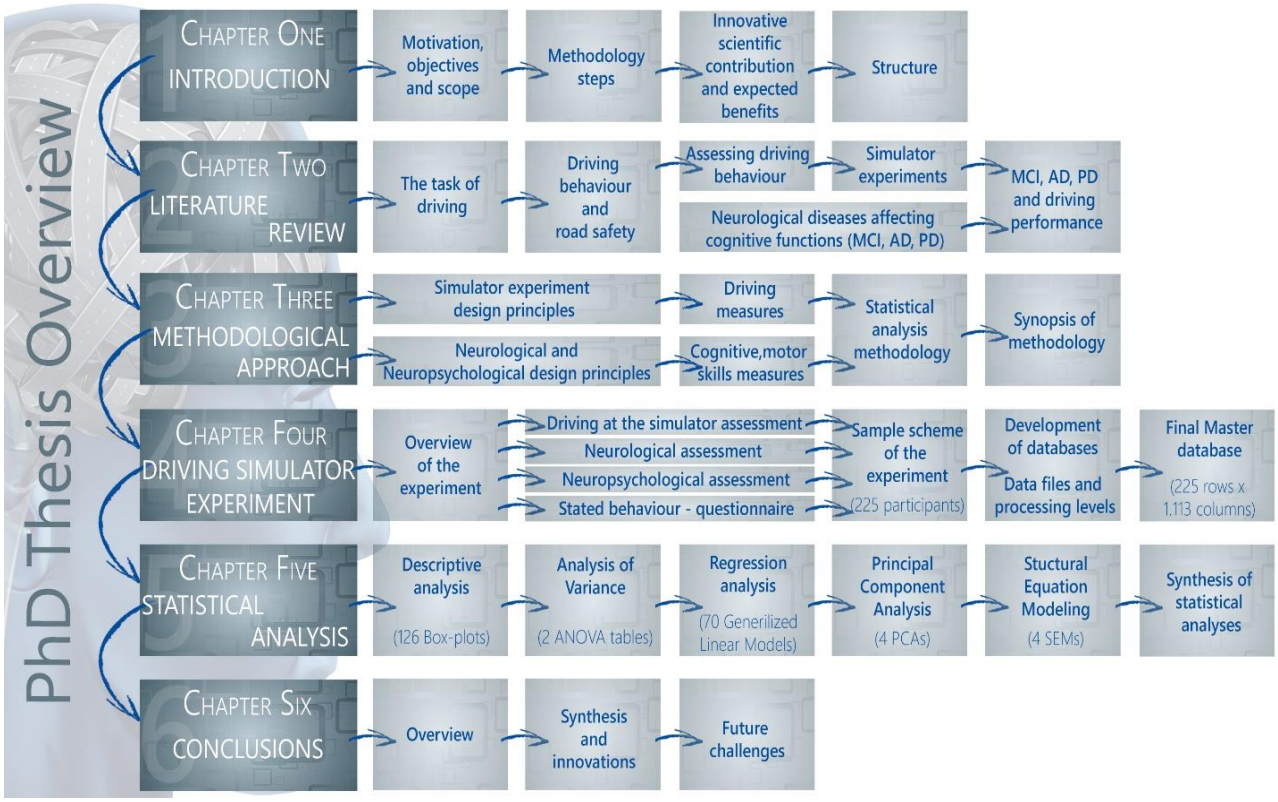


Figure 6.1. PhD Thesis Structure

Firstly, within the framework of Chapter 2, **an exhaustive literature review was carried out** examining in a comprehensive way driving behaviour and road safety, ways to assess driving behaviour, driving simulator characteristics as well as neurological

diseases affecting cognitive functions (MCI, AD and PD) and how these cerebral diseases affect driving performance.

More precisely, after some historical facts about car driving and the basic characteristics and skills a driver should have, an introduction to **road safety and driving behaviour** was presented with special focus on the **importance of human factors and cognitive functioning in road safety**. Additionally, the risks of driver distraction while driving were underlined and the possible compensatory strategies the drivers use in these driving conditions. Then, moving on to the ways that the scientific community assesses the driving behaviour, advantages and limitations of on-road experiments, naturalistic studies, simulator experiments, in-depth investigation studies and surveys which were examined, concluded that driving simulator experiments offer a safe environment, greater experimental control, and large range of test conditions, but at the same time learning effect, simulator sickness, and high cost.

Alongside, the literature review entered into the fields of **neurological diseases affecting cognitive functions** and focused on the following three: Mild Cognitive Impairment (MCI), Alzheimer's disease (AD), Parkinson's disease (PD). The main part of this review included several studies, which allowed the drawing of conclusions about the driving deficits of drivers suffering from MCI, AD and PD.

Reviewing studies about patients with MCI, of those studies assessing driving performance through on road testing, it seems that MCI patients, although they experience subtle changes in their driving competence are still able to drive. However, a level of impairment compared to healthy controls is generally being reported meaning that they still constitute a population at risk that warrants close supervision. Studies on a simulator environment have demonstrated that individuals with MCI are deficient in a number of variables compared to their healthy counterparts.

Reviewing studies about patients with AD, driving performance declines considerably in individuals with AD and several on-road and simulator studies indicated worse driving performance of AD group compared to healthy controls in several driving measures. Moreover, early AD patients may attempt to compensate for their reduced driving skills by limiting the number and length of own driving trips, by avoiding demanding driving situations and by driving at reduced speeds. Ideally, neuropsychological tests should be used in combination with other measures, such as findings from a neurological assessment and the administration of actual or simulated road tests, to make driving recommendations.

Reviewing studies about patients with PD, several lines of previous research indicate that driving capacity of patients with PD is mainly compromised due to cognitive deficits. Moreover, pronounced difficulties in several indexes of driving performance seem to appear in drivers with PD under demanding driving conditions that involve increased cognitive load. The use of multiple measures, apart from driving experiments, that assess various driving domains appears to be essential. 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 in isolation, because this practice could lead to imprecise decisions that can have dangerous consequences.

Moving on, within the framework of Chapter 3, an **innovative statistical analysis methodology** in the field of assessing driving behaviour of drivers with cerebral diseases was developed. This innovative methodological approach is based on literature review regarding simulator experiment, neurological and neuropsychological design principles, driving performance, cognitive and neurological state measures and statistical analysis methods.

More precisely, regarding the methodological approach, it was revealed that the **driving simulator experimental design** could be within or between-subject or full factorial and there are possible methodological threats that need to be taken into consideration when designing an experiment. Driver behaviour is a multidimensional phenomenon which means that no single driving performance measure can capture all effects of neurological diseases affecting cognitive functions. For that reason, a lot of different methods and measures exist for evaluating driving performance the most common of which include **lateral control, longitudinal control, reaction time, eye movement and workload measures**.

Alongside, in order to evaluate driving performance of patients with neurological diseases affecting cognitive functions, apart from the driving experiment, **neurological and neuropsychological experimental designs** are necessary. The neurological experimental design should deal with several domains: memory, orientation in time/space, motor system, daily activities, emotional state, sleep behaviour and motor abilities. The neuropsychological experimental design should deal with cognitive domains: global cognitive status, verbal memory and learning, verbal working memory, visual scanning and spatial memory and learning, visuospatial perception and working memory, constructional ability, attention/information processing speed/perception, selective and divided attention, executive functions and psychomotor vigilance.

Methodological review indicated that **latent model analysis and especially structural equation models have never been implemented** in the field of driver behaviour of patients with neurological diseases affecting cognitive functions. For that reason and within the framework of this PhD dissertation an innovative statistical analysis methodology has been developed, the theoretical background of which was presented analytically and consists of five steps: a) descriptive analysis, b) Analysis Of Variance (ANOVA), c) Regression Models, d) Principal Component Analysis (PCA), and e) Structural Equation Models (SEMs).

Moving on, within the framework of Chapter 4, based on the literature and methodology review, **a large driving simulator experiment took place** at the Department of Transportation Planning and Engineering of the NTUA, aiming to assess driving performance of patients with neurological diseases affecting cognitive functions. The objective of this chapter was to present the experiment design both in terms of conceptual framework and implementation as well as to record basic parameters regarding the data storage/processing and sample characteristics.

The experiment was designed in an inter-disciplinary way including two research teams: **Transportation Engineers** of the National Technical University of Athens (NTUA), and **Neurologists**, **Neuropsychologists and a Psychiatrist** of the Behavioural Neurology and Neuropsychology Unit, 2nd Department of Neurology, National and Kapodistrian University of Athens, "Attikon" University Hospital and includes three scientific assessment branches:

» **Driving at the simulator**: Firstly, the design and implementation of the driving simulator experiment was thoroughly investigated as it constitutes an innovating component of the PhD dissertation, allowing to address its complex challenges. All individual experiment parts were carefully designed and executed tackling the limitations and needs identified in similar driving simulator experiments reviewed in the previous chapters.
» **Medical / neurological assessment**: The second assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of the examined disorders (MCI, AD, PD).
» **Neuropsychological assessment**: The third 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.

The procedure of the "Driving at the simulator" included:

» **1 practice drive** (familiarization)
» **1 rural session** (2,1km long, single carriageway, 3m lane width)
» **1 urban session** (1,7km long, at its bigger part dual carriageway, 3.5m lane width)
» **2 traffic scenarios** for each session:
  » Q_M: Moderate traffic conditions (Q=300 vehicles/hour)
  » Q_H: High traffic conditions (Q=600 vehicles/hour)
» **3 distraction conditions** for each traffic scenario:
  » Undistracted driving
  » Driving while conversing with a passenger
  » Driving while conversing on a hand-held mobile phone
» **2 unexpected incidents** during each trial:
  » Sudden appearance of an animal (deer or donkey) on the roadway
  » Sudden appearance of a child chasing a ball or of a car getting out of a parking position.

In total, the whole experimental procedure included 12 trials. All these conditions were analyzed within a **full factorial within-subject design**. Furthermore, several other relevant aspects of the design were provided concerning dealing with simulator sickness, conversation topics, incidents, and randomization of trials as well as how the driving simulator scenarios were programmed. Moreover, the neurological and the neuropsychological tests were presented analytically, followed by the questionnaire assessment regarding their driving habits and their self-stated driving behaviour.

For the purpose of this PhD thesis 274 participants started the driving simulator experiment that was described analytically in the above chapters. 49 participants were eliminated from the study because of their simulator sickness issues from the very beginning of the driving simulator experiment. Thus, **the sampling scheme included 225 participants** (76% males - 24% females): **133 "patients"** with a neurological disease affecting cognitive functions (**28 AD patients, 45 MCI patients, 25 PD patients,** and 35 patients of other cognitive disorders) and **92 "Controls"** without any cognitive disorder. **From the age perspective**, three age groups were developed and the sampling scheme is also divided as follows: 30 Young drivers (age<34), 42 Middle Aged drivers (35<age<54) and 153 Old drivers (age>55)

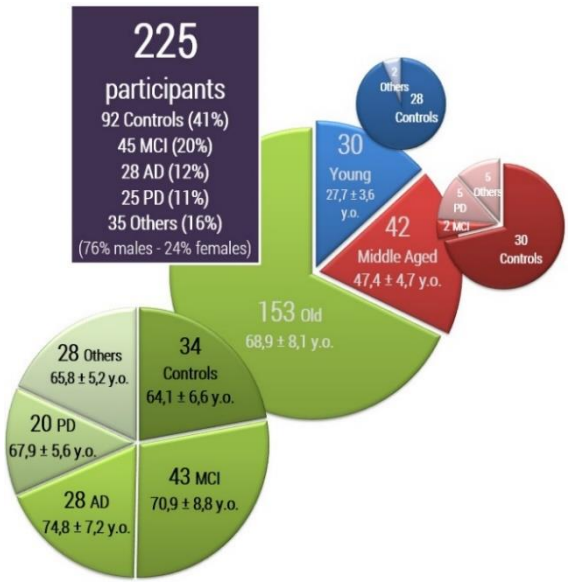


Figure 6.2. Sample Scheme of the PhD thesis

Then, **6 discrete Driving Simulator Data Processing Levels (PL)** were developed, in order to suitably deal with the large and diversified amount of data collected:

» **PL0.** Traffic Session Original Log Files (900 .txt files in total ~ 60.000 rows each)
» **PL1.** Driver Original Data Excel Files (225 .xls files in total~4 sheets~60.000 rows each)
» **PL2.** Driver Processed Data Excel Files (225 .xls files in total~2 sheets~60.000 rows each)
» **PL3.** All Drivers Processed Data Excel File (1 .accdb file ~ 20 million rows x 40 columns)
» **PL4.** All Drivers Summary Data Excel File (1 .xls file ~ 2.700 rows x 40 columns)
» **PL5.** All Assessments Processed Data File (1 .xls file~225 rows x 1.113 columns)

Within the framework of Chapter 5, All Drivers and All Assessments Processed Data File, was analyzed by means of **a dedicated and innovative statistical analysis method**. In the first step, the **descriptive analysis** of all the experiment variables took place, which allows for a first understanding of the large number of parameters examined. More precisely, an overview of all variables that are provided by the driving simulator is provided, investigating the effect of specific driving characteristics on selected driving performance measures. **126 boxplots were developed** correlating mean speed, time headway, lateral position, steering angle variability, reaction time at unexpected incidents, accident probability, and driving errors, with traffic volume, driving area, regarding age and cerebral disease of the participants.

Moving on, Analysis Of Variance (ANOVA) took place in order to extract significant differences in the driving performance indexes extracted from the driving simulator assessment. More precisely, **two Analysis Of Variance (ANOVA)** were extracted regarding identification of significant differences in the driving performance indexes that were extracted from the driving simulator assessment and in the answers that were extracted from the behaviour questionnaires, between two groups: groups of healthy controls and patients with neurological diseases affecting cognitive functions.

In the third step, within the framework of the explanatory analysis, the development of **a series of Regression Models** took place regarding key performance parameters in order to estimate the effect of cerebral diseases and driving characteristics on specific driving performance parameters and indirectly on driving behaviour and road safety. More specifically 28 General Linear Models (GLMs) were extracted regarding the effect of MCI, AD and PD on: mean speed, time headway, lateral position, steering angle variability, reaction time at unexpected incidents, accident probability, and driving errors and 42 General Linear Models regarding the effect of distraction on the same driving performance measures of patients with MCI, AD and PD and controls.

In the fourth step, **four Principal Component Analyses (PCA)** were implemented regarding driving performance, driving errors, neuropsychological state and neurological state, in order to investigate which observed variables are most highly correlated with the common factors and how many common factors are needed to give an adequate description of the data.

In the fifth and final step, the core statistical analysis of the present PhD thesis took place, including the implementation of **four Structural Equation Models (SEMs)** for the first time in the scientific field of driving behaviour of drivers with neurological diseases affecting cognitive functions. Within the framework of latent analysis and based on the factor loadings that were extracted from the PCA analyses, **four latent variables were developed** namely, "driving performance", "driving errors", "neurological state" and "neuropsychological state" in order to implement four SEMs.

The following five driving measures were placed under the factor that was considered to reflect the **latent variable "driving performance"**: a) average speed, b) lateral position variability, c) steering angle variability, d) average gear, and e) time to line crossing. The following four driving measures were placed under the factor that was considered to reflect **latent variable "driving errors"**: a) outside road lines, b) hits of sidebars, c) speed limit violations and d) sudden brakes. The four following neuropsychological measures could describe the factor that was considered to reflect **the latent variable "neuropsychological state"** sufficiently: a) Witkin's Embedded Figure Test, b) Brief Visuospatial Memory Test, c) Comprehensive Trail Making Test - 1, and d) Hopkins Verbal Learning Test. Finally, the following four neurological tests were placed under the factor that was considered to reflect the **latent variable "neurological state"**: a) Tandem Walking Errors, b) Tandem Walking Time, c) Patient Health Questionnaire (PHQ-9) and d) Foot Tapping Errors.

Four SEMs were developed aiming to quantify the impact of neurological diseases affecting cognitive functions, driver distraction, driver characteristics, neurological state, neuropsychological state as well as road and traffic environment directly on driver behaviour characteristics, namely the observed variables "reaction time" and "accident probability" and the latent variables "driving performance" and "driving errors". The four different SEMs are developed as described in the next Figure (Figure 6.3) graphically and explained below:

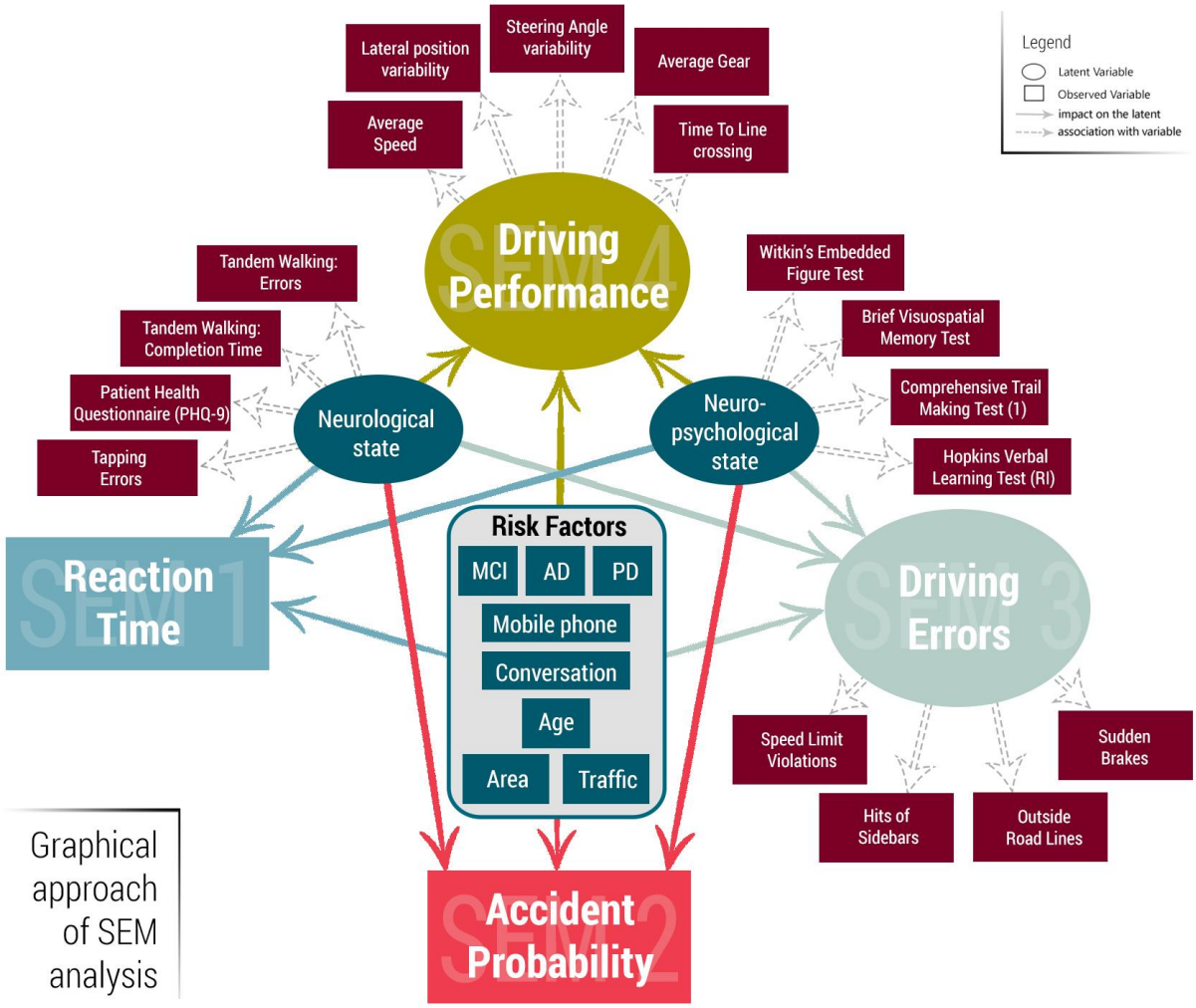


Figure 6.3. Graphical Approach of Structural Equation Model Analysis

In the **first and the second SEMs**, the objective is the quantification of the impact of neurological diseases affecting cognitive functions, distraction, age and road and traffic environment on the observed variables "**reaction time**" and "**accident probability**". Additionally, the quantified impact of two latent variables regarding neurological state and neuropsychological state of the drivers on the observed variables is analyzed.

In the **third and fourth SEMs**, the key latent variables reflects the underlying "**driving errors**" and "**driving performance**" and the objective is the quantification of the impact of neurological disease affecting cognitive functions, distraction, driver characteristics and road and traffic environment on "driving errors" and "driving performance". Additionally, the quantified impact of latent variable regarding "neurological state" and latent variable regarding "neuropsychological state" of the drivers on the latent variables "driving errors" and "driving performance" is analyzed.

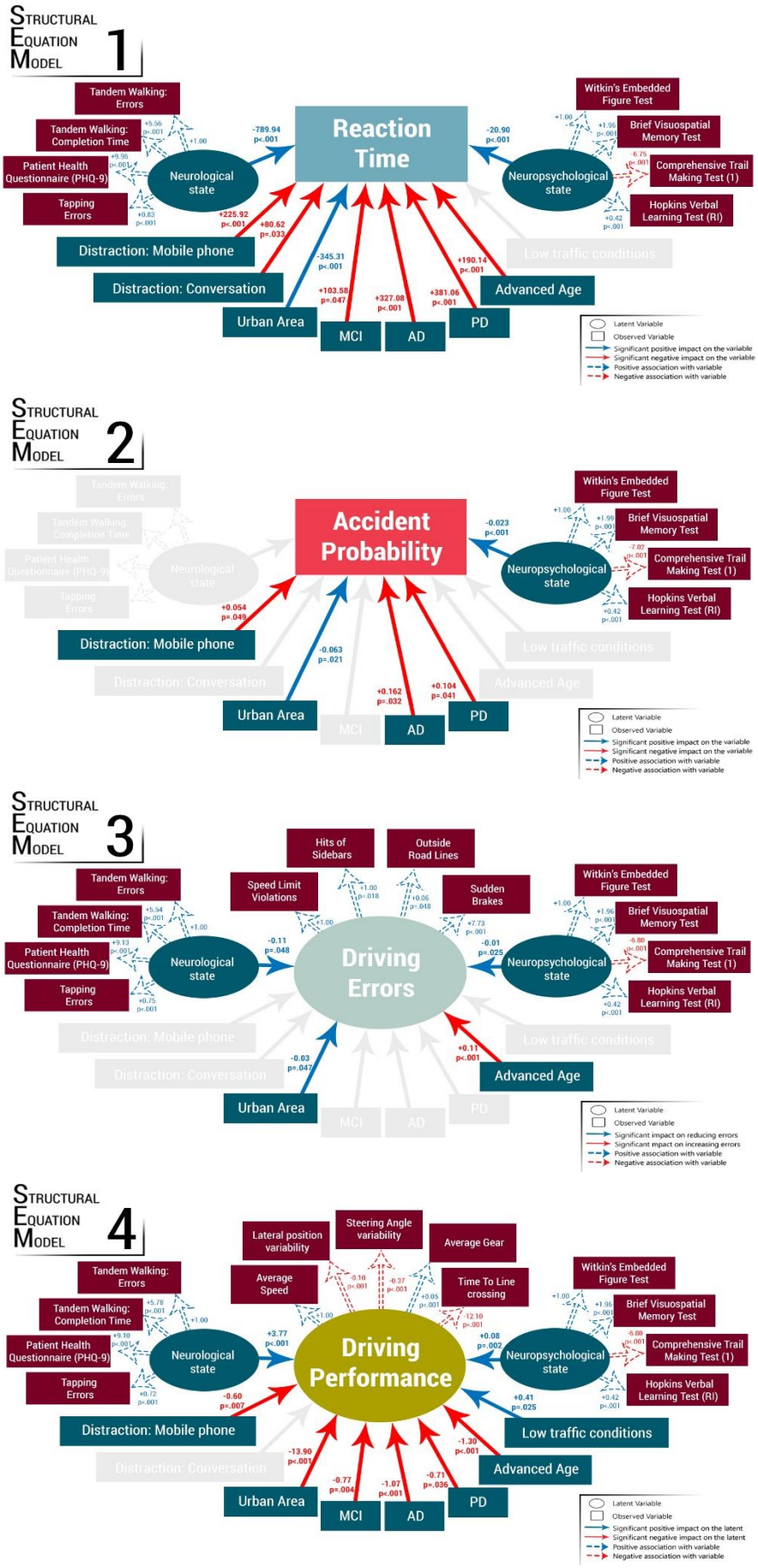


Figure 6.4. Structural Equation Models

6.2. Synthesis and innovations of the PhD dissertation

In this chapter, the **conclusions** extracted from this PhD dissertation will be presented, with focus on the **innovative** scientific contribution and the **synthesis** of the most pronounced and interesting results of this research. The innovative scientific outcome of this PhD dissertation consists of five original scientific contributions as presented here-after (Figure 6.5).

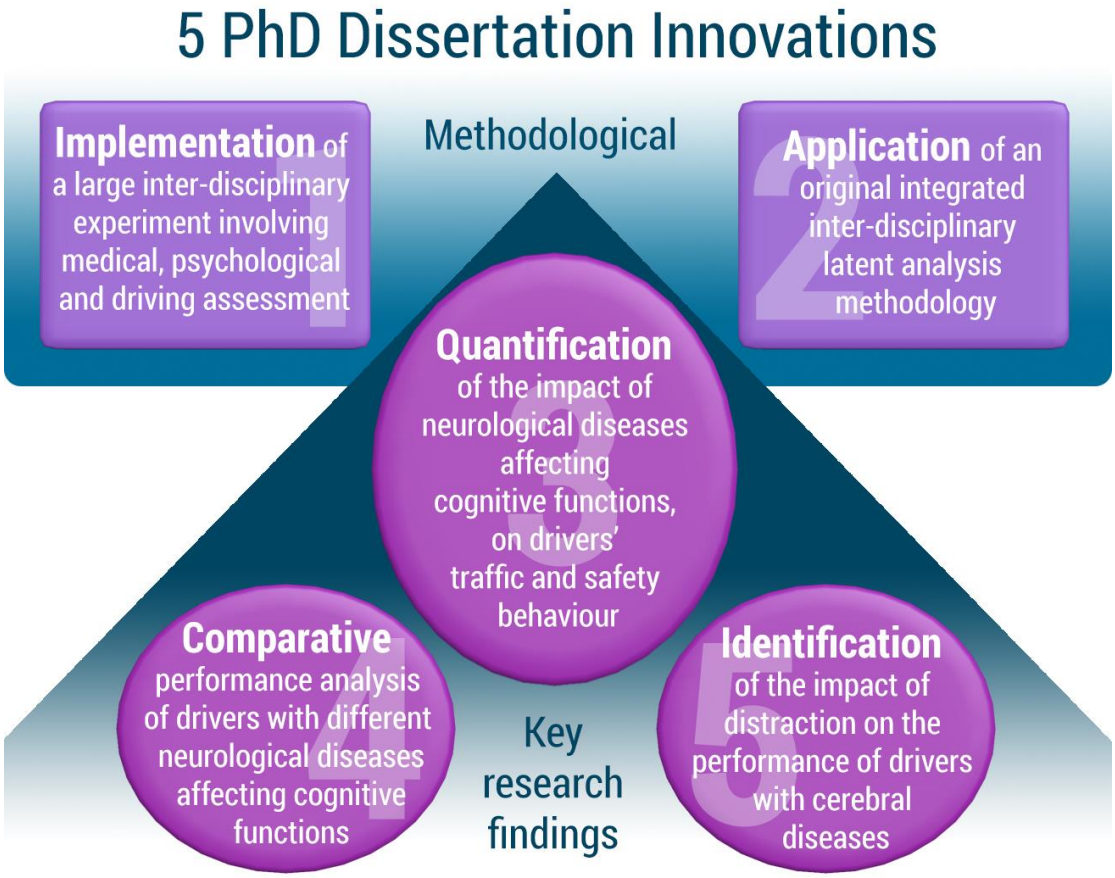


Figure 6.5. PhD dissertation innovations

6.2.1. Implementation of a large inter-disciplinary experiment involving medical, psychological and driving assessment

The first innovation of this PhD dissertation is methodological. **The design and implementation of a large scale inter-disciplinary experiment** which includes two scientific branches, a traffic engineering and a neurological sciences (neurology and neuropsychology), is a central component of the present PhD thesis. Because of the integration of these different scientific disciplines involved in impaired driving research

(**traffic engineering, and medicine**), this PhD dissertation covers a research field with an obvious but not previously exploited multidisciplinary nature.

More precisely, the aspects of driver behaviour and safety research addressed were inherently interdisciplinary, and the experiment was designed by an interdisciplinary research team including three types of assessment:

» **Driving at the simulator (12 driving trials~1.5 hour[7])**: The first assessment concerns the driving behaviour by means of programming of a set of driving tasks into a driving simulator for different driving scenarios. Randomization among trials, adequate practice drive and investigation of an optimum number of driving conditions are considered as simulator experimental design innovations.
» **Medical / neurological assessment (19 tests~2 hours)**: The second assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of the examined disorders (MCI, AD, PD).
» **Neuropsychological assessment (20 tests~2.5 hours)**: The third 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.

In total, **225 drivers** (133 patients with MCI, AD and PD and 92 healthy controls) went through the whole experimental procedure in **2 years' time**. This sample size is considered large and representative, which is of great significance, taking into account the design limitations extracted from the international literature.

The primary goal concerning the planning of the experiment was on the one hand to go through all the required neurological, neuropsychological **evaluations and assessments**, questionnaires and the driving simulator experiment and on the other hand to make sure that the process **is not too demanding or even overwhelming** for the participants either physically or mentally (especially for those with neurological diseases affecting cognitive functions). For that purpose the 6 hours of total medical, neuropsychological and simulator assessments were divided into 3 days.

[7] Approximately 40 minutes + 15 minutes of practice drive + 35 minutes of mini breaks during the driving

6.2.2. Application of an original integrated inter-disciplinary latent analysis methodology

The second innovation of this PhD dissertation is also methodological, suggesting the implementation of **four latent variables covering all three fields of this inter-disciplinary PhD thesis**: "driving performance" and "driving errors" extracted from the driving simulator experiment, "neurological state" extracted from the neurological database and "neuropsychological state" extracted from the neuropsychological database, in order to **construct four Structural Equation Models (SEMs)**. The four latent variables were developed using the most critical indexes (neurological, neuropsychological, and driving measures) extracted from the PCA analyses.

The exploratory PCA analysis was performed so as to investigate which driving simulator indexes had the most important contribution on explaining the higher order factor "**driving performance**". The following five driving measures were placed under the factor that was considered to reflect driving performance: a) average speed, b) lateral position variability, c) steering angle variability, d) average gear, and e) time to line crossing. In addition, an exploratory PCA analysis was performed to investigate which driving simulator indexes had the most important contribution on explaining the higher order factor "**driving errors**". The following four driving measures were placed under the factor that was considered to reflect driving errors: a) outside road lines, b) hits of sidebars, c) speed limit violations and d) sudden brakes.

Based on the same approach, exploratory PCA analysis was performed to investigate which neuropsychological measures had the most important contribution on explaining the higher order factor "**neuropsychological state**". The factor loadings that were extracted, indicated that the four following neuropsychological measures could describe sufficiently the factor that was considered to reflect neuropsychological state: a) Witkin's Embedded Figure Test, b) Brief Visuospatial Memory Test, c) Comprehensive Trail Making Test - 1, and d) Hopkins Verbal Learning Test. Additionally, an exploratory PCA analysis was performed to investigate which neurological tests assessing aspects of motor fitness had the most important contribution on explaining the higher order factor "**neurological state**". Based on the factor loadings that were extracted, the following four neurological tests were placed under the factor that was considered to reflect neurological state: a) Tandem Walking Errors, b) Tandem Walking Time, c) Patient Health Questionnaire (PHQ-9) and d) Foot Tapping Errors.

Latent analysis allowed an important scientific step forward from piecemeal analyses to a sound combined analysis of the **inter-disciplinary interrelationship** between risk factors, neurological state, neuropsychological state, driving performance, driving error and accident probability at unexpected incidents. **It is the first time and it is considered as a methodological originality of this PhD dissertation**, that latent variables reflecting neurological and neuropsychological status (neurological state and neuropsychological state) interact with other latent driving variables (driving performance an driving errors) and with other observed driving variables such as reaction time and accident probability.

6.2.3. Quantification of the impact of neurological diseases affecting cognitive functions, on drivers' traffic and safety behaviour

The quantification of the impact of neurological diseases affecting cognitive functions, on drivers' traffic and safety behaviour is an innovation which is considered to be the core of this PhD dissertation, regarding the key research findings. The first three statistical steps, indicated **statistically significant differences between the group of patients with neurological diseases affecting cognitive functions and the healthy controls** of similar demographics in several driving performance measures.

More specifically the Generalized Linear Models that were extracted, indicated that all three groups of **patients were found to drive at significantly lower mean speed** (more than 20% lower) and had larger time headway (more than 20% larger) compared to the healthy control group drivers in rural and urban roads, both at low and high traffic volume. Analyzing the lateral control measures it was observed that **patients with MCI drove more closely to the right border of the road** (slightly yet significantly) in urban area and in both traffic volumes and, in rural area, PD group had low steering variability in high traffic volume due to their low speed, their conservative driving and maybe this is a compensatory behaviour. By the use of GLMs regarding the reaction time of the patients at unexpected incidents, it was observed that **patients had significantly larger reaction times** in all examined conditions compared with the cognitively intact group. It is worth highlighting that their reaction times were more than 40% worse than that of the control group. Moving on to the accident probability, **significantly higher accident probability was detected for the AD group** in all examined conditions (accident probability for the AD group was more than 20%) and for the MCI and PD groups only in urban area. On the other hand patients and controls had not differences in the driving errors they made during the driving session at the driving simulator experiment.

This part of the analysis further demonstrates how the progression of the disease (i.e. from MCI to AD) leads to more pronounced driving impairments in several longitudinal or lateral control measures. While the reduced mean speed, the increased headways and the driving closer to the right road border may be considered beneficial for road safety, as they reflect a more conservative and cautious driving pattern, **the negative effect on reaction time and accident probability overcomes all of them and leads to risky and dangerous driving behaviour**.

The ANOVA investigated the self-stated questionnaires and indicated that drivers with MCI, AD and PD **are aware of their deterioration of their driving performance**. On the basis of the above, it is suggested that the examined cognitive impairments result in impaired driving behaviour based on development of **compensatory driving behaviour**, due to drivers' awareness of own deficits, expressed by reduced speed, increased headways, more conservative vehicle positioning (and as a consequence less manoeuvre and overtaking). Finally and more importantly, moving on to the SEM analysis regarding driver behaviour characteristics (observed variables reaction time and accident probability, and latent variables driving errors and driving performance), the basic quantified conclusions for the predictors of the SEM analysis regarding neurological diseases affecting cognitive functions are presented in Figure 6.6.

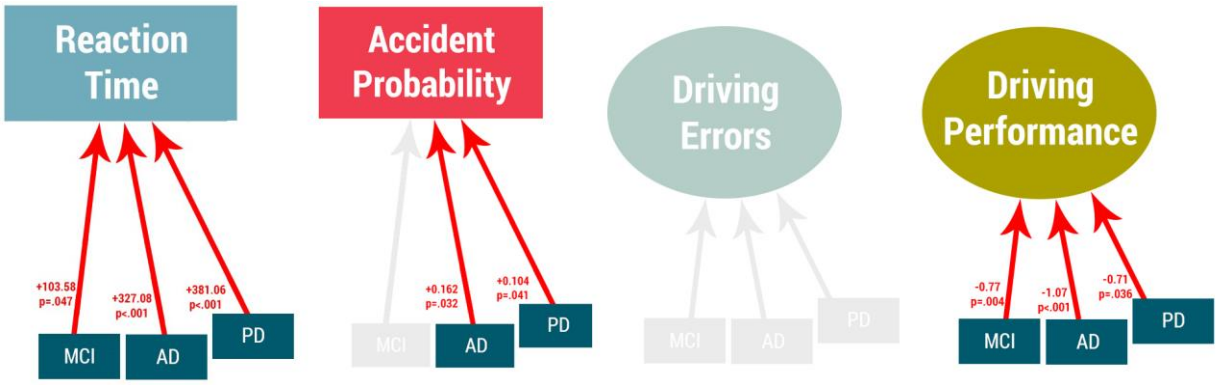


Figure 6.6. Impact of MCI, AD, and PD directly on the 4 examined variables
(red arrows mean negative impact, and grey no significant impact on the variable)

Drivers with MCI, AD and PD overall performed significantly worse than the healthy controls regarding the four examined driver behaviour characteristics. More precisely, they were associated with significantly lower levels of the latent variable "driving performance" that reflected a broad range of driving indexes and were associated with significantly worse "reaction time". Also, the clinical conditions of AD

and PD were associated with a negative impact on accident probability. Finally, none of the clinical groups showed a significantly increased amount of driving errors.

The findings about the AD and the PD patients were in the expected direction and are in line with previous research that indicates impairments in driving performance of the two clinical groups both in the case of driving simulator experiments and on-road evaluations. Regarding MCI patients, the present analysis by utilizing latent variables that assess a broad range of driving indexes, indicates that they had **a significantly altered driving performance** as compared to healthy controls. It was noted that despite their worse "reaction times", "driving performance" and their "accident probability", the latent variable "driving errors" did not significantly differ from the healthy controls. Nonetheless, **the parameter that renders originality to the present analysis** is the development of latent variables for the evaluation of driving behaviour that encompasses a variety of driving indexes. In addition, another novel element is the application of multivariate SEM models that make feasible the exploration of the **unique impact** of neurological diseases affecting cognitive functions on driving behaviour.

Additionally, the quantification of the impact of other risk factors on driving behaviour is under investigation. The basic quantified conclusions for the predictors of the SEM analysis regarding neuropsychological state and neurological state are presented in Figure 6.7. Latent variable **"neuropsychological state"** had a significant positive effect on all outcome variables indicating its importance as a predictor of driving competence that was assessed by the use of latent variables. Latent variable **"neurological state"** had a significant positive effect on "driving performance", "driving

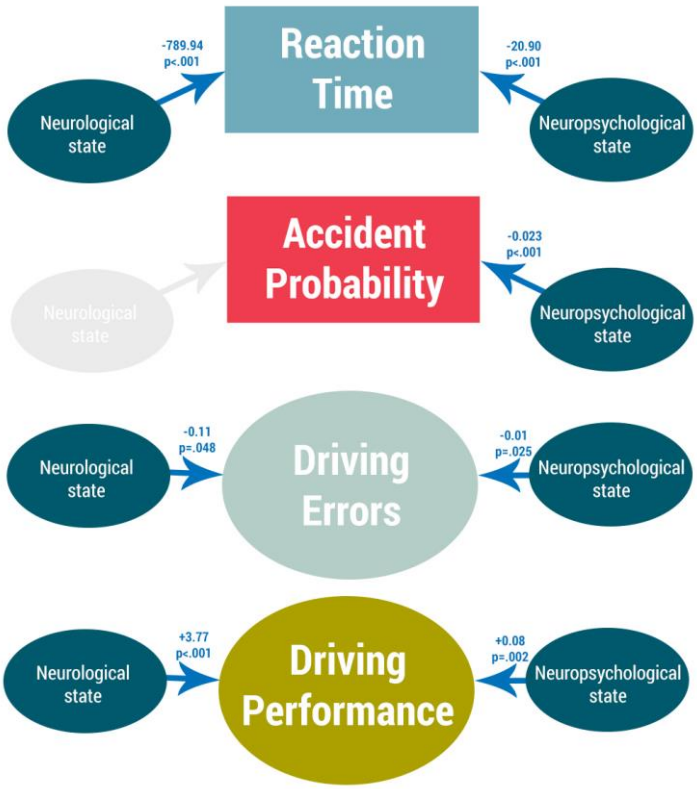


Figure 6.7. Impact directly on the 4 examined variables (blue arrows mean positive impact and grey no significant impact on the variable)

errors" and reaction time, whereas, its impact on accident probability was not statistically significant.

Neurological and neuropsychological state appear to influence driving behaviour as they reflect the level of motor coordination and behavioural stability on one hand and functioning on cognitive domains, such as working memory, information processing speed, and visual attention on the other.

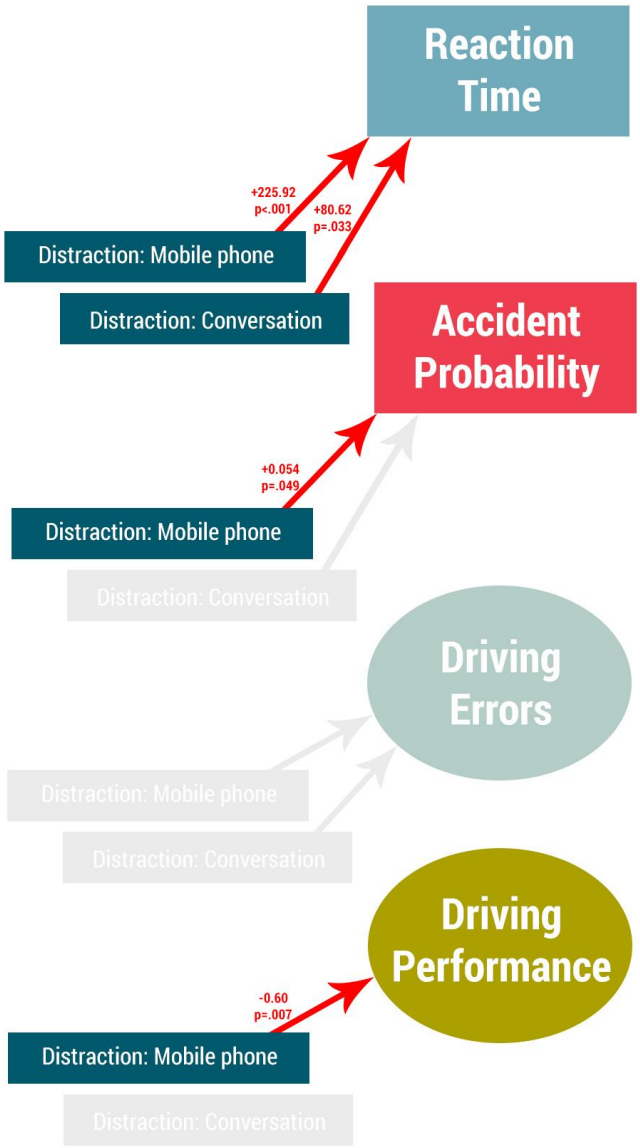


Figure 6.8. Impact of driver distraction directly on the 4 examined variables (red arrows mean negative impact, and grey no significant impact on the variable)

The basic quantified conclusions for the predictors of the SEM analysis regarding driver distraction are presented in Figure 6.8. **Conversation with the passenger** was found to have a critical impact only on their reaction time, indicating that drivers don't alter their driving behaviour in an important way under this type of distraction, but have worse reaction time.

On the other hand, **mobile phone use** had a significant negative effect on "driving performance", "accident probability", and "reaction time" but not on "driving errors". The negative effect of the use of mobile phone on driving behaviour can be probably explained by **the accumulating role of two synergistic mechanisms**. Firstly, due to the amount of physical and cognitive resources that drivers allocate to performing the distraction task. Secondly, by adopting a compensatory behaviour that nevertheless only partially counterbalances the impact of distraction on overall driving behaviour.

The basic quantified conclusions for the predictors of the SEM analysis regarding age are presented in Figure 6.9. **Advanced age had a significant unique negative impact** on "driving performance" "driving errors" and reaction time, whereas, its impact on accident risk was not statistically significant. As indicated by the unique significant main effect that was observed in the three SEM models, the role of advanced age on driving behaviour appears to generalize as well as on the control group of the study that included cognitively intact individuals.

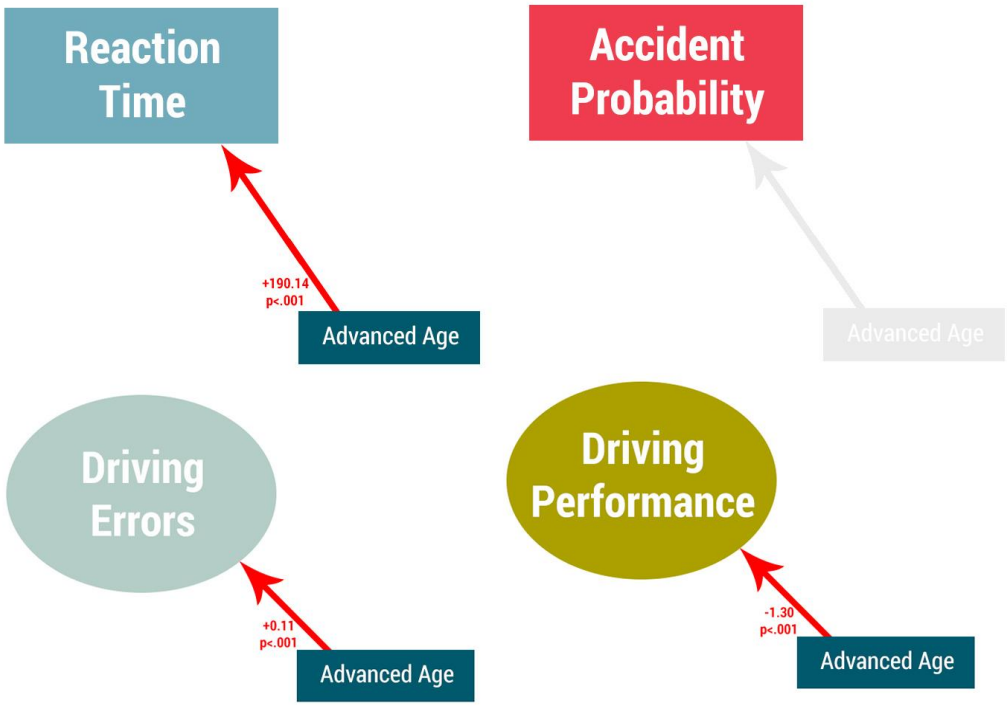


Figure 6.9. Impact of advanced age to the 4 examined variables (red arrows mean negative impact, and grey no significant impact on the variable)

The basic quantified conclusions for the predictors of the SEM analysis regarding area and traffic characteristics are presented in Figure 6.10. **Urban area had a significant negative impact on "driving performance"**, whereas its impact on "driving errors", reaction time and accident probability was positive. Possibly, the more complex environment of the urban region **increased the levels of awareness**, thus leading to less driving errors, better reaction time and less accident probability. Low traffic conditions affected positively the "driving performance", whereas it didn't have any significant impact on the other examined variables, which was an intuitive finding. In high traffic, the complicated road environment including **a lot of interactions between vehicles** has a totally negative effect on driving performance.

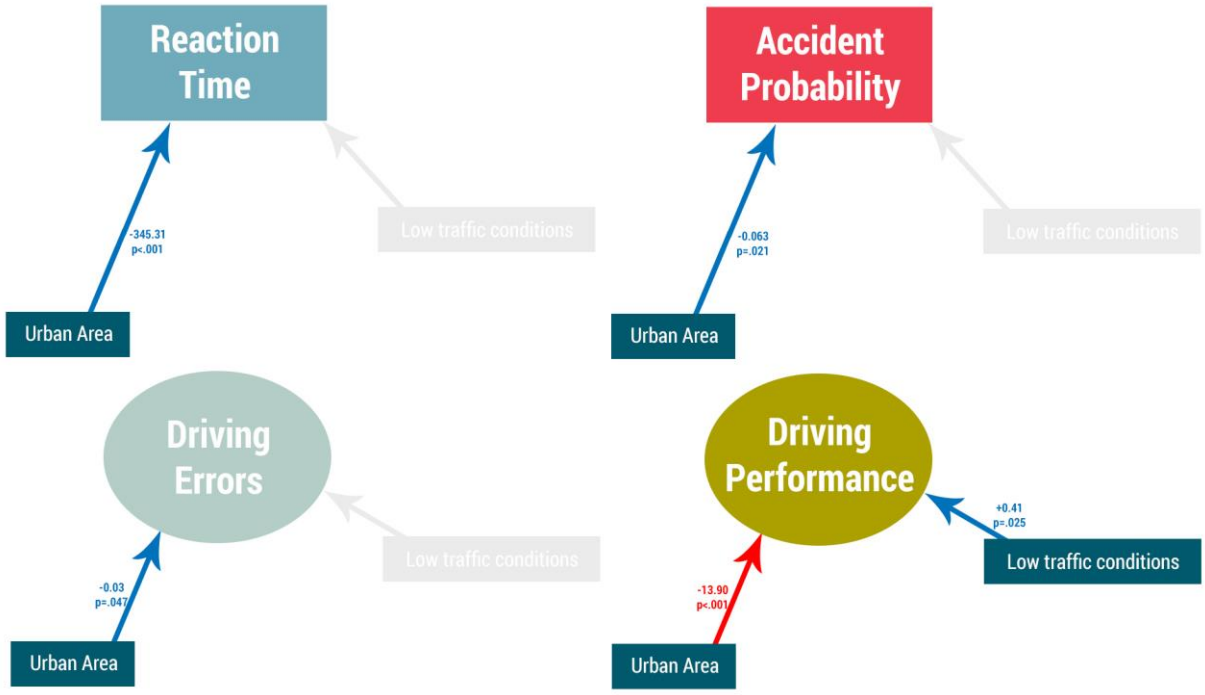


Figure 6.10. Impact of low traffic conditions and urban area directly to the 4 examined variables (red arrows mean negative impact, blue positive impact and grey no significant impact on the variable)

6.2.4. Comparative performance analysis of drivers with different neurological diseases

The fourth innovation of this PhD dissertation is derived also from the key research findings and concerns the comparative performance analysis of drivers with different neurological diseases affecting cognitive functions. In the previous sub-chapter, it was derived that the 4 SEMs included the 3 examined neurological diseases affecting cognitive functions indicated significantly **worse reaction time and "driving performance"** for drivers with MCI, AD and PD compared to healthy controls. Furthermore, the clinical conditions of AD and PD were associated with a **negative impact on accident probability**. Moving one step forward, the parameter estimates of the 4 SEMs provide the opportunity to compare the 3 examined neurological diseases affecting cognitive functions, regarding their impact on the 4

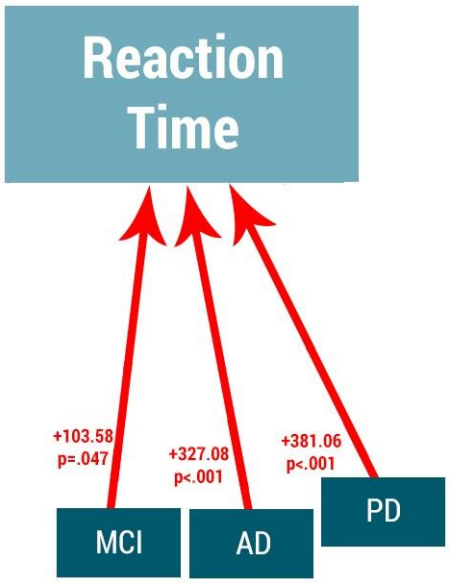


Figure 6.11. Quantified impact of MCI, AD, and PD on reaction time

examined driver behaviour characteristics. Firstly, **the impact of PD and AD is much more detrimental on reaction time**, compared to the impact of MCI (Figure 6.11). In particular, PD leads to an increase of 0.38 sec of the reaction time, AD leads to an increase of approximately 0.33 sec of the reaction time and MCI to an increase of 0.1 sec. This finding is of great significance regarding road safety, because higher reaction time is probably leading to higher accident probability.

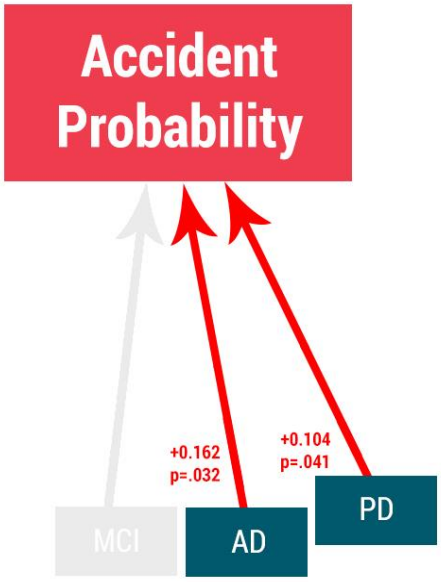


Figure 6.12. Quantified impact of MCI, AD, and PD on accident probability

Indeed, moving on to the next SEM, the comparative analysis of the three examined neurological diseases affecting cognitive functions follows the same pattern (Figure 6.12). MCI didn't have any significant impact on accident probability, whereas **AD increased the accident probability by 16% and PD by 10%**. The worse reaction times of AD and PD patients lead to higher accident probability. It is notable that although PD had more detrimental effect on reaction time than AD, the AD leads to 1.6 times higher accident probability as the PD. Moving on to driving errors, none of the three examined brain pathologies had a significant effect on driving errors, whereas **AD had the highest negative impact on driving performance**, followed by MCI, followed by PD (Figure 6.13). Summarizing, the innovative 4 comparative performance analyses of drivers with different neurological diseases affecting cognitive functions, indicated **AD as the riskiest group of drivers** (had the greatest impact on accident probability and driving performance and almost the greatest on reaction time), **followed by PD**, whereas the group of MCI is considered as safer compared to the other two examined brain pathologies.

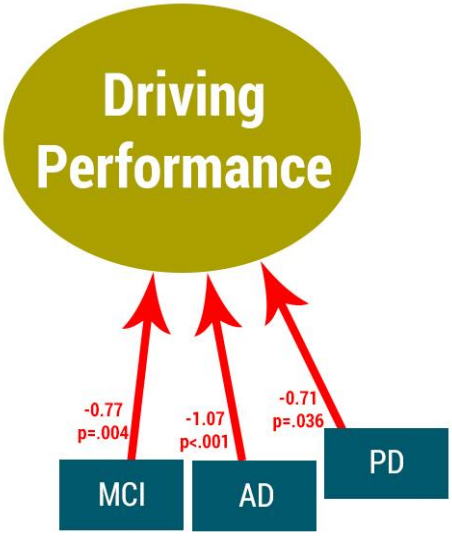


Figure 6.13. Quantified impact of MCI, AD, and PD on driving performance

6.2.5. Identification of the impact of distraction on the performance of drivers with cerebral diseases

The fifth innovation of this PhD dissertation concerns the effect of distraction of the performance of drivers with MCI, AD and PD, by exploring driving while conversing with a co-passenger and driving while conversing through a handheld mobile phone. Exploring and quantifying the impact distraction on drivers with MCI, AD and PD has not been addressed so far among the international scientific community. It appeared that overall, the distraction conditions appeared not to have such a significant impact on several driving performance measures in the group of controls, in contrast with the findings extracted from the **patients' groups regression analyses in whom the impact of distraction and especially the mobile phone use, was detrimental**.

In particular, the **reaction time** of drivers with brain pathologies **increased more than 30%** under the driving condition with the use of mobile phone (AD patients increased their reaction times even 50%, catapulting them to more than 3.5 sec), whereas in the group of cognitively intact drivers the equivalent increase was about 10%. Moreover, the group of drivers with neurological diseases affecting cognitive functions had **a striking increase of the risk of being engaged in a car accident** when using a mobile phone (in AD and PD patients there was more than 30% accident probability when using their mobile phone). Notably, the aforementioned pattern of findings was observed despite the fact that the drivers with neurological diseases affecting cognitive functions tried to adjust their driving behaviour by reducing at an important extent their driving speed and time headway when using a mobile phone. On the other hand, control group was unaffected by the mobile phone use distraction.

Also, the presence of a **conversation with a passenger had an impact** on the driving performance of the patients, **but of a smaller magnitude** as compared to the case of the mobile phone use. In particular, under the specific driving condition there was an accentuation of the difference on reaction time and accident probability between group of patients and cognitive intact individuals, but only for the MCI and the PD groups in an urban area. Overall, the conversation with passenger didn't seem to have a detrimental effect on the majority of the examined conditions.

The **driving profile** of individuals with neurological diseases affecting cognitive functions according to these results **changed radically under the more demanding driving condition** that included the use of a hand-held mobile phone. It is suggested

that the parallel execution of two tasks, namely of driving and using a hand-held mobile phone, placed the group of drivers with cerebral diseases in **a particularly vulnerable position** due to the need to effectively divide their attention under this demanding driving condition. In line with this approach, the driving condition with conversation, that is of intermediate difficulty and also requires by the drivers to divide their attention at a certain level, had an increased negative effect on the driving performance of individuals with AD and PD, but of a smaller extent as compared to the case of the mobile phone. Notably, in the driving condition with the mobile phone, the drivers with MCI, AD and PD applied again the compensatory strategy of reducing their speed but in this case the outcome was not successful, as indicated by the pronounced increase of their accident risk.

6.3. Future research and challenges

6.3.1. Future research

In the present PhD thesis an original methodological and statistical concept was developed for the analysis of the effect of neurological diseases affecting cognitive functions, road and traffic characteristics and driver distraction on driver behaviour. The application of this methodology also revealed a number of open issues for further research in the inter-disciplinary field of driving behaviour and brain pathologies.

Firstly, in future research the experimental sample size could be strengthened **in terms of size** (more participants with MCI, AD and PD), **in terms of the type of the neurological diseases** affecting cognitive functions (participants with REM Behaviour Disorder, Frontotemporal Dementia, Stroke, Multiple Sclerosis etc. are of great interest regarding their driving behaviour and could be inserted in the research) and **in terms of location and origin** (MCI, AD and PD drivers in Greece may present differences in driving behaviour with drivers of the same brain pathologies living in other countries).

Moreover, it would be an interesting future research challenge to **periodically assess** the driving behaviour of patients with cerebral diseases over time (i.e. driving simulator experiment combined to neurological and neuropsychological assessments, every 1 year), in order to **identify to which extent, the progression of the disease deteriorates several driving performance measures**.

Additionally, the innovative methodological approach which consists of the implementation of structural equation model on the basis of the creation of latent (unobserved) variables, could be further developed and applied in more general driving behaviour scientific fields. The effect of **several other driving, medical and neuropsychological parameters** can be estimated on reaction time, accident probability, driving performance, and driving errors of drivers with brain disorders, as well as other demographic characteristics as gender, educational level, driving experience. In addition, **more latent variables could be developed and investigated**, depending on the experimental database and the specific research questions.

Finally, this innovative methodology should be developed on different types of assessing driver behaviour of drivers with neurological diseases affecting cognitive functions. More specifically, as the application of structural equation models needs a large dataset with several parameters, SEMs can be developed on **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 behaviour of patients with MCI, AD or PD.

6.3.2. Future challenges

The benefits from the present PhD thesis are **both scientific and socioeconomic**. The scientific benefits concern the enhancement of existing knowledge on impaired driving mechanisms and driving performance at unexpected incidents, as well as the methods for designing and conducting simulator experiments. The socioeconomic benefits concern the improvement of road safety that will be achieved once impaired driving mechanisms due to neurological diseases affecting cognitive functions are better understood and explicitly tackled.

The results of this PhD dissertation **can be exploited in the development of recommendations and measures** for addressing all aspects of impaired driving due to neurological diseases affecting cognitive functions, such as the early identification of the problem, the effectiveness of measures on the improvement of the performance of older or impaired drivers, the education and training schemes for safe driving and dealing with unexpected incidents, the special measures for specific high-risk groups and the medical and neurological criteria for safe driving and monitoring of drivers at risk for presenting a condition that is associated with unsafe driving.

A future goal is to improve impaired drivers' performance in general and at unexpected incidents in particular, as well as to **promote knowledge** of driving situations that should be avoided by people belonging to vulnerable groups. Consequently, the results of the PhD thesis, in addition to researches in the fields of road safety and medicine, are of particular interest in the following groups:

» **Road safety decision makers** involved in driver training, licensing and evaluation procedures.
» **Neurologists or other practitioners** involved in the treatment, monitoring and evaluation of individuals with neurological diseases affecting cognitive functions.
» **Families of older people** and those with neurological diseases affecting cognitive functions in particular (through public campaigns, dissemination of information etc.).

Definition of successful early predictors of driving ability in patients with mild AD or MCI will allow the development of thoughtful guidelines and national policies to improve public road safety (Papageorgiou, 2016). Thus, it is important to take into consideration that **every driver with a neurological disease affecting cognitive functions 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. Additionally, it should be in positive direction an effective monitoring of drivers that are at-risk of developing an underlying neurological condition that is associated with unsafe driving and the development of interventions that have the capacity to improve or preserve the driving fitness of older individuals and of drivers with cerebral diseases.

Overall, the results of this PhD thesis can potentially contribute to a significant reduction in road accidents and related casualties, which are especially prevalent in Greece, if the data and the results extracted from this PhD dissertation **be exploited by the authorities in order to implement appropriate road safety policy directions regarding the vulnerable group** of drivers with neurological diseases affecting cognitive functions. Enhanced understanding of the medical, behavioural and social issues related to impaired driving due to neurological diseases affecting cognitive functions will lead to more appropriate driver training and licensing, criteria for driver license renewal for people belonging to vulnerable groups, more appropriate legislation and awareness campaigns.

References

Abdi. H., & Williams, L.J. (2010). "Principal component analysis". Wiley Interdisciplinary Reviews: Computational Statistics 2: 433–459. doi:10.1002/wics.101.

Adler G, Kuskowski M (2003) Driving cessation in older men with dementia. Alzheimer Dis Assoc Disord 17, 68-71.

Adler, G., Rottunda, S., & Dysken, M. (2005). The older driver with dementia: an updated literature review. J Safety Res, 36(4), 399-407. doi: 10.1016/j.jsr.2005.07.005.

Aggarwal NT, Wilson RS, Beck TL, Bienias JL, Bennett DA. (2005). Mild cognitive impairment in different functional domains and incident Alzheimer's disease. J Neurol Neurosurg Psychiatry. 2005 Nov;76(11):1479-84.Akaike, H., 1987. Factor analysis and AIC, Psychometrika 52, 317-332.

Alm, H., Nilsson, L., 1990. Changes in driver behaviour as a function of hands-free mobile telephones: a simulator study, Accident Analysis & Prevention 26, 441-451.

Alm, H., Nilsson, L.,1995. The effects of a mobile telephone on driver behaviour in a car following situation, Accident Analysis & Prevention 27(5), 707-715.

Amick, M. M., Grace, J., & Ott, B. R. (2007). Visual and cognitive predictors of driving safety in Parkinson's disease patients. Arch Clin Neuropsychol, 22(8), 957-967. doi: 10.1016/j.acn.2007.07.004.

Anderson SW, Rizzo M, Skaar N, Stierman L, Cavaco S, Dawson J, Damasio H (2007) Amnesia and driving. J Clin Exp Neuropsychol 29, 1-12.

Arbuckle, J., Wothke, W., 1995. AMOS User's Guide. Version 4.0. SmallWaters Corporation, Chicago, IL.

Arminger, G., Clogg, C., Sobel, M., 1995. Handbook of Statistical Modeling for the Social and Behavioural Sciences. Plenum Press, NY.

Asimakopulos, J., Boychuck, Z., Sondergaard, D., Poulin, V., Menard, I., & Korner-Bitensky, N. (2012). Assessing executive function in relation to fitness to drive: a review of tools and their ability to predict safe driving. Aust Occup Ther J, 59(6), 402-427. doi: 10.1111/j.1440-1630.2011.00963.x

Asoh, T., Kimura, K., Ito, T., 2000. JAMA's Study on the location of in-vehicle displays. Paper 2000-01-C010, In SAE Conference Proceedings, pp. 37-42.

Baldock, M. R. J., Mathias, J., McLean, J., & Berndt, A. Visual attention as a predictor of on-road driving performance of older adults. Australian Journal of Psychology, 59, 2007, pp. 159-168.

Ball, K., & Owsley, C. (1993). The useful field of view test: a new technique for evaluating age-related declines in visual function. J Am Optom Assoc, 64(1), 71-79.

Ball, K., Ackerman, M., (2011). The older driver (Training and assessment: Knowledge skills and attitudes. Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press.

Ballard C, Gauthier S, Corbett A, et al. (19 March 2011). "Alzheimer's disease.". Lancet 377 (9770): 1019–31. doi:10.1016/S0140-6736(10)61349-9. PMID 21371747.

Benedict. R. H. B. (1997). Brief Visuospatial Memory Test—Revised. Psychological Assessment Resources, Inc, Odessa, FL.

Benedict, R. H. B., Schretlen, D., Groninger, L., & Brandt, J. (1998). Hopkins Verbal Leaning Test-Revised: Normative data and analysis of inter-form and test-retest reliability. The Clinical Neuropsychologist, 12, 43–55. doi: 10.1076/clin.12.1.43.1726.

Bennett DA, Wilson RS, Schneider JA, Evans DA, Beckett LA, Aggarwal NT, Barnes LL, Fox JH, Bach J. (2002). Natural history of mild cognitive impairment in older persons. Neurology. 2002 Jul 23;59(2):198-205.

Bentler, P., 1990. Comparative fit indexes in structural models. Psychological Bulletin 107, 238-246.

Bentler, P., Bonett, D., 1980. Significance tests and goodness of fit in the analysis of covariance structures. Psychological bulletin 88, 588-606.

Bentler, P., Weeks, D., 1980. Linear structural equations with latent variables. Psychometrika 45, 289-307.

Benton, A.L., 1994. Neuropsychological assessment. Annual Review of Psychology, 45, 1-23.

Beratis, I. N., Rabavilas, A. D., Kyprianou, M., Papadimitriou, G. N., & Papageorgiou, C. (2013). Investigation of the link between higher order cognitive functions and handedness. J Clin Exp Neuropsychol, 35(4), 393-403. doi: 10.1080/13803395.2013.778231.

Beratis I., Andronas N., Kontaxopoulou D., Fragkiadaki S., Liozidou A., Economou A., Papatriantafyllou J., Papantoniou P., Stefanis L., Yannis G., Papageorgiou S.G. (2015) "Motor abilities and driving performance in Parkinson's Disease" *Neurology*, April 6, 2015 vol. 84 no. 14 Supplement P3.023.

Bieliauskas L. A., Roper B. R., Trobe J., Green P., Lacy M. (1998). Cognitive measures, driving safety, and Alzheimer's disease. The Clinical Neuropsychologist, 12 (2), 206–212.

Bieliauskas LA, Roper BR, Trobe J, Lacy M (1998) Cognitive Measures, Driving Safety, and Alzheimer's Disease. The Clinical Neuropsychologist 12, 206-212.

Blaauw, G.J., 1982. Driving experience and task demands in simulator and instrumented car: a validation study, Human Factors 24, 473-486.

Blana E., Golias J., (2002), "Differences between vehicle lateral displacement on the road and in a fixed-base simulator", Human Factors, Vol. 44, 2.

Blomberg, O. (2011). "Concepts of cognition for cognitive engineering". International Journal of Aviation Psychology 21 (1): 85–104. doi:10.1080/10508414.2011.537561.

Bodis-Wollner, I., & Tzelepi, A. (1998). The push-pull action of dopamine on spatial tuning of the monkey retina: the effects of dopaminergic deficiency and selective D1 and D2 receptor ligands on the pattern electroretinogram. Vision Res, 38(10), 1479-1487.

Bollen, K., 1986. Sample size and Bentler and Bonett's nonnormed fit index. Psychometrika 51, 375-377.

Bollen, K., Long, J. Eds., 1993. Testing structural Equation Models. Sage, Newbury Park, CA.

Bollen, K., Stine, R., 1992. Bootstrapping goodness-of-fit measures in structural equation models. Sociological Methods and Research 21, 205-229.

Bowers, A.R., Anastasio, R.J., Sheldon, S.S., O'Connor, M.G., Hollis, A.M., Howe, P.D., Horowitz, T.S., 2013. Can we improve clinical prediction of at-risk older drivers? Accident Analysis and Prevention, 59, 537-547.

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.

Breen, J., 2009. Car telephone use and road safety, an overview prepared for the European Commission, European Commission.

Brookhuis, K.A., de Vries, G., de Waard, D., 1991. The effects of mobile telephoning on driving performance, Accident Analysis & Prevention 23(4), 309-316.

Brown LB, Ott BR, Papandonatos GD, Sui Y, Ready RE, Morris JC (2005). Prediction of on-road driving performance in patients with early Alzheimer's disease. Journal of the American Geriatrics Society 53, 94-98.

Brown LB, Stern RA, Cahn-Weiner DA, Rogers B, Messer MA, Lannon MC, Maxwell C, Souza T, White T, Ott BR (2005) Driving scenes test of the Neuropsychological Assessment Battery (NAB) and on-road driving performance in aging and very mild dementia. Arch Clin Neuropsychol 20, 209-215.

Brown, L. B. & Ott, B. R. (2004). Driving and Dementia: A Review of the Literature. Journal of Geriatric Psychiatry and Neurology, 17 (4), 232-240.

Browne, M., 1984). Asymptotically distribution-free methods for the analysis of covariance structures. British Journal of Mathematics and Statistical Psychology 37, 62-83.

Browne, M., Cudeck, R., 1989. Single sample cross-validation indices for covariance structures. Multivariate Behavioural Research 24, 445-455.

Browne, M., Cudeck, R., 1993. Alternative ways of assessing model fit. In Testing Structural Equation Models, Bollen, K., Long, J., Sage, Eds., Newbury Park, CA, 136-162.

Burns A, Iliffe S (5 February 2009). "Alzheimer's disease". BMJ 338: b158. doi:10.1136/bmj.b158. PMID 19196745.

Burns, P.C., Parkes, A., Burton, S., Smith, R.K., Burch, D., 2002. How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol, TRL Limited, Crow Thorne, UK.

Byrne, B., 1989. A primer of LISREL: Basic Applications and Programming for Confirmatory Factor Analytic Methods. Springer-Verlag, NY.

Caird, J. K., Chisholm, S., & Lochhart, J. (2008). The effect of in-vehicle advanced signs on older and younger drivers' intersection performance. International Journal of Human Computer Studies, 66(3), 132–144.

Caird, J.K., Horrey, W. Twelve practical and useful questions about driving simulation. In Fisher, D.L., Rizzo, M., Caird, J.K., & Lee, J.D. (Eds). (2011). Handbook of Driving Simulation for Engineering, Medicine, and Psychology. Boca Raton, FL:, 2011, CRC Press.

Caird, J. K., Chisholm, S., Edwards, C., & Creaser, J. (2007). The effect of yellow light onset time on older and younger drivers' perception response time (PRT) and intersection behavior. Transportation Research: Part F, 10(5), 383–396.

Caird, J.K., Willness, C.R., Steel, P., Scialfa, C., 2008. A meta-analysis of the effects of cell phones on driver performance. Accident Analysis & Prevention 40 (4),1282–1293.

Cameron I.M., Crawford J.R., Lawton K., et al; Psychometric comparison of PHQ-9 and HADS for measuring depression severity in primary care. Br J Gen Pract. 2008 Jan;58(546):32-6. doi: 10.3399/bjgp08X263794.

Carmines, E., McIver, J., 1981. Analyzing models with unobserved variables. In Social Measurement: Current Issues, G. Bohrnstedt and E. Borgatta, Eds. Sage, Beverly Hills, CA.

Carr D. B,, Duchek J,, Morris J, C. (2000). Characteristics of motor vehicle crashes in drivers with dementia of the Alzheimer type. Journal of the American Geriatrics Society, 48, 18–22.

Carsten, O.M.J., Groeger, J.A., Blana, E., Jamson, A.H., 1997. Driver Performance in the EPSRC Driving Simulator (LADS): A Validation Study. Final report for EPSRC project GR/K56162, Leeds University, UK.

Casali, J. G., & Frank, L. H. (1988). Manifestation of visual/vestibular disruption in simulators: Severity and empirical measurement of symptomatology. In AGARD, Motion cues in flight simulation and simulator induced sickness (AGARD Conference Proceedings No. 433, pp. 11.1-11.18). Neuilly Sur Seine, France: Advisory Group for Aerospace Research and Development.

Cattell, R., Burdsal, C., 1975. The radial parcel double factoring design: a solution to the item-vs.-parcel controversy. Multivariate Behavioural Research 10, 165-179.

Century Dictionary, (1891)

Chiang, D.P., Brooks, A.M., Weir, D.H.D.H., 2004. On the Highway measures of driver glance behaviour with an example automobile navigation system, Applied Ergonomics 35(3), 215-223.

Chu, X. (1994). The effect of age on driving habits of the elderly: Evidence from the 1990 national personal transportation study (Rep. DOT-T-95-12). Washington, DC: US Department of Transportation.

Chou, C., Bentler, P., Satorra, A., 1991. Scaled test statistics and robust standard errors for non-normal data in covariance structure analysis: a Monte Carlo study. British Journal of Mathematical and Statistical Psychology 44, 347-357.

Classen, S., McCarthy, D. P., Shechtman, O., Awadzi, K. D., Lanford, D. N., Okun, M. S., . . . Fernandez, H. H. (2009). Useful field of view as a reliable screening measure of driving performance in people with Parkinson's disease: results of a pilot study. Traffic Inj Prev, 10(6), 593-598. doi: 10.1080/15389580903179901.

Classen, S., Witter, D. P., Lanford, D. N., Okun, M. S., Rodriguez, R. L., Romrell, J., Malaty, I., & Fernandez, H. H. (2011). Usefulness of screening tools for predicting driving performance in people with Parkinson's disease. The American Journal of Occupational Therapy, 65, 579-588.

Clay, O. J., Wadley, V. G., Edwards, J. D., Roth, D. L., Roenker, D. L., & Ball, K. 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(8), 724–731.

Cobb, S., Nichols, S., Ramsey, A., Wilson, J., 1999. Virtual reality-induced symptoms and effects (VRISE). Presence 8 (2), 169–186.

Cordell, R., H. C. Lee, et al. Driving assessment in Parkinson's disease - a novel predictor of performance?. Mov Disord 23(9), 2008, pp 1217-1222.

Cox D. J., Quillian W. C., Thorndike F.P. (1998). Evaluating driving performance of outpatients with Alzheimer disease. The Journal of the American Board of Family Medicine, 11, 264-271.

Crizzle, A. M., Myers, A. M., & Almeida, Q. J. (2012). Drivers with Parkinson's disease: who participates in research studies? Parkinsonism Relat Disord, 18(7), 833-836. doi: 10.1016/j.parkreldis.2012.04.003

Crowe, S. F. (1998). The differential contribution of mental tracking, cognitive flexibility, visual search, and motor speed to performance on parts A and B of the Trail Making Test. J Clin Psychol, 54(5), 585-591.

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

Cummings, J. L. (1997). The Neuropsychiatric Inventory: Assessing psychopathology in dementia patients. Neurology, 48, S10-S16.

Cuenen A., Jongen E., Brijs T., Brijs K., Lutin M., Vlierden K., Wets G., (2015). The relations between specific measures of simulated driving ability and functional ability: New insights for assessment and training programs of older drivers, Transportation Research Part F, Traffic Psychology and Behaviour 06/2015; DOI:10.1016/j.trf.2015.05.007Daniel, C., Wood, F., 1980. Fitting equations to Data. John Wiley & Sons, NY.

Dawson JD, Anderson SW, Uc EY, Dastrup E, Rizzo M (2009) Predictors of driving safety in early Alzheimer disease. Neurology 72, 521-527.

De Raedt R, Ponjaert-Kristoffersen I. (2001). Short cognitive/neuropsychological test battery for first-tier fitness-to-drive assessment of older adults. Clinical Neuropsychology, 15, 329-336.

De Veaux, R., 1990. Finding transformations for regression using the ACE algorithm. In Modern Methods of Data Analysis, J. Fox and J.S. Long, Eds. Sage, Newbury Park, CA, 177-208.

De Waard, D., 1996. The measurement of drivers' mental workload. Doctoral dissertation, University of Groningen, Haren, the Netherlands, Traffic Research Centre.

Deffenbacher, J. L., Oetting, E. R., Lynch, R. S., 1994. Development of a driving anger scale. Psychological Reports, 74, 83-91.

Department for Transport, 2008. Reported road casualties, Great Britain 2008: Annual Report.

Derrick, W. L., 1988. Dimensions of Operator Workload. Human Factors, 30(1), 95-110.

Devlin A, McGillivray J, Charlton J, Lowndes G, Etienne V. (2012). Investigating driving behaviour of older drivers with mild cognitive impairment using a portable driving simulator. Accident Analysis & Prevention, 49, 300-307.

Di Stefano, M., & McDonald, W. (2003). Assessment of older drivers: Relationships among on-road errors, medical conditions and test outcome. Journal of Safety Research, 34, 415–429.

Dingus T.A., Guo F., Lee S., Antin J.F., Perez M., Buchanan-King M., Hankey J. (2016), Driver crash risk factors and prevalence evaluation using naturalistic driving data, Proceedings of the National Academy of Sciences of the United States of America, vol. 113 no. 10, pp. 2636–2641, doi: 10.1073/pnas.1513271113

Donmez, B., Boyle, L., Lee, J., McGehee, D., 2006. Drivers' attitudes toward imperfect distraction mitigation strategies, Transportation Research Part F, n.9, pp.387–398.

Drachman D. A., Swearer J. M., the Collaborative Group. (1993). Driving and Alzheimer's disease: the risk of crashes. Neurology, 43, 2448-2456.

Dragutinovits, N., Twisk, D., 2005. Use of mobile phones while driving – effects on road safety SWOV publication R-2005-12 7 SWOV Institute for Road Safety Research - Leidschendam, the Netherlands.

Dubinsky RM, Stein AC, Lyons K (2000) Practice parameter: risk of driving and Alzheimer's disease (an evidence-based review): report of the quality standards subcommittee of the American Academy of Neurology. Neurology 54, 2205-2211.

Dubinsky RM, Williamson A, Gray CS, Glatt SL (1992) Driving in Alzheimer's disease. J Am Geriatr Soc 40, 1112-1116.

Dubinsky, R. M., Gray, C., Husted, D., Busenbark, K., Vetere-Overfield, B., Wiltfong, D., . . . Koller, W. C. (1991). Driving in Parkinson's disease. Neurology, 41(4), 517-520.

Dubois, B, &Pillon, B. (1997). Cognitive deficits in Parkinson's disease. Journal of Neurology, 244, 2-8.

Dubois, R., Slachevsky, A., Litvan, I., & Pillon, B. (2000) The FAB: A frontal assessment battery at bedside. Neurology 55, 1621–1628.

Duchek J.M., Carr D.B., Hunt L., Roe C.M., Xiong C., Shah K., Morris J.C. (2003). Longitudinal Driving Performance in Early-Stage Dementia of the Alzheimer Type. Journal of the American Geriatrics Society, 51, 1342–1347.

Duchek J. M., Hunt L., Ball K., Buckles V., Morris J. C. (1998). Attention and Driving Performance in Alzheimer's disease. Journal of Gerontology: Psychological Sciences, 53B, 130-141.

Duchek, J. M., Hunt, L., Ball, K., Buckles, V., & Morris, J. C. (1997). The role of selective attention in driving and dementia of the Alzheimer's type. Alzheimer Disease and Associated Disorders, 11 (Suppl. 1), 48– 56.

Eby DW, Silverstein NM, Molnar LJ, LeBlanc D, Adler G (2012) Driving behaviours in early stage dementia: a study using in-vehicle technology. Accid Anal Prev 49, 330-337.

Economou A., Papageorgiou S.G., Karageorgiou C., Vassilopoulos D., (2007), Nonepisodic Memory Deficits in Amnestic MCI, Cognitive and Behavioral Neurology 20(2):99-106 · July 2007

Efron, B., Tibshirani, R., 1986. Bootstrap methods for standard errors, confidence intervals and other measures of statistical accuracy. Statistical Science 1, 54-74.

Elkin-Frankston S, Lebowitz BK, Kapust LR, Hollis AM, O'Connor MG (2007) The use of the Color Trails Test in the assessment of driver competence: preliminary report of a culture-fair instrument. Arch Clin Neuropsychol 22, 631-635.

Elvik R, Vaa T., 2004. The handbook of road safety measures. Amsterdam, Elsevier Science.

Emerson, J. and Stoto, M. (1983). Transforming data. In understanding Robust and Exploratory Data Analysis, D.C. Hoaglin, F. Mosteller, and J. Tukey, Eds. John Wiley & Sons, NY, 97-127.

Emery, L., Heaven, T. J., Paxton, J. L., & Braver, T. S. (2008). Age-related changes in neural activity during performance matched working memory manipulation. Neuroimage, 42, 1577-1586.

Engström, J., Johansson, E., Östlund, J., 2005. Effects of visual and cognitive load in real and simulated motorway driving. Transportation Research Part F: Traffic Psychology and Behaviour, 8, 97-120.

Ernst J, Krapp S, Schuster T, Förstl H, Kurz A, Diehl-Schmid J. Car driving ability of patients with frontotemporal lobar degeneration and Alzheimer's disease. Nervenarzt. 2010;81: 79–85. doi: 10.1007/s00115-009-2847-5

Etienne V., Marin-Lamellet C., Laurent B., 2013, Mental flexibility impairment in drivers with early Alzheimer's disease: A simulator-based study, IATSS Research Volume 37, Issue 1, July 2013, pp.16–20, doi:10.1016/j.iatssr.2013.06.005

Evans, L., 2004. Traffic safety. Bloomfield Hills, MI: Science Serving Society.

European Commission - Transport-Road Safety, March (2016), CARE EU road accidents database, http://ec.europa.eu/transport/road_safety/specialist/statistics/index_en.htm

Finch, J., Curran, P., West, S., 1994. The effects of model and data characteristics on the accuracy of parameter estimates and standard errors in confirmatory factor analysis. Unpublished manuscript. University of North Carolina. Chapel Hill, NC.

Fisher R.A., (1934), Discussion of "Statistics in agricultural research" by J. Wishart, Journal of the Royal Statistical Society, Supplement, 1, 26-61

Fitten LJ, Perryman KM, Wilkinson CJ, Little RJ, Burns MM, Pachana N, Mervis JR, Malmgren R, Siembieda DW, Ganzell S (1995) Alzheimer and vascular dementias and driving. A prospective road and laboratory study. JAMA 273, 1360-1365.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). ""Mini-mental state". A practical method for grading the cognitive state of patients for the clinician". Journal of Psychiatric Research 12, 189–198. doi: 10.1016/0022-3956(75)90026-6.

Forbes D, Thiessen EJ, Blake CM, Forbes SC, Forbes S (4 December 2013). "Exercise programs for people with dementia". The Cochrane Database of Systematic Reviews 12: CD006489. doi:10.1002/14651858.CD006489.pub3. PMID 24302466.

Fowler, H.W.; Fowler, F.G., eds. (1976). Pocket Oxford Dictionary. Oxford University Press. ISBN 978-0198611134.

Fox G. K., Bowden S. C., Bashford G. M., Smith D. S. (1997). Alzheimer's disease and driving: prediction and assessment of driving performance. Journal of the American Geriatrics Society, 45, 949-953.

Fragkiadaki S., Kontaxopoulou D., Beratis I., Andronas N., Economou A., Yannis G., Papanicolaou A., Papageorgiou S.G., (2016), Self-awareness of cognitive efficiency: differences between healthy elderly and patients with Mild Cognitive Impairment (MCI), Journal of Clinical and Experimental Neuropsychology, accepted for publication.

Frantzeskakis, I., Giannopoulos, G., 1986. Transportation Planning and Traffic Engineering. Paratiritis Publications, Athens.

Freund B., Gravenstein S., Ferris R., Shaheen E. (2002). Evaluating driving performance of cognitive impaired and healthy older adults: a pilot study comparing on-road testing and driving simulation. Journal of the American Geriatrics Society, 50, 1315.

Freund, B., Gravenstein, S., Ferris, R., Burke, B., Shaheen, E., 2005. Drawing clocks and driving cars: Use of Brief Tests of Cognition to Screen Driving Competency in Older Adults. J Gen Intern Med. 20 (3), pp. 240-4.

Friedland, R. P., Koss, E., Kumar, A., Gaine, S., Metzler, D., Haxby, J. V., & Moore, A. (1988). Motor vehicle crashes in dementia of the Alzheimer type. Annals of Neurology, 24, 782-786.

Fritsch, T., Smyth, K. A., Wallendal, M. S., Hyde, T., Leo, G., & Geldmacher, D. S. (2012). Parkinson disease: research update and clinical management. South Med J, 105(12), 650-656. doi: 10.1097/SMJ.0b013e318273a60d.

Frittelli C, Borghetti D, Iudice G, Bonanni E, Maestri M, Tognoni G, Pasquali L, Iudice A (2009) Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test. Int J Geriatr Psychiatry 24, 232-238.

Gardezi F, Wilson KG, Man-Son-Hing M, Marshall SC, Molnar FJ, Dobbs BM, Tuokko HA (2006) Qualitative Research on Older Drivers. Clinical Gerontologist 30, 5-22.

Gaudino, E. A., Geisler, M. W., & Squires, N. K. (1995). Construct validity in the Trail Making Test: what makes Part B harder? J Clin Exp Neuropsychol, 17(4), 529-535. doi: 10.1080/01688639508405143

Gazewood, J. D., Richards, D. R., & Clebak, K. (2013). Parkinson disease: an update. Am Fam Physician, 87(4), 267-273.

GBD 2013 Mortality and Causes of Death, Collaborators (17 December 2014). "Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013.". Lancet 385: 117–71. doi:10.1016/S0140-6736(14)61682-2. PMC 4340604. PMID 25530442.

Gibson, J.J., 1986. The ecological approach to visual perception. Hillsdale, NJ: Lawrence Erlbaum.

Godley, S.T., Triggs, T.J., and Fildes, B.N., 2002. Driving simulator validation for speed research, Accident Analysis and Prevention 34 (5), 589-600.

Golias J., Matsoukis E., Yannis G., (1997), "An Analysis of Factors Affecting Road Safety: The Greek Experience", Journal of the Institute of Transportation Engineers, Nov. 1997.

Gopher, D., Donchin, E., 1986. Workload - An examination of the concept. Handbook of perception and human performance, 2, 41-49.

Gorrie, C.A., Brown, J., Waite, P.M.E., 2008. Crash characteristics of older pedestrian fatalities: dementia pathology may be related to 'at risk' traffic situations. Accid. Anal. Prev. 40, 912–919.

Grace, J., Amick, M. M., D'Abreu, A., Festa, E. K., Heindel, W. C., & Ott, B. R. (2005). Neuropsychological deficits associated with driving performance in Parkinson's and Alzheimer's disease. J Int Neuropsychol Soc, 11(6), 766-775. doi: 10.1017/S1355617705050848.

Green, M. (2000). "How long does it take to stop?" Methodological analysis of driver perception-brake times. Transportation Human Factors, 2(3), 195–216.

Green, P. (2007). Where do drivers look while driving (and for how long)? In R. E. Dewar & R. Olson (Eds.), Human factors in traffic safety (2nd ed., pp. 57–82). Tucson, AZ: Lawyers &

Judges Publishing. Greenberg, J., Artz, B., Cathey, L., 2003. The effect of lateral motion cues during simulated driving. Proceedings of Driving Simulation Conference North America 2003, Dearborn, MI.

Goetz C.G., Tilley B.C., Shaftman S.R., et al., (2008), Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale Presentation and Clinimetric Testing Results, Movement Disorders, Vol. 23, No. 15, 2008, pp. 2129–2170

Griffith HR, Okonkwo OC, Stewart CC, Stoeckel LE, Hollander JA, Elgin JM, Harrell LE, Brockington JC, Clark DG, Ball KK, Owsley C, Marson DC, Wadley VG. (2013). Lower hippocampal volume predicts decrements in lane control among drivers with amnestic mild cognitive impairment. J Geriatr Psychiatry Neurol. 2013 Dec; 26(4):259-66. doi: 10.1177/0891988713509138.

Guerrero, Anthony (2008). Problem-Based Behavioural Science of Medicine. New York: Springer. pp. 367–79.

Gullikson, H., Tukey, J., 1958. Reliability for the law of comparative judgment. Psychometrika 23, 95-110.

Guttman, L. (1954). Some necessary conditions for common-factor analysis. Psychometrika, 19, 149-161.

Haigney, D.E., Taylor, R.G., Westerman, S.J., 2000. Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes. Transportation Research Part F, 3, 113-121.

Hakamies-Blomqvist, L., 1993. Fatal accidents of older drivers. Accident Analysis and Prevention, 25, 19-27.

Hankey, J.M., Wierwille, W.W., Cannell, W.J., Kieliszewski, C.A., Medina, A., Dingus, T.A., Cooper, L.M., 1999. Identification and Evaluation of Driver Errors: Task C Report, Driver Error Taxonomy Development (Draft Technical Report). Project No. DTFH-61-97-C-00051. Center for Transportation Research, Blacksburg, VA, Virginia Tech.

Harbluk, J.L., Noy, Y.I., Eizenman, M., 2002. The impact of cognitive distraction on driver visual behaviour and vehicle control, Report No. TP No. 13889 E, Road Safety Directorate and Motor Vehicle Regulation Directorate, Ottawa, Canada.

Harms, L., 1992. Experimental studies of dual-task performance in a driving simulator – the relationship between task demands and subjects' general performance, IATSS Research 16(1), 35-41.

Harnois, C., & Di Paolo, T. (1990). Decreased dopamine in the retinas of patients with Parkinson's disease. Invest Ophthalmol Vis Sci, 31(11), 2473-2475.

Hastie T. and Tibshirani R., (1990), Generilized Additive Models, Chapman and Hall

Chaudhuri K R, Pal S, DiMarco A, C Whately-Smith, K Bridgman, R Mathew, F R Pezzela, A Forbes, B Högl, C Trenkwalder, (2002) The Parkinson's disease sleep scale: a new instrument for assessing sleep and nocturnal disability in Parkinson's disease, J Neurol Neurosurg Psychiatry 2002; 73:629–635

Heikkilä, V. M., Turkka, J., Korpelainen, J., Kallanranta, T., &Summala, H. (1998). Decreased driving ability in people with Parkinson's disease. Journal of Neurology Neurosurgery & Psychiatry, 64, 325-330.

Hellenic Statistical Authority, 2014. Road Accident data, El.STAT.

Hill, J., Aldah, M., Talbot, R., Giustiniani, G., Fagerlind, H., Jänsch, M., 2012. Final Report, Deliverable 2.5 of the EC FP7 project DaCoTA.

Ho, G., Scialfa, C. T., Caird, J. K., & Graw, T. (2001). Traffic sign conspicuity: The effects of clutter, luminance, and age. Human Factors, 43(2), 194–207.

Horberry, T., Anderson, J., Regan, M.A., Triggs, T.J., Brown, J., 2006. Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. Accident Analysis and Prevention, n.38, pp.185-191.

Horswill, M. S., & Plooy, A. M. (2008). Reducing contrast makes speeds in a video-based driving simulator harder to discriminate as well as making them appear slower. Perception, 37, 1269–1275.

Hoyle, R., 1995. Structural Equation modeling: Concepts, Issues, and Applications. Sage, Thousand Oaks, CA.

Hu, J., Bentler, P., Kano, Y., 1992. Can test statistics in covariance structure analysis be trusted? Psychological Bulletin 112, 351-362.

Hughes CP, Berg L, Danziger WL, Coben LA, Martin RL (1982) A new clinical scale for the staging of dementia. Br J Psychiatry 140, 566-572.

Hunt LA, Murphy CF, Carr D, Duchek JM, Buckles V, Morris JC (1997) Reliability of the Washington University Road Test. A performance-based assessment for drivers with dementia of the Alzheimer type. Arch Neurol 54, 707-712.

Hunt, L., Morris, J. C, Edwards, D., & Wilson, B. S. (1993). Driving performance in persons with mild senile dementia of the Alzheimer type. Journal of the American Geriatric Society, 41, 747-753.

International Transport Forum (2008). "Towards Zero, Ambitious Road Safety Targets and the Safe System Approach". OECD. Retrieved 26 January 2012. It recognises that prevention efforts notwithstanding, road users will remain fallible and crashes will occur.

Iverson DJ, Gronseth GS, Reger MA, Classen S, Dubinsky RM, Rizzo M (2010) Practice parameter update: evaluation and management of driving risk in dementia: report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology 74, 1316-1324.

Jacobs G, Aeron-Thomas A, Astrop A., 2000. Estimating global road fatalities. Crowthorne, Transport Research Laboratory, (TRL Report 445).

Jamson, A.H., 2001. Image characteristics and their effect on driving simulator validity. Proceedings of the first international driving symposium on human factors in driver assessment, training and vehicle design (pp.190-195). Aspen, CO.

Jamson, A.H., Westerman, S.J., Hockey, G.R.J., Carsten, O.M.J., 2004. Speech-based e-mail and driver behaviour: effects of an in-vehicle message system interface, Human Factors 46 (4), 625-639.

Johansson K, Lundberg C (1997) The 1994 International Consensus Conference on Dementia and Driving: a brief report. Swedish National Road Administration. Alzheimer Dis Assoc Disord 11 Suppl 1, 62-69.

Johnson DA, Frank O, Pond D, Stocks N (2013) Older people with mild cognitive impairment -- their views about assessing driving safety. Aust Fam Physician 42, 317-320.

Johns MW (1991). "A new method for measuring daytime sleepiness: the Epworth sleepiness scale" (PDF). Sleep 14 (6): 540–5. PMID 1798888

Jorm AF, Scott R, Cullen JS, et al; Performance of the Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE) as a screening test for dementia. Psychol Med. 1991 Aug;21(3):785-90.

Jolliffe I.T. Principal Component Analysis, Series: Springer Series in Statistics, 2nd ed., Springer, NY, 2002, XXIX, 487 p. 28 illus. ISBN 978-0-387-95442-4.

Jones M.B., Kennedy R.S., Stanney K.M., Toward systematic control of cybersickness, Presence, 13 (5) (2004), pp. 589–600

Joreskog, K., 1969. A general approach to confirmatory maximum likelihood factor analysis. Psychometrika 34, 138-202.

Kaptei, N.A., Theeuwes, J., van der Horst, R., 1996. Driving simulator validity: some considerations, Transportation Research Record 1550, 30, 1996.

Kaszniak, A. W., Nussbaum, P., & Allender, J. A. (1990), Driving in elderly patients with dementia or depression. Paper presented at the 98th Annual Convention of the American Psychological Association, Boston, MA.

Kawano N, Iwamoto K, Ebe K, Suzuki Y, Hasegawa J, Ukai K, Umegaki H, Iidaka T, Ozaki N. (2012). Effects of mild cognitive impairment on driving performance in older drivers. Journal of the American Geriatrics Society, 60(7), 1379-1381.

Kearney & Grechkin, (2011), Handbook of driving simulation for engineering, medicine, and psychology, Chapter 6

Keay, L., Munoz, B., Turano, K. A., Hassan, S. E., Munro, C. A., Duncan, D. D., West, S. K. (2009). Visual and cognitive deficits predict stopping or restricting driving: The Salisbury Eye Evaluation Driving Study (SEEDS). Investigative Ophthalmology, 50, 107-113. doi:10.1167/iovs.08-2367

Kelley, K., Clark, B., Brown, V., Sitzia, J., 2003. Good practice in the conduct and reporting of survey research, International Journal for Quality in Health care, Volume 15, N 3, pp. 261-266.

Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G., 1993. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The international journal of aviation psychology 3, 203-220.

Kertesz A, Davidson W, Fox H. Frontal Behavioral Inventory: Diagnostic criteria for frontal lobe dementia. Can J Neurol Sci. 1997;24:29–36.

Kircher, K., 2007. Driver distraction - A review of the literature. VTI Report 594A. VTI, Linköping, Sweden.

Kline, D., & Dewar, R. (2004). The aging eye and transport signs. In C. Castro & T. Horberry (Eds.), The human factors of transport signs (pp. 115–134). New York: CRC Press.

Kline, R., 1998. Principles and Practice of Structural Equation Modeling. Guilford Press, NY.

Kortte, K. B., Horner, M. D., & Windham, W. K. (2002). The trail making test, part B: cognitive flexibility or ability to maintain set? Appl Neuropsychol, 9(2), 106-109. doi: 10.1207/s15324826an0902_5.

LaBerge, D., 1997. Attention, awareness, and the triangular circuit. Consciousness and Cognition, 6, 148-181.

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. J Geriatr Psychiatry Neurol, 21(3), 171-182. doi: 10.1177/0891988708316861.

Lajunen, T., Summala, H., 1995. Driver experience, personality, and skill and safety motive dimensions in drivers' self-assessments. Personality and Individual Differences, 19, 307-318.

Lamble, D., Kauranen, T., Laakso, M., & Summala, H. (1999). Cognitive load and detection thresholds in car following situations: Safety implications for using mobile telephone (cellular) telephones while driving. Accident Analysis & Prevention, 31, 617–623.

Lamble, D., Rajalin, S., Summala, H., 2002. Mobile phone use while driving: public opinions on restrictions, Transportation 29, 233-236.

Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist. 1969;9(3):179-186.

Lazano, R., Naghavi, M., Foreman, K., Lim, S., Shibuya, K., Aboyans, V., Abraham, J., Adair, T., Aggarwal, R., Ahn, S.Y., AlMazroa, M.A, Alvarado, M., Anderson, H.R., Anderson, L.M., Andrews, K.G., Atkinson, C., Baddour, L.M., Barker-Collo, S., Bartels, D.H., Bell, M.L., Benjamin, E.J., 2012. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet, 380:2095–2128.

Lee, H., Falkmer, T., Rosenwax, L., Cordell, R., Granger, A., Vieira, B. and Lee, A. (2007). Validity of Driving Simulator in Assessing Drivers with Parkinson's disease. Advances in transportation studies,Special Issue, 81-90.

Lee, J.D., Young, K.L., Regan, M.A., 2008. Driver Distraction, Theory, Effects and Mitigation, CRC Press, Taylor and Francis Group.

Lesikar S. E., Gallo J. J., Rebok G. W., Keyl P. M. (2002). Prospective study of brief neuropsychological measures to assess crash risk in older primary care patients. The Journal of the American Board of Family Practice, 15, 11-19.

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). Neuropsychological Assessment (4th ed.). New York, NY: Oxford University Press.

Lincoln NB, Taylor JL, Vella K, et al. (2009) A prospective study of cognitive tests to predict performance on a standardised road test in people with dementia. International Journal of Geriatric Psychiatry 25: 489–96.

Lozano R, Naghavi M, Foreman K (15 December 2012). "Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010.". Lancet 380 (9859): 2095–128. doi:10.1016/S0140-6736(12)61728-0. PMID 23245604.

Lucas-Blaustein MJ, Filipp L, Dungan C, Tune L (1988) Driving in patients with dementia. J Am Geriatr Soc 36, 1087-1091.

MacCallum, R., 1990. The need for alternative measures of fit in covariance structure modeling. Multivariate Behavioural Research 25, 157-162.

Manly, B., 1986. Multivariate Statistical Methods, A Primer. Chapman & Hall, NY.

Man-Son-Hing, M., Marshall S., Molnar, F. & Wilson, K. (2007). Systematic Review of Driving Risk and the Efficacy of Compensatory Strategies in Persons with Dementia. Journal of the American Geriatrics Society, 55, 878-884.

Marottoli, R.A., Richardson, E.D., Stowe, M.H., Miller, E.G., Brass, L.M. & Cooney Jr., L.W. (1998). Development of a test battery to identify older drivers at risk for self-reported adverse driving events. The Journal of the American Geriatrics Society.46, 562-568.

Marsh, H., Hocevar, D., 1985. Application of confirmatory factor analysis to the study of self-concept: first-and higher-order factor models and their invariance across groups. Psychological Bulletin 97, 562-582.

Massie DL, Campbell KL (1993) Accident involvement rates by age and gender. UMTRI Research Review 23, 1-20.

Mathias, J. L., & Lucas, L. K. (2009). Cognitive predictors of unsafe driving in older drivers: a meta-analysis. Int Psychogeriatr, 21(4), 637-653. doi: 10.1017/S1041610209009119.

Mauri M., Sinforiani E., Cuzzoni M.G., Bono G., Zuchella Z., (2014), Driving habits in patients with dementia: a report from Alzheimer's disease assessment units in northern Italy, functional Neurology, 2014, 29(2)

McEvoy, S.P., Stevenson, M.R., McCartt, A.T., Woodward, M., Haworth, C., Palamara, P., Cercarelli, R., 2005. Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. BMJ, Aug. 20; 331(7514):428, Epub 2005.

McLane, R.C., Wierwille, W.W., 1975. The influence of motion and audio cues on driver performance in an automobile simulator, Human Factors 17, 488-501.

McLean, R., Anderson V., 1984. Applied factorial and fractional designs. Marcel Dekker Inc., New York, USA.

Meindorfner, C., Korner, Y., Moller, J. C., Stiasny-Kolster, K., Oertel, W. H., & Kruger, H. P. (2005). Driving in Parkinson's disease: mobility, accidents, and sudden onset of sleep at the wheel. Mov Disord, 20(7), 832-842. doi: 10.1002/mds.20412

Mendez MF (November 2012). "Early-onset Alzheimer's disease: nonamnestic subtypes and type 2 AD". Archives of Medical Research 43 (8): 677–85. doi:10.1016/j.arcmed.2012.11.009. PMID 23178565.

Meng A., Siren A., Teasdale T.W., (2013). Older drivers with cognitive impairment: Perceived changes in driving skills, driving-related discomfort and self-

regulation of driving, European Geriatric Medicine, Volume 4, Issue 3, June 2013, Pages 154–160, doi:10.1016/j.eurger.2013.01.002

Michon, J. (1989). Explanatory pitfalls and rule-based driver models. Accident Analysis & Prevention, 21(4), 341–353.

Miller, S., 2001. Literature review: Workload measures, National Advanced Driving Simulator, Document ID: N01-006.

Milloy S.L., Caird J.K., (2011), External Driver Distractions: The Effects of Video Billboards and Wind Farms on Driving Performance, Handbook of driving simulation for engineering, medicine, and psychology, Chapter 16.

Montgomery, D, 2000. Design and analysis of experiments. (5th ed.) Wiley and Sons, New York, USA.

Moray, N., 1979. Models and Measures of Mental Workload. In N. Moray (Ed.), Mental Workload (Vol. 8). New York: Plenum Press.

Moroney J.T., Bagiella E., Desmond D.W. Hachinski V.C., Molsa P.K., Gustafson L., Brun A., Fischer P., Erkinjuntti T., Rosen W., Paik M.C., Tatemichi T.K., (1997), Meta-analysis of the Hachinski Ischemic Score in pathologically verified dementias, Neurology October 1997 vol. 49 no. 4 1096-1105

Morris JC (1993) The Clinical Dementia Rating (CDR): current version and scoring rules. Neurology 43, 2412-2414.

Mulaik, S., James, L., Van Alstine, J., Bennett, N., Lind, S., Stilwell, C., 1989. Evaluation of goodness of fit indices for structural equation models. Psychological Bulletin 105, 430-445.

Muthen, B, 1984. A general structural equation model with dichotomous, ordered Categorical, and continuous latent variable indicators. Psychometrika 49, 115-132.

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. Journal of the American Geriatrics Society, 53, 695–699.

National Institute for Health and Clinical Excellence. "Low-dose antipsychotics in people with dementia". National Institute for Health and Care Excellence (NICE). Retrieved 29 November 2014.

Neurogenerative Disease Research Strategic Research Agenda 2016 (JPND-SRA 2016), http://www.neurodegenerationresearch.eu/fileadmin/Documents/2012/SRA-related/JPND_brochure_final_Hyperlink_2012.pdf

NHTSA, 2008. The impact of driver inattention on near-crash/crash risk: An analysis using the 100-Car Naturalistic driving study Data. US Department of Transportation.

Nilsson, L., Alm, H., 1991. Effects of Cell Telephone Use on Elderly Drivers' Behaviour Including Comparisons to Young Drivers' Behaviour (No. VTI Report No. 53).

O'Connor ML, Edwards JD, Bannon Y (2013) Self-rated driving habits among older adults with clinically-defined mild cognitive impairment, clinically-defined dementia, and normal cognition. Accid Anal Prev 61, 197-202.

O'Connor ML, Edwards JD, Wadley VG, Crowe M (2010) Changes in mobility among older adults with psychometrically defined mild cognitive impairment. J Gerontol B Psychol Sci Soc Sci 65b, 306-316.

Odenheimer, G.L., Beaudet, M., Jette, A.M., Albert, M.S., Grande. L., Minaker, K.L., 1994. Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. Journal of Gerontology. 49(4):153-159.

Okonkwo OC, Wadley VG, Ball K, Vance DE, Crowe M., (2008). Dissociations in visual attention deficits among persons with mild cognitive impairment. Neuropsychol Dev Cogn B Aging Neuropsychol Cogn. 2008 Jul; 15(4):492-505.

Okonkwo OC, Griffith HR, Vance DE, Marson DC, Ball KK, Wadley VG (2009) Awareness of functional difficulties in mild cognitive impairment: a multidomain assessment approach. J Am Geriatr Soc 57, 978-984.

Olivera-Souza, R. D., Moll, J., Passman, L. J., Cunha, F. C., Paes, F., Adriano, M. V., . . . Marrocos, R. P. (2000). Trail making and cognitive set-shifting. Arq Neuropsiquiatr, 58(3b), 826-829.

Olsen, K., Taylor, J. P., & Thomas, A. (2014). Mild Cognitive Impairment: safe to drive? Maturitas, 78, 82-85. doi: 10.1016/j.maturitas.2014.03.004.

Olson, P. L., & Farber, E. (2003). Forensic aspects of driver perception and response (2nd ed.). Lawyers & Judges, Tucson, AZ.

Olson, P. L., & Sivak, M. (1986). Perception-response time to unexpected roadway hazards. Human Factors, 28, 91–96.

Olstam, J.J., 2003. Traffic Generation for the VTI Driving Simulator. DSC North America 2003 Proceedings, Dearborn, Michigan, October 8-10, 2003 (ISSN 1546-5071).

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

Organisation for Economic Co-operation and Development, European Conference of Ministers of Transport. Paris, OECD, 2013.

Ott BR, Heindel W. C., Whelihan W. M., et al. (2000). A single-photon emission computed tomography imaging study of driving impairment in patients with Alzheimer's disease. Dementia and Geriatrics Cognitive Disorders, 11, 153-160.

Ott BR, Heindel W.C., Papandonatos G.D., Festa, E.K., Davis J.D., Daiello L.A., Morris J.C. (2008). A longitudinal study of drivers with Alzheimer disease. Neurology, 70, 1171–1178.

Ott BR, Daiello LA. (2010). How does dementia affect driving in older patients? Aging health, 6(1), 77-85.

Ott BR, Festa EK, Amick MM, Grace J, Davis JD, Heindel WC. (2008). Computerized maze navigation and on-road performance by drivers with dementia. Journal of Geriatric Psychiatry and Neurology, 21, 18-25.

Ott BR, Heindel WC, Papandonatos GD, Festa EK, Davis JD, Daiello LA, Morris JC (2008) A longitudinal study of drivers with Alzheimer disease. Neurology 70, 1171-1178.

Ott BR, Heindel WC, Whelihan WM, Caron MD, Piatt AL, DiCarlo MA. (2003). Maze Test performance and reported driving ability in early dementia. Journal of Geriatric Psychiatry and Neurology, 16,151-155.

Owsley C, Ball K, Sloane ME, Roenker DL, Bruni JR (1991) Visual/cognitive correlates of vehicle accidents in older drivers. Psychol Aging 6, 403-415.

Paas, F., Vanmerrienboer, J. J. G., 1993. The Efficiency of Instructional Conditions – an Approach to Combine Mental Effort and Performance-Measures. Human Factors, 35(4), 737-743.

Paccalin M, Bouche G, Barc-Pain S, Merlet-Chicoine I, Nedelec C, Gil R. (2005). Automobile driving among patients with dementia. Survey in the Poitou-Charentes region. La PresseMédicale, 24, 919-922.

Papageorgiou S.G., Beratis I., Andronas N, Economou A., Pavlou, D., Bonakis A., Tsivgoulis G., Stefanis L., Yannis G., (2014), "Predictors of driving performance in individuals with MCI: preliminary results", Congress of European Neurology, Istanbul, May-June 2014

Papageorgiou S.G., (2016), Driving errors, accidents and their predictors in patients with mild cognitive impairment (MCI) or mild Alzheimer's disease (AD), *Neurobiology of aging*, Vol.39, S.1, pg. s15.

Papantoniou, P., Papadimitriou, E., Yannis, G., 2013. Assessment of driving simulator studies on driver distraction. Advances in Transportation Studies, in press

Parasuraman, R., Nestor, P.G., 1991. Attention and Driving Skills in Aging and Alzheimer's disease, Human Factors: The Journal of the Human Factors and Ergonomics Society, 33, no. 5, 539-557.

Parkinson, D. (1989). Evidence for a dopaminergic innervation of cat primary visual cortex. Neuroscience, 30(1), 171-179.

Patel J., Ball, D. J., Jones H., 2008. Factors influencing subjective ranking of driver distractions. Accident Analysis and Prevention 40, 392-395.

Pavlou D., Papadimitriou E., Antoniou C., Papantoniou P., Yannis G., Golias J., Papageorgiou S., (2015a). "Driving behaviour of drivers with mild cognitive impairment and Alzheimer's disease: a driving simulator study", Proceedings of the 94th Annual meeting of the Transportation Research Board, Washington, January 2015.

Pavlou D., Papadimitriou E., Vardaki S., Papantoniou P., Andronas N., Yannis G., Golias J., Papageorgiou S., (2015b). "Driving performance profiles of drivers with Parkinson's disease", Proceedings of the 14th international conference on mobility and transport for elderly and disabled persons, University of Lisbon, Lisbon, July 2015.

Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A.A., Jarawan, E., Mathers, C., 2004, World report on road traffic injury prevention. Geneva, World Health Organization.

Perkinson MA, Berg-Weger ML, Carr DB, Meuser TM, Palmer JL, Buckles VD, Powlishta KK, Foley DJ, Morris JC (2005) Driving and dementia of the Alzheimer type: beliefs and cessation strategies among stakeholders. Gerontologist 45, 676-685.

Petersen RC (2004) Mild cognitive impairment as a diagnostic entity. J Intern Med 256, 183-194.

Petersen RC, Doody R, Kurz A, Mohs RC, Morris JC, Rabins PV, Ritchie K, Rossor M, Thal L, Winblad B. (2001). Current concepts in mild cognitive impairment. Archives in Neurology, 58, 1985-1992

Petersen RC, Smith GE, Ivnik RJ Tangalos EG, Schaid DJ, Thibodeau SN, Kokmen E, Waring SC, Kurland LT. (1995) Apolipoprotein E status as a predictor of the development of Alzheimer's disease in memory impaired individuals. Journal of the American Medical Association, 16, 1274-1278.

Petersen RC, Stevens JC, Ganguli M, Tangalos EG, Cummings JL, DeKosky ST (2001) Practice parameter: early detection of dementia: mild cognitive impairment (an evidence-based review). Report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology 56, 1133-1142.

Petridou, E., Moustaki, M., 2000.Human factors in the causation of road traffic crashes, European Journal of Epidemiology, 16, pp 819-826.

Piersma D, Fuermaier ABM, de Waard D, Davidse RJ, de Groot J, Doumen MJA, et al. (2016) Prediction of Fitness to Drive in Patients with Alzheimer's Dementia. PLoS ONE 11(2): e0149566. doi:10.1371/journal.pone.0149566

Pollatsek, A., Fisher, D.L., Pradhan, A.K., 2006. Identifying and remediating failures of selective attention in younger drivers. Current directions in Psychological Science, 15, 255-259.

Pollatsek A., Vlakveld W., Kappé B., Pradhan A.K., and Fisher D.L., 2011, Driving Simulators as Training and Evaluation Tools: Novice Drivers, Handbook of driving simulation for engineering, medicine, and psychology, Chapter 30.

Poysti, L., Rajalin, S., Summala, H., 2005. Factors influencing the use of cellular (mobile) phone during driving and hazards while using it, Accident Analysis & Prevention 37, 47-51.

Querfurth HW, LaFerla FM (28 January 2010). "Alzheimer's disease". The New England Journal of Medicine 362 (4): 329–44. doi:10.1056/NEJMra0909142. PMID 20107219.

Radford, K.A., Lincoln, N. B., Murray-Leslie, C., 2004. Validation of the stroke drivers screening assessment for people with traumatic brain injury. Brain Injury, 18, 775-786.

Rakauskas, M. E., Gugerty, L.J., Ward, N.J., 2004. Effects of naturalistic cell phone conversations on driving performance, Journal of Safety Research 35 (4), 453-464, 2004.

Ranchet M, Paire-Ficout L, Uc EY, Bonnard A, Sornette D, Broussolle E. (2013). Impact of specific executive functions on driving performance in people with Parkinson's disease. MovDisord. 2013 Dec; 28(14):1941-8. doi: 10.1002/mds.25660.

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.

Reason, J.T., 1978. Motion sickness adaptation: a neural mismatch model. Journal of the Royal Society of Medicine 71 (11), 819–829.

Reason, J., 1990. Human Error. Cambridge University Press, Cambridge.

Recarte, M.A., Nunes, L.M., 2003. Mental workload while driving: effects on visual search, discrimination and decision making, Journal of Experimental Psychology: Applied 9, 119-137.

Reed, M.P., Green, P.A., 1999. Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task, Ergonomics 42(8), 1015-1037.

Regan, M.A., Hallett, C. and Gordonb, C.P. (2011). Driver distraction and driver inattention: Definition, relationship and taxonomy, Accident Analysis and Prevention 43 (2011) 1771–1781.

Regan, M. A., Young, K. L., Johnston, I. J., 2005. Monash University Accident Research Centre Submission to the Parliamentary Road Safety Committee: Inquiry into Driver Distraction. Monash University Accident Research Centre, Clayton, Victoria.

Regan, M., Williamson, A., Grzebieta, R., Tao, L., 2012. Naturalistic driving studies: literature review and planning for the Australian Naturalistic Driving Study, A safe system: expanding the reach: Australasian College of Road Safety national conference, Sydney.

Regan, M.A., Lee, J.D., Young, K.L. (Eds.), 2008. Driver Distraction: Theory, Effects, and Mitigation. CRC Press Taylor & Francis Group, Boca Raton, FL, USA, pp. 31–40.

Reger M. A., Welsh R. K., Stennis Watson G., Cholerton B., Baker L., Craft S. (2004). The Relationship between Neuropsychological Functioning and Driving Ability in Dementia: A Meta-Analysis. Neuropsychology, 18, 85-93.

Rehmann A.J., Mitman R.D., Reynolds M.C., A handbook of flight simulation fidelity requirements for human factos research, Report No. DOT/FFF/CT-TN95/46, U.S. Department of transportation, Federal Aviation Administration, Atlantic City, NJ, 1995

Reisberg, B, Ferris SH, Kluger A, Frassen E, Jerzy W, De Leon MJ. (2008). Mild Cognitive Impairment (MCI): A historical perspective. International Psychogeriatrics, 20:1, 18-31

Reitan, R. (1979). Trail-making test. Arizona: Reitan Neuropsychology Laboratory.

Reuben, D. B. (1991). Dementia and driving. Journal of the American Geriatrics Society, 39, 1137-1138.

Reynolds, C. R. (2002). Comprehensive Trail Making Test: Examiner's manual. Austin, TX: Pro-Ed.

Rigdon, E., Schumacher, R., Wothke, W., 1998. A comparative review of interaction and nonlinear modeling. In Interaction and Nonlinear Effects in Structural Equation Modeling, R. Schumacher and G. Marcoulides, Eds. Lawrence Erlbaum Associates, Mahwah, NJ.

Rizzo M, McGehee DV, Dawson JD, Anderson SN (2001) Simulated car crashes at intersections in drivers with Alzheimer disease. Alzheimer Dis Assoc Disord 15, 10-20.

Rizzo, M., Jermeland, J., Severson, J., 2002. Instrumented vehicles and driving simulators. Gerontechnology, 1 (4), 291-296.

Roenker, D., Cissell, G., & Ball, K. (2003). Speed-of-processing and driving simulator training result in improved driving performance. Human Factors, 45(2), 218–233.

Royall, D., 2000. Executive cognitive impairment: a novel perspective on dementia. Neuroepidemiology, 19, 293-299.

Rumar, K., 1990. The basic driver error: late detection. Ergonomics 33 (10–11), 1281–1290.

Sabey, B.E., Taylor, H., 1980. The known Risks We Run: The Highway. TRRL Report SR 567, Crowthorne, TRRL.

Sagberg, F., 2001. Accident risk of car drivers during mobile telephone use. Int. J. Vehicle Design 26, 57–69.

Salmon, P., Young, K., Lenné, M., Williamson, A., Tomasevic, N., 2011. The Nature of Errors made by Drivers. Austroads Publication No. AP–R378/11. Austroads Ltd., Australia.

Satorra, A., 1990. Robustness issues in structural equation modeling: a review of recent developments. Quality and Quantity 24, 367-386.

Scialfa, C. T., Adams, E., & Giovanetto, M. (1991). Reliability of the Vistech Contrast Test System in a life-span sample. Optometry and Vision Science, 68, 270–274.

Setright, L. J. K. (2004). Drive On!: A Social History of the Motor Car. Granta Books. ISBN 1-86207-698-7.

Shaw P.J.A. (2003) Multivariate statistics for the Environmental Sciences, Hodder-Arnold. ISBN 0-340-80763-6.[page needed].

Sheikh, J.I., & Yesavage, J.A. (1986). Geriatric Depression Scale (GDS). Recent evidence and development of a shorter version. In T.L. Brink (Ed.), Clinical Gerontology: A Guide to Assessment and Intervention (pp. 165-173). NY: The Haworth Press, Inc.

Shelton, J. T., Elliott, E. M., Hill, B. D., Calamia, M. R., & Gouvier, W. D. (2009). A Comparison of Laboratory and Clinical Working Memory Tests and Their Prediction of Fluid Intelligence. Intelligence, 37, 283.

Sheridan, T., 2004. Driver distraction from a control theory perspective. Human Factors 46 (4), pp. 587-599.

Sims, R. V., Owsley, C., Allman, R. M., Ball, K., & Smoot, T. (1998). A preliminary assessment of the medical and functional factors associated with vehicle crashes by older adults. Journal of the American Geriatric Society, 46, 556–561.

Singh R, Pentland B, Hunter J, and Provan F. (2006). Parkinson's disease and driving ability. J NeurolNeurosurg Psychiatry. 2007 Apr; 78(4): 363–366.

Smith, A. (1991). Symbol Digit Modalities Test. Los Angeles, CA: Western Psychological Services.

Snellgrove CA (2005) in Australian Transport Safety Bureau Australian Capital Territory.

Soldatos CR, Dikeos DG, Paparrigopoulos TJ (June 2000). "Athens Insomnia Scale: validation of an instrument based on ICD-10 criteria". Journal of Psychosomatic Research 48 (6): 555–60. doi:10.1016/S0022-3999(00)00095-7. PMID 11033374

Sousanis, John (2011-08-15). "World Vehicle Population Tops 1 Billion Units". Wards Auto. Retrieved 2012-07-17.

Staplin, L., Lococo, K. H., Gish, K. W., Decina, L.E. (2003a). Model Driver Screening and Evaluation Program. Volume 2: Maryland Pilot Older Driver Study. Washington, D.C.: National Highway and Traffic Safety Administration. Retrieved October 15, 2003 from the World Wide Web: http://www.nhtsa.dot.gov/people/injury/olddrive/modeldriver/

Staplin, L., Lococo, K. H., Gish, K. W., Decina, L.E. (2003b). Model Driver Screening and Evaluation Program: Guidelines foe Motor Vehicle Administrators. . Washington, D.C.: National Highway and Traffic Safety Administration. Retrieved October 15, 2003 from the World Wide Web: http://www.nhtsa.dot.gov/people/injury/olddrive/modeldriver/

Staplin, L., Lococo, K.H., Stewart, J., Decina, L.E. (1998). Safe Mobility for Older People. Washington, D.C.: National Highway and Traffic Safety Administration. Retrieved October 15, 2003 from the World Wide Web: http://www.nhtsa.dot.gov/people/injury/ olddrive/safe/safe-toc.htm

Steiger, J., 1990. Structural model evaluation and modification: An interval estimation approach. Multivariate Behavioural Research 25, 173-180.

Steiger, J., Shapiro, A., Browne, M., 1985. On the multivariate asymptotic distribution and sequential chi-square statistics. Psychometrika 50, 253-263.

Stein A.C, Dubinsky R.M., (2011), Driving Simulator Performance in Patients with Possible and Probable Alzheimer's Disease, Ann Adv Automot Med. 2011 Oct; 55: 325–334. PMCID: PMC3256816

Stein, Ralph (1967). The Automobile Book. Paul Hamlyn.

Stern RA, White T (2003) NAB, Neuropsychological Assessment Battery: Attention Module Stimulus Book. Form 2, Psychological Assessment Resources.

Sternberg, R. J., & Sternberg, K. (2009). Cognitive psychology (6th Ed.). Belmont, CA: Wadsworth, Cengage Learning.

Stolwyk, R. J., Charlton, J. L., Triggs, T. J., Iansek, R., & Bradshaw, J. L. (2006). Neuropsychological function and driving ability in people with Parkinson's disease. J Clin Exp Neuropsychol, 28(6), 898-913. doi: 10.1080/13803390591000909

Stolwyk, R. J., Scally, K. A., Charlton, J. L., Bradshaw, J. L., Iansek, R., & Georgiou-Karistianis, N. (2015). Self-Regulation of Driving Behaviour in People with Parkinson Disease. Cogn Behav Neurol, 28(2), 80-91. doi: 10.1097/WNN.0000000000000058.

Stolwyk, R. J., Triggs, T. J., Charlton, J. L., Moss, S., Iansek, R., & Bradshaw, J. L. (2006). Effect of a concurrent task on driving performance in people with Parkinson's disease. Mov Disord, 21(12), 2096-2100. doi: 10.1002/mds.21115.

Strauss, E., Sherman, E. M. S., Spreen, O., & Spreen, O. (2006). A compendium of neuropsychological tests : administration, norms, and commentary (3rd ed.). Oxford ; New York: Oxford University Press.

Strayer, D., Drews, F., Johnston, W., 2003. Cell phone-induced failures of visual attention during simulated driving. Journal of Experimental Psychology: Applied, 9(1), 23-32.

Strayer, D.L., Drews, F. A., 2004. Profiles in driver distraction: Effects of cell phone conversations on younger and older drivers. Human Factors, 46, 640-649.

Stutts, J.C., Reinfurt, D.W., Staplin, L., Rodgman, E.A., 2001. The role of driver distraction in traffic crashes. Report Prepared for AAA Foundation for Traffic Safety.

Summala, H. (2000). Brake reaction times and driver behavior analysis. Transportation Human Factors, 2(3), 217–226.

SWOV, 2008. Fact sheet. Use of mobile phone while driving, SWOV, Leidschendam, the Netherlands.

SWOW, 2010. Naturalistic Driving: observing everyday driving behaviour, SWOW factsheet, Leidschendam, Nederlands.

Szlyk J. P., Myers L., Zhang Y., Wetzel L., Shapiro R. (2002). Development and assessment of a neuropsychological battery to aid in predicting driving performance. Journal of Rehabilitation Research and Development, 34 (4), 1-13.

Tabachnick, B. G., & Fidell, L. S. (2006). Using multivariate statistics (5th ed.). Boston, MA: Pearson, Allyn & Bacon.

Thompson CA, Spilsbury K, Hall J, Birks Y, Barnes C, Adamson J. Systematic Review of Information and Support Interventions for Caregivers of People with Dementia. BMC Geriatrics. 2007;7:18. doi:10.1186/1471-2318-7-18. PMID 17662119.

Todd S, Barr S, Roberts M, Passmore AP (November 2013). "Survival in dementia and predictors of mortality: a review". International Journal of Geriatric Psychiatry 28 (11): 1109–24. doi:10.1002/gps.3946. PMID 23526458.

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.

Torpy, Janet (2008). "Delirium". The Journal of the American Medical Association 300 (19).

Torpy, Janet (2010). "Dementia". The Journal of American Medical Association 304 (7).

Treat, J.R., 1980. A study of precrash factors involved in traffic accidents. HSRI Research Review 10(6)/11(1), 1-36.

Trich L.M., Caird J.K., (2011), Methodological Issues When Conducting Research on Older Drivers, Handbook of driving simulation for engineering, medicine, and psychology, Chapter 26

Triggs, T.J., 1996. Driving simulation for railway crossing research, In Seventh International Symposium on Railroad-Highway Grade Crossing Research and Safety – Getting Active at Passive Crossings, Monash University, Clayton, Australia.

Trobe J. D., Waller P. F., Cook-Flannagan C. A., et al. (1996). Crashes and violations among drivers with Alzheimer's disease. Archives of Neurology, 53, 411-416.

Tuokko H., Tallman K., Beattie B. L., et al. (1995). An examination of driving records in a dementia clinic. Journal of Gerontology Series B Psychological Sciences and Social Sciences, 50B, S173-S181.

Uc E. Y., Rizzo M., Anderson S. W. et al. (2005). Driver landmark and traffic sign identification in early Alzheimer's disease. Journal of Neurology, Neurosurgery and Psychiatry, 76, 764–768.

Uc E.Y., Rizzo M., Anderson S.W., Shi Q., Dawson J.D., (2004). Driver route-following and safety errors in early Alzheimer disease, Neurology 63,832–837.

Uc E.Y., Rizzo M., Anderson S.W., Shi Q., Dawson J.D., (2006). Unsafe rear-end collision avoidance in Alzheimer's disease. Journal of the Neurological Sciences 251, 35–43.

Uc, E. Y., & Rizzo, M. (2008). Driving and neurodegenerative diseases. Current Neurology and Neuroscience Reports, 8, 377–383.

Uc, E. Y., Rizzo, M., Anderson, S. W., Dastrup, E., Sparks, J. D., & Dawson, J. D. (2009). Driving under low-contrast visibility conditions in Parkinson disease. Neurology, 73(14), 1103-1110. doi: 10.1212/WNL.0b013e3181bacf6e

Uc, E. Y., Rizzo, M., Anderson, S. W., Sparks, J. D., Rodnitzky, R. L., & Dawson, J. D. (2006b). Driving with distraction in Parkinson disease. Neurology, 67(10), 1774-1780. doi: 10.1212/01.wnl.0000245086.32787.61

Uc, E. Y., Rizzo, M., Anderson, S. W., Sparks, J. D., Rodnitzky, R. L., & Dawson, J. D. (2007). Impaired navigation in drivers with Parkinson's disease. Brain, 130(Pt 9), 2433-2440. doi: 10.1093/brain/awm178.

Uc, E. Y., Rizzo, M., Anderson, S. W., Sparks, J., Rodnitzky, R. L., & Dawson, J. D. (2006a). Impaired visual search in drivers with Parkinson's disease. Ann Neurol, 60(4), 407-413. doi: 10.1002/ana.20958

Uc, E. Y., Rizzo, M., Johnson, A. M., Dastrup, E., Anderson, S. W., & Dawson, J. D. (2009). Road safety in drivers with Parkinson disease. Neurology, 73(24), 2112-2119. doi: 10.1212/WNL.0b013e3181c67b77

Uc, E. Y., Rizzo, M., Johnson, A. M., Emerson, J. L., Liu, D., Mills, E. D., . . . Dawson, J. D. (2011). Real-life driving outcomes in Parkinson disease. Neurology, 76(22), 1894-1902. doi: 10.1212/WNL.0b013e31821d74fa

Uitti, R. J. (2009). Parkinson's disease and issues related to driving. Parkinsonism Related Disorders, 15, 122–125.

Van Schagen, I., Welsh, R., Backer-Grondahl, A., Hoedemaeker, M., Lotan, T., Morris, A., Sagberg, F., Winkelbauer, M., 2011. Towards a large-scale European Naturalistic Driving study: final report of Prologue, Deliverable D4.2.

Vardaki, S., Karlaftis, M., 2011. An investigation of older driver road safety perceptions and driving performance on freeways. 3rd International Conference on Road Safety and Simulation, Indianapolis, USA.

Vardaki S., Dickerson A., Beratis I., Yannis G., Papageorgiou S., 2016, "Simulator measures and identification of older drivers with MCI", American Journal of Occupational Therapy, in press.

Vaux L. M., Ni R., Rizzo M., Uc E.Y. and Andersen G.J. (2010). Detection of imminent collisions by drivers with Alzheimer's disease and Parkinson's disease: A preliminary study, Accident Analysis & Prevention, 42(3), 852-858.

Verwey, V., 2000. On-line driver workload estimation. Effects of road situation and age on secondary task measures, Ergonomics, vol 43, no, 2, 187-209.

Wadley VG, Okonkwo O, Crowe M, Vance DE, Elgin JM, Ball KK, Owsley C (2009) Mild cognitive impairment and everyday function: an investigation of driving performance. J Geriatr Psychiatry Neurol 22, 87-94.

Waller JA (1967) Cardiovascular disease, aging, and traffic accidents. Journal of Chronic Diseases 20, 615-620.

Waller, J.A., 1980. Physician's role in highway safety. Functional impairment in driving. N Y State J Med 1980; 80:1987-1991.

Washington S.P., Karlaftis M.G., Mannering F., 2011, Statistical and Econometric Methods for Transportation Data Analysis, Second Edition, Chapman & Hall/CRC, ISBN-13: 978-1420082852

Weathers, S. P., Kotagal, V., Bohnen, N. I., & Chou, K. L. (2014). Risky driving and pedunculopontine nucleus-thalamic cholinergic denervation in Parkinson

disease. Parkinsonism Relat Disord, 20(1), 13-16. doi: 10.1016/j.parkreldis.2013.08.021.

Wechsler, D. (1997a). Manual for the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III). San Antonio, TX: The Psychological Corporation.

Wechsler, D. (1997b). Wechsler Memory Scale - Third Edition. Manual. San Antonio, TX: The Psychological Corporation.

Whelihan WM, DiCarlo MA, Paul RH (2005). The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. Archives of Clinical Neuropsychology, 20, 217-222.

White, T., & Stern, R. A. (2003). Neuropsychological Assessment Battery (NAB): Demographically Corrected Norms Manual. Lutz, FL: Psychological Assessment Resources, Inc.

WHO, 2014. Global status report on Road Safety 2013, supporting a decade of action, World Health Organisation.

WHO, 2015. Global status report on Road Safety 2014, supporting a decade of action, World Health Organisation.

Wiggins, J.S., Steiger, J. H. & Gaelick, L. (1981). Evaluating circumplexity in personality data. Multivariate Behavioral Research, 16, 263-289.

Winblad B, Palmer K, Kivipelto M, Jelic V, Fratiglioni L, Wahlund LO, Nordberg A, Backman L, Albert M, Almkvist O, Arai H, Basun H, Blennow K, de Leon M, DeCarli C, Erkinjuntti T, Giacobini E, Graff C, Hardy J, Jack C, Jorm A, Ritchie K, van Duijn C, Visser P, Petersen RC (2004) Mild cognitive impairment--beyond controversies, towards a consensus: report of the International Working Group on Mild Cognitive Impairment. J Intern Med 256, 240-246.

Witkin, H. A., Oltman, P. K., Raskin, E., & Karp, S. A. (1971). A manual for the Embedded Figures Test. Palo Alto, CA: Consulting Psychologists Press.

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

Yannis, G., Papadimitriou, E., Karekla, X., Kontodima, F., 2010. Mobile phone use by young drivers: effects on traffic speed and headways, Transportation Planning and Technology, n.4(33), pp.385-394.

Yannis G., Antoniou C., Papadimitriou E., Katsohis D., When may road fatalities start to decrease?, Journal of Safety Research,Vol. 42, Issue 1, 2011, pp. 17-25.

Yannis G., Papantoniou P., Nikas M., (2015). "Comparative analysis of young drivers behavior in normal and simulation conditions at a rural road", Proceedings of the 5th International Conference on Road Safety and Simulation, Universities of Central Florida and Tennessee, Orlando, Florida, October 2015

Yiannopoulou K.G., Papageorgiou S.G., (2013), "Current and future treatments for Alzheimer's disease", *Therapeutic advances in neurological disorders,* Volume 6, Issue 1, pg. 19-33

Yeh, Y.Y., Wickens, C. D., 1988. Dissociation of Performance and Subjective Measures of Workload. Human Factors, 30(1), 111-120.

Young, K., Regan, M., Hammer, M., 2003. Driver distraction: a review of the literature, MUARC, Report No. 206.

Appendix

A1. INCLUSION CRITERIA FORM

1. Συγκοινωνιακά κριτήρια αποκλεισμού (CT)

CT1. Έχετε δίπλωμα οδήγησης επιβατικού οχήματος εν ισχύ; ΝΑΙ – ΟΧΙ
(Αν όχι, αποκλείεται)

CT2. Πόσα χρόνια οδηγείτε; .....
(Αν <3 χρόνια, αποκλείεται)

CT3. Τους τελευταίους 12 μήνες, πόσα χιλιόμετρα κάνατε; .....
(Αν <2.500 km, αποκλείεται)

CT3a. Τους τελευταίους 12 μήνες πόσες μετακινήσεις κάνετε κατά μέσο όρο την εβδομάδα; .....
(Αν <1 μετακίνηση/εβδομάδα, αποκλείεται)

CT3b. Τους τελευταίους 12 μήνες πόσα χιλιόμετρα κάνετε κατά μέσο όρο την εβδομάδα; .....
(Αν <10 km/εβδομάδα, αποκλείεται)

2. Ιατρικά κριτήρια αποκλεισμού (CM)

CM1. Πόσος είναι ο δείκτης CDR; .....
(Αν ≥2, αποκλείεται)

CM2. Υπάρχει σημαντικό ψυχιατρικό ιστορικό για ψύχωση; ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM3. Έχετε κάποια σοβαρή κινητική διαταραχή που να εμποδίζει την οδήγηση κανονικού αυτοκινήτου (π.χ δυσκολία στον χειρισμό χειροκίνητου κιβώτιου ταχυτήτων, δυσκολία στη χρήση του πεντάλ σύμπλεξης); ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM4. Έχετε ίλιγγο, ναυτία κατά την οδήγηση, είτε ως οδηγός, είτε ως συνοδηγός; ΝΑΙ – ΟΧΙ
(Αν ναι, αποκλείεται)

CM5. Είστε έγκυος; ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM6. Είστε αλκοολικός ή έχετε κάποια εξάρτηση από άλλες ουσίες; ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM7. Έχετε κάποια οφθαλμική πάθηση που να απαγορεύει νομικά την οδήγηση (πχ Οπτική οξύτητα <10/20 και για τους 2 οφθαλμούς); ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

CM8. Έχετε κάποια πάθηση του Κεντρικού Νευρικού Συστήματος (ΚΝΣ) που είναι εκτός των παθήσεων που εξετάζονται στην παρούσα μελέτη (π.χ Όγκοι ΚΝΣ, Σκλήρυνση κατά Πλάκας, Επιληψία κλπ); ΝΑΙ - ΟΧΙ
(Αν ναι, αποκλείεται)

A2. NEUROLOGICAL/NEUROPSYCHOLOGICAL TESTS

UPDRS-III. Motor Examination

0 = Normal.
1 = Slight loss of expression, diction and/or volume.
2 = Monotone, slurred but understandable; moderately impaired.
3 = Marked impairment, difficult to understand.
4 = Unintelligible.

Speech
0 = Normal.
1 = Minimal hypomimia, could be normal "Poker Face".
2 = Slight but definitely abnormal diminution of facial expression
3 = Moderate hypomimia; lips parted some of the time.
4 = Masked or fixed facies with severe or complete loss of facial expression; lips parted 1/4 inch or more.

Facial Expression
(head, upper and lower extremities)
0 = Absent.
1 = Slight and infrequently present.
2 = Mild in amplitude and persistent. Or moderate in amplitude, but only intermittently present.
3 = Moderate in amplitude and present most of the time.
4 = Marked in amplitude and present most of the time.

Tremor at rest
0 = Absent.
1 = Slight; present with action.
2 = Moderate in amplitude, present with action.
3 = Moderate in amplitude with posture holding as well as action.
4 = Marked in amplitude; interferes with feeding.

Action or Postural Tremor of hands
(Judged on passive movement of major joints with patient relaxed in sitting position. Cogwheeling to be ignored.)
0 = Absent.
1 = Slight or detectable only when activated by mirror or other movements.
2 = Mild to moderate.
3 = Marked, but full range of motion easily achieved.
4 = Severe, range of motion achieved with difficulty.

Rigidity
(Patient taps thumb with index finger in rapid succession.)
0 = Normal.

1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

Finger Taps
(Patient opens and closes hands in rapid succession.)
0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

Hand Movements
(Pronation-supination movements of hands, vertically and horizontally,
with as large an amplitude as possible, both hands simultaneously.)
0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

Rapid Alternating Movements of Hands
(Patient taps heel on the ground in rapid succession picking up entire leg. Amplitude should be at least 3 inches.)
0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

Leg Agility
(Patient attempts to rise from a straight backed chair, with arms folded across chest.)
0 = Normal.
1 = Slow; or may need more than one attempt.
2 = Pushes self up from arms of seat.
3 = Tends to fall back and may have to try more than one time, but can get up without help.
4 = Unable to arise without help.

Arising from Chair
0 = Normal erect.
1 = Not quite erect, slightly stooped posture; could be normal for older person.
2 = Moderately stooped posture, definitely abnormal; can be slightly leaning to one side.
3 = Severely stooped posture with kyphosis; can be moderately leaning to one side.
4 = Marked flexion with extreme abnormality of posture.

Posture

0 = Normal.

1 = Walks slowly, may shuffle with short steps, but no festination (hastening steps) or propulsion.

2 = Walks with difficulty, but requires little or no assistance; may have some festination, short steps, or propulsion.

3 = Severe disturbance of gait, requiring assistance.

4 = Cannot walk at all, even with assistance.

Gait

(Response to sudden, strong posterior displacement produced by pull on shoulders while patient erect with eyes open and feet slightly apart. Patient is prepared.)

0 = Normal.

1 = Retropulsion, but recovers unaided.

2 = Absence of postural response; would fall if not caught by examiner.

3 = Very unstable, tends to lose balance spontaneously.

4 = Unable to stand without assistance.

Postural Stability

(Combining slowness, hesitancy, decreased arm swing, small amplitude, and poverty of movement in general.)

0 = None.

1 = Minimal slowness, giving movement a deliberate character; could be normal for some persons. Possibly reduced amplitude.

2 = Mild degree of slowness and poverty of movement which is definitely abnormal. Alternatively, some reduced amplitude.

3 = Moderate slowness, poverty or small amplitude of movement.

4 = Marked slowness, poverty or small amplitude of movement.

Modified HOEHN AND YAHR STAGING

Stage 0 = No signs of disease.

Stage 1 = Unilateral disease.

Stage 1.5 = Unilateral plus axial involvement.

Stage 2 = Bilateral disease, without impairment of balance.

Stage 2.5 = Mild bilateral disease, with recovery on pull test.

Stage 3 = Mild to moderate bilateral disease; some postural instability; physically independent.

Stage 4 = Severe disability; still able to walk or stand unassisted.

Stage 5 = Wheelchair bound or bedridden unless aided.

Geriatric Depression Scale

Choose the best answer for how you have felt over the past week:

1. Are you basically satisfied with your life?	YES / NO
2. Have you dropped many of your activities and interests?	YES / NO
3. Do you feel that your life is empty?	YES / NO
4. Do you often get bored?	YES / NO
5. Are you in good spirits most of the time?	YES / NO
6. Are you afraid that something bad is going to happen to you?	YES / NO
7. Do you feel happy most of the time?	YES / NO
8. Do you often feel helpless?	YES / NO
9. Do you prefer to stay at home, rather than going out and doing new things?	YES / NO
10. Do you feel you have more problems with memory than most?	YES / NO
11. Do you think it is wonderful to be alive now?	YES / NO
12. Do you feel pretty worthless the way you are now?	YES / NO
13. Do you feel full of energy?	YES / NO
14. Do you feel that your situation is hopeless?	YES / NO
15. Do you think that most people are better off than you are?	YES / NO

PDSS-2

Please rate the severity of the following based on your experiences during the past week (7 days). Please make a cross in the answer box

	Very often (This means 6 to 7 days a week)	Often (This means 4 to 5 days a week)	Sometimes (This means 2 to 3 days a week)	Occasionally (This means 1 day a week)	Never
1) Overall, did you sleep well during the last week?	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
2) Did you have difficulty falling asleep each night?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
3) Did you have difficulty staying asleep?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
4) Did you have restlessness of legs or arms at nights causing disruption of sleep?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
5) Was your sleep disturbed due to an urge to move your legs or arms?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
6) Did you suffer from distressing dreams at night?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
7) Did you suffer from distressing hallucinations at night (seeing or hearing things that you are told do not exist)?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
8) Did you get up at night to pass urine?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
9) Did you feel uncomfortable at night because you were unable to turn around in bed or move due to immobility?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
10) Did you feel pain in your arms or legs which woke you up from sleep at night?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
11) Did you have muscle cramps in your arms or legs which woke you up whilst sleeping at night?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
12) Did you wake early in the morning with painful posturing of arms and legs?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
13) On waking, did you experience tremor?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
14) Did you feel tired and sleepy after waking in the morning?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0
15) Did you wake up at night due to snoring or difficulties with breathing?	☐ 4	☐ 3	☐ 2	☐ 1	☐ 0

Patient Health Questionnaire (PHQ-9)

The Patient Health Questionnaire (PHQ-9)

Patient Name _____ Date of Visit _____

Over the past 2 weeks, how often have you been bothered by any of the following problems?	**Not At all**	**Several Days**	**More Than Half the Days**	**Nearly Every Day**
1. Little interest or pleasure in doing things	0	1	2	3
2. Feeling down, depressed or hopeless	0	1	2	3
3. Trouble falling asleep, staying asleep, or sleeping too much	0	1	2	3
4. Feeling tired or having little energy	0	1	2	3
5. Poor appetite or overeating	0	1	2	3
6. Feeling bad about yourself - or that you're a failure or have let yourself or your family down	0	1	2	3
7. Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8. Moving or speaking so slowly that other people could have noticed. Or, the opposite - being so fidgety or restless that you have been moving around a lot more than usual	0	1	2	3
9. Thoughts that you would be better off dead or of hurting yourself in some way	0	1	2	3
Column Totals	_____ +	_____ +	_____	
Add Totals Together	_____			

10. If you checked off any problems, how difficult have those problems made it for you to Do your work, take care of things at home, or get along with other people?

☐ Not difficult at all ☐ Somewhat difficult ☐ Very difficult ☐ Extremely difficult

Athens Insomnia Scale (AIS)

Instructions: This scale is intended to record your own assessment of any sleep difficulty you might have experienced. Please, check (by circling the appropriate number) the items below to indicate your estimate of any difficulty, provided that it occurred at least three times per week during the last month.

Sleep induction (time it takes you to fall asleep after turning-off the lights)

0: No problem
1: Slightly delayed
2: Markedly delayed
3: Very delayed or did not sleep at all

Awakenings during the night

0: No problem
1: Minor problem
2: Considerable problem
3: Serious problem or did not sleep at all

Final awakening earlier than desired

0: Not earlier
1: A little earlier
2: Markedly earlier
3: Much earlier or did not sleep at all

Total sleep duration

0: Sufficient
1: Slightly insufficient
2: Markedly insufficient
3: Very insufficient or did not sleep at all

Overall quality of sleep (no matter how long you slept)

0: Satisfactory
1: Slightly unsatisfactory
2: Markedly unsatisfactory
3: Very unsatisfactory or did not sleep at all

Sense of well-being during the day

0: Normal
1: Slightly decreased
2: Markedly decreased
3: Very decreased

Functioning (physical and mental) during the day

0: Normal
1: Slightly decreased
2: Markedly decreased
3: Very decreased

Sleepiness during the day

0: None
1: Mild
2: Considerable
3: Intense

Epworth Sleepiness Scale

Epworth Sleepiness Scale

Name: _____ Today's date: _____

Your age (Yrs): _____ Your sex (Male = M, Female = F): _____

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired?

This refers to your usual way of life in recent times.

Even if you haven't done some of these things recently try to work out how they would have affected you.

Use the following scale to choose the **most appropriate number** for each situation:

0 = would **never** doze
1 = **slight chance** of dozing
2 = **moderate chance** of dozing
3 = **high chance** of dozing

It is important that you answer each question as best you can.

Situation	**Chance of Dozing (0-3)**
Sitting and reading	___
Watching TV	___
Sitting, inactive in a public place (e.g. a theatre or a meeting)	___
As a passenger in a car for an hour without a break	___
Lying down to rest in the afternoon when circumstances permit	___
Sitting and talking to someone	___
Sitting quietly after a lunch without alcohol	___
In a car, while stopped for a few minutes in the traffic	

THANK YOU FOR YOUR COOPERATION

Simple Screening Instrument for Substance Abuse Self-Administered Form

Directions: The questions that follow are about your use of alcohol and other drugs. Your answers will be kept private. Mark the response that best fits for you. Answer the questions in terms of your experiences in the past 6 months. Do not include time incarcerated.

During the last 6 months….
1. Have you used alcohol or other drugs? (Such as wine, beer, hard liquor, pot, coke, heroin, or other opioids, uppers, downers, hallucinogens, or inhalants)
_____Yes _____No
2. Have you felt that you use too much alcohol or other drugs?
_____Yes _____No
3. Have you tried to cut down or quit drinking or using alcohol or other drugs?
_____Yes _____No
4. Have you gone to anyone for help because of your drinking or drug use? (Such as Alcoholics Anonymous, Narcotics Anonymous, Cocaine Anonymous, counselors or a treatment program.)
_____Yes _____No
5. Have you had any health problems? For example, have you:
___Had blackouts or other periods of memory loss
___Injured your head after drinking or using drugs
___Had convulsions, delirium tremens (DTs)
___Had hepatitis or other liver problems
___Felt sick, shaky, or depressed when you stopped
___Felt "coke bugs" or a crawling feeling under the skin after you stopped using drugs
___Been injured after drinking or using
___Used needles to shoot drugs
6. Has drinking or other drug use caused problems between you and your family or friends?
_____Yes _____No
7. Has your drinking or other drug use caused problems at school or work?
_____Yes _____No
8. Have you been arrested or had other legal problems? (Such as bouncing bad checks, driving while intoxicated, theft, or drug possession.)
_____Yes _____No
9. Have you lost your temper or gotten into arguments or fights while drinking or using other drugs?
_____Yes _____No
10. Are you needing to drink or use drugs more and more to get the effect you want?
_____Yes _____No
11. Do you spend a lot of time thinking about or trying to get alcohol or other drugs?
_____Yes _____No
12. When drinking or using drugs are you more likely to do something you wouldn't normally do, such as break rules, break the law, sell things that are important to you, or have unprotected sex with someone?
_____Yes _____No
13. Do you feel bad or guilty about your drinking or drug use?
_____Yes _____No
The next questions are about your lifetime experiences.
14. Have you ever had a drinking or other drug problem?
_____Yes _____No

15. Have any of your family members ever had a drinking or drug problem?
_____Yes _____No
16. Do you feel that you have a drinking or drug problem now?
_____Yes _____No
Items 1 and 15 are not scored. The following items are scored as 1 (yes) or 0 (no):
___2 ___7 ___12
___3 ___8 ___13
___4 ___9 ___14
___5 ___10 ___16

Total Score_____

Preliminary interpretation of responses:
Score Degree of Risk for Substance Abuse
0 – 1 None to low
2 – 3 Minimal
>4 Moderate to high: possible need for further assessment

NPI

Name of patient: _____ Date: _____

Informant: Spouse: _____ Child: _____ Other: _____

Please answer the following questions based on *changes* that have occurred since the patient first began to experience memory problems.

Circle "yes" only if the symptom has been present in the *past month*. Otherwise, circle "no".

For each item marked "yes":

Rate the *severity* of the symptom (how it affects the patient):
1 = Mild (noticeable, but not a significant change)
2 = Moderate (significant, but not a dramatic change)
3 = Severe (very marked or prominent; a dramatic change)

Rate the *distress* you experience because of that symptom (how it affects you):
0 = Not distressing at all
1 = Minimal (slightly distressing, not a problem to cope with)
2 = Mild (not very distressing, generally easy to cope with)
3 = Moderate (fairly distressing, not always easy to cope with)
4 = Severe (very distressing, difficult to cope with)
5 = Extreme or very severe (extremely distressing, unable to cope with)

Please answer each question honestly and carefully. Ask for assistance if you are not sure how to answer any question.

Delusions	Does the patient believe that others are stealing from him or her, or planning to harm him or her in some way?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Hallucinations	Does the patient act as if he or she hears voices? Does he or she talk to people who are not there?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Agitation or aggression	Is the patient stubborn and resistive to help from others?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Depression or dysphoria	Does the patient act as if he or she is sad or in low spirits? Does he or she cry?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Anxiety	Does the patient become upset when separated from you? Does he or she have any other signs of nervousness, such as shortness of breath, sighing, being unable to relax, or feeling excessively tense?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Elation or euphoria	Does the patient appear to feel too good or act excessively happy?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Apathy or indifference	Does the patient seem less interested in his or her usual activities and in the activities and plans of others?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Disinhibition	Does the patient seem to act impulsively? For example, does the patient talk to strangers as if he or she knows them, or does the patient say things that may hurt people's feelings?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Irritability or lability	Is the patient impatient and cranky? Does he or she have difficulty coping with delays or waiting for planned activities?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Motor disturbance	Does the patient engage in repetitive activities, such as pacing around the house, handling buttons, wrapping string, or doing other things repeatedly?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Nighttime behaviors	Does the patient awaken you during the night, rise too early in the morning, or take excessive naps during the day?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5
Appetite and eating	Has the patient lost or gained weight, or had a change in the food he or she likes?									
Yes	No	Severity:	1	2	3	Distress:	0	1	2	3	4	5

Frontal Behavioural Inventory (FBI)

Explain to the caregiver that you are looking for a change in behaviour and personality. Ask the caregiver these questions in the absence of the patient. Elaborate if necessary. At the end of each question, ask about the extent of the behavioural change, and then score it according to the following: 0 = none, 1 = mild, occasional, 2 = moderate, 3 = severe, most of the time.

1. Apathy: Has s/he lost interest in friends or activities or is s/he interested in seeing people or doing things?

_____

2. Aspontaneity: Does s/he start things on his/her own, or does s/he have to be asked?

_____

3. Indifference / Emotional Flatness: Does s/he respond to occasions of joy or sadness as much as ever, or has s/he lost emotional responsiveness?

_____

4. Inflexibility: Can s/he change his/her mind with reason or does s/he appear stubborn or rigid in thinking lately?

_____

5. Disorganization: Can s/he plan and organize complex activity or is s/he easily distractible, indecisive, or unable to complete a job?

_____

6. Inattention: Does s/he pay attention to what is going on or does s/he seem to lose track or not follow at all?

_____

7. Personal Neglect: Does s/he take as much care of his/her personal hygiene and appearance as usual, or does s/he neglect to wash or change his/her underwear?

_____

8. Loss of Insight: Is s/he aware of any problems or changes in behaviour, or does s/he seem unaware of them or deny them when discussed?

_____

9. Logopenia: Is s/he as talkative as before or has the amount of speech significantly decreased?

_____

10. Aphasia and Verbal Apraxia: Does s/he make language or pronunciation errors or has s/he developed stuttering or grammatical errors recently?

_____

11. Comprehension (Semantic) deficit: Does s/he ask what words mean, has trouble comprehending words, and/or objects, or does s/he know the meaning of words?

_____

12. Alien Hand and/or Apraxia: Has s/he developed clumsiness, stiff hand, inability to use utensils or appliances, or does a hand interfere with the other, or behaves as if it did not belong, or can s/he use both hands as before? _____

_____ Negative Behaviour Score Total of 1 – 12

13. Perseveration, Obsessions (Stereotypy): Does s/he repeat or perseverate actions or remarks? Are there any obsessive routines or behaviours, or has s/he always been a creature of habit?

_____

14. Hoarding: Has s/he started to hoard objects or money excessively or has her/his saving habits remained unchanged?

_____

15. Inappropriateness: Has s/he kept social rules or has s/he said or done things outside what are acceptable? Has s/he been rude, or childish?

_____

16. Excessive jocularity: Has s/he been making jokes excessively or offensively or at the wrong time, or has s/he always had a jocular manner or a quirk sense of humor?

_____

17. Poor Judgment and Impulsivity: Has s/he been using good judgment in decisions, spending or driving, or has s/he acted impulsively, irresponsibly, neglectfully or in poor judgment?

_____

18. Restlessness / Roaming: Has s/he been roaming, pacing, walking, driving excessively or is the activity level normal?

_____

19. Irritability: Has s/he been irritable, short-tempered, or is s/he reacting to stress or frustration as s/he always had?

_____

20. Aggression: Has s/he shown aggression, or shouted at anyone or hurt anyone physically, or is there no change in this respect?

_____

21. Hyperorality/food fads: Has s/he been drinking or eating excessively anything in sight, or developing food fads, a sweet tooth, eating bananas or cookies excessively, or even putting objects in his/her mouth, or has s/he always had a large appetite and the eating habits have not changed? Has s/he lost table manners?

_____

22. Hypersexuality: Has sexual behaviour been unusual or excessive? This could include remarks or undressing, or is there no change in this respect?

_____

23. Utilization Behaviour: Does s/he seem to need to touch, feel, examine, or pick-up objects within reach and sight, or can she/he keep his/her hands to him/herself?

_____

24. Incontinence: Has s/he wet or soiled his or herself, or does s/he have problems that can be explained by urinary infection or childbirth/prostate?

_____

The scoring is intended to capture severity rather than the frequency of abnormalities.

_____ Disinhibition Score Total of 13-24

Total Score: _____

IADL

Instrumental Activities of Daily Living (IADL)

Instructions: Circle the scoring point for the statement that most closely corresponds to the patient's current functional ability for each task. The examiner should complete the scale based on information about the patient from the patient him-/herself, informants (such as the patient's family member or other caregiver), and recent records.

A. Ability to use telephone	Score
1. Operates telephone on own initiative; looks up and dials numbers, etc.	1
2. Dials a few well-known numbers	1
3. Answers telephone but does not dial	1
4. Does not use telephone at all	0

B. Shopping	
1. Takes care of all shopping needs independently	1
2. Shops independently for small purchases	0
3. Needs to be accompanied on any shopping trip	0
4. Completely unable to shop	0

C. Food preparation	
1. Plans, prepares, and serves adequate meals independently	1
2. Prepares adequate meals if supplied with ingredients	0
3. Heats and serves prepared meals, or prepares meals but does not maintain adequate diet	0
4. Needs to have meals prepared and served	0

D. Housekeeping	
1. Maintains house alone or with occasional assistance (e.g., "heavy work domestic help")	1
2. Performs light daily tasks such as dishwashing, bed making	1
3. Performs light daily tasks but cannot maintain acceptable level of cleanliness	1
4. Needs help with all home maintenance tasks	1
5. Does not participate in any housekeeping tasks	0

E. Laundry	Score
1. Does personal laundry completely	1
2. Launders small items; rinses stockings, etc.	1
3. All laundry must be done by others	0

F. Mode of transportation	
1. Travels independently on public transportation or drives own car	1
2. Arranges own travel via taxi, but does not otherwise use public transportation	1
3. Travels on public transportation when assisted or accompanied by another	1
4. Travel limited to taxi or automobile with assistance of another	0
5. Does not travel at all	0

G. Responsibility for own medications	
1. Is responsible for taking medication in correct dosages at correct time	1
2. Takes responsibility if medication is prepared in advance in separate dosages	0
3. Is not capable of dispensing own medication	0

H. Ability to handle finances	
1. Manages financial matters independently (budgets, writes checks, pays rent and bills, goes to bank), collects and keeps track of income	1
2. Manages day-to-day purchases, but needs help with banking, major purchases, etc.	1
3. Incapable of handling money	0

(Lawton & Brody, 1969)

Scoring: The patient receives a score of 1 for each item labeled A – H if his or her competence is rated at some minimal level or higher. Add the total points circled for A – H. The total score may range from 0 – 8. A lower score indicates a higher level of dependence.

Sources:

- Cromwell DA, Eagar K, Poulos RG. The performance of instrumental activities of daily living scale in screening for cognitive impairment in elderly community residents. *J Clin Epidemiol.* 2003;56(2):131-137.
- Lawton MP. The functional assessment of elderly people. *J Am Geriatr Soc.* 1971;19(6):465-481.
- Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. *Gerontologist.* 1969;9(3):179-186.
- Polisher Research Institute. Instrumental Activities of Daily Living Scale (IADL). Available at: http://www.abramsoncenter.org/PRI/documents/IADL.pdf. Accessed February 15, 2005.

FAQ

Functional Activities Questionnaire

Administration

Ask informant to rate patient's ability using the following scoring system:

- Dependent = 3
- Requires assistance = 2
- Has difficulty but does by self = 1
- Normal = 0
- Never did [the activity] but could do now = 0
- Never did and would have difficulty now = 1

Writing checks, paying bills, balancing checkbook	
Assembling tax records, business affairs, or papers	
Shopping alone for clothes, household necessities, or groceries	
Playing a game of skill, working on a hobby	
Heating water, making a cup of coffee, turning off stove after use	
Preparing a balanced meal	
Keeping track of current events	
Paying attention to, understanding, discussing TV, book, magazine	
Remembering appointments, family occasions, holidays, medications	
Traveling out of neighborhood, driving, arranging to take buses	
TOTAL SCORE:	

Evaluation

Sum scores (range 0-30). Cutpoint of 9 (dependent in 3 or more activities) is recommended to indicate impaired function and possible cognitive impairment.

Pfeffer RI et al. Measurement of functional activities in older adults in the community. J Gerontol 1982; 37(3):323-329. Reprinted with permission of The Gerontological Society of America, 1030 15th Street NW, Suite 250, Washington, DC 20005 via Copyright Clearance Center, Inc.

IQ-CODE

		1	2	3	4	5
1	Remembering things about family and friends, eg occupations, birthdays, addresses	Much improved	A bit improved	Not much change	A bit worse	Much worse
2	Remembering things that have happened recently	Much improved	A bit improved	Not much change	A bit worse	Much worse
3	Recalling conversations a few days later	Much improved	A bit improved	Not much change	A bit worse	Much worse
4	Remembering her/his address and telephone number	Much improved	A bit improved	Not much change	A bit worse	Much worse
5	Remembering what day and month it is	Much improved	A bit improved	Not much change	A bit worse	Much worse
6	Remembering where things are usually kept	Much improved	A bit improved	Not much change	A bit worse	Much worse
7	Remembering where to find things which have been put in a different place from usual	Much improved	A bit improved	Not much change	A bit worse	Much worse
8	Knowing how to work familiar machines around the house	Much improved	A bit improved	Not much change	A bit worse	Much worse
9	Learning to use a new gadget or machine around the house	Much improved	A bit improved	Not much change	A bit worse	Much worse
10	Learning new things in general	Much improved	A bit improved	Not much change	A bit worse	Much worse
11	Following a story in a book or on TV	Much improved	A bit improved	Not much change	A bit worse	Much worse
12	Making decisions on everyday matters	Much improved	A bit improved	Not much change	A bit worse	Much worse
13	Handling money for shopping	Much improved	A bit improved	Not much change	A bit worse	Much worse
14	Handling financial matters, eg the pension, dealing with the bank	Much improved	A bit improved	Not much change	A bit worse	Much worse
15	Handling other everyday arithmetic problems, eg knowing how much food to buy, knowing how long between visits from family or friends	Much improved	A bit improved	Not much change	A bit worse	Much worse
16	Using his/her intelligence to understand what's going on and to reason things through	Much improved	A bit improved	Not much change	A bit worse	Much worse

Clinical Dementia Rating - CDR

CLINICAL DEMENTIA RATING (CDR)

CLINICAL DEMENTIA RATING (CDR):	0	0.5	1	2	3

	Impairment				
	None 0	Questionable 0.5	Mild 1	Moderate 2	Severe 3
Memory	No memory loss or slight inconsistent forgetfulness	Consistent slight forgetfulness; partial recollection of events; "benign" forgetfulness	Moderate memory loss; more marked for recent events; defect interferes with everyday activities	Severe memory loss; only highly learned material retained; new material rapidly lost	Severe memory loss; only fragments remain
Orientation	Fully oriented	Fully oriented except for slight difficulty with time relationships	Moderate difficulty with time relationships; oriented for place at examination; may have geographic disorientation elsewhere	Severe difficulty with time relationships; usually disoriented to time, often to place	Oriented to person only
Judgment & Problem Solving	Solves everyday problems & handles business & financial affairs well; judgment good in relation to past performance	Slight impairment in solving problems, similarities, and differences	Moderate difficulty in handling problems, similarities, and differences; social judgment usually maintained	Severely impaired in handling problems, similarities, and differences; social judgment usually impaired	Unable to make judgments or solve problems
Community Affairs	Independent function at usual level in job, shopping, volunteer and social groups	Slight impairment in these activities	Unable to function independently at these activities although may still be engaged in some; appears normal to casual inspection	No pretense of independent function outside home Appears well enough to be taken to functions outside a family home	Appears too ill to be taken to functions outside a family home
Home and Hobbies	Life at home, hobbies, and intellectual interests well maintained	Life at home, hobbies, and intellectual interests slightly impaired	Mild but definite impairment of function at home; more difficult chores abandoned; more complicated hobbies and interests abandoned	Only simple chores preserved; very restricted interests, poorly maintained	No significant function in home
Personal Care	Fully capable of self-care		Needs prompting	Requires assistance in dressing, hygiene, keeping of personal effects	Requires much help with personal care; frequent incontinence

Score only as decline from previous usual level due to cognitive loss, not impairment due to other factors.

Hachinski Ischaemic Score

Item No.	Description	Value
1	Abrupt onset	2
2	Stepwise deterioration	1
3	Fluctuating course	2
4	Nocturnal confusion	1
5	Preservation of personality	1
6	Depression	1
7	Somatic complaints	1
8	Emotional incontinence	1
9	History of hypertension	1
10	History of stroke	2
11	Associated atherosclerosis	1
12	Focal neurological symptoms	2
13	Focal neurological signs	2

A cut-off score ≤ 4 for DAT and ≥ 7 for VaD has a sensitivity of 89% and a specificity of 89% (Moroney 1997).

A3. SELF-STATED DRIVING BEHAVIOUR QUESTIONNAIRE

Q1.0.1		
Q1.0.2		
Q1.0.3		
Q1.0.4		
Q1.0.5	Άντρας (1)	Γυναίκα (2)

Κωδικός Συμμετέχοντα:

Ονοματεπώνυμο Συμμετέχοντα:

Ημερομηνία συμπλήρωσης:

Ηλικία:

Φύλο (κυκλώστε)**:**

Α. ΟΔΗΓΙΚΗ ΕΜΠΕΙΡΙΑ - ΜΕΤΑΚΙΝΗΣΕΙΣ

Q1.1							
Q1.2	Ναι (1)		Όχι (2)				
Q1.3							
Q1.4							
Q1.5	Ναι (1)		Όχι (2)				
Q1.6	1	2	3	4	5	6	7
Q1.7	<20	20-50	50-100	100-150	150+	Δεν ξέρω	
Q1.8	1	2	3	4	5+		
Q1.9	1-2	3-5	6-9	10-15	16-29	30+	Δεν ξέρω
Q1.10	Έχει περιορισθεί (1)		Είναι η ίδια (2)		Έχει αυξηθεί (3)		Δεν ξέρω (4)

1. Πόσα χρόνια οδηγείτε;

2. Σας αρέσει η οδήγηση (κυκλώστε)**;**

3. Πότε αποκτήσατε την άδεια οδήγησης σας;

4. Πότε λήγει η άδεια οδήγησης σας;

5. Είσαστε ή ήσασταν επαγγελματίας οδηγός (κυκλώστε)**;**

6. Πόσες ημέρες την εβδομάδα χρησιμοποιείτε το αυτοκίνητό σας (κυκλώστε)**;**

7. Πόσα χιλιόμετρα περίπου οδηγείτε την εβδομάδα (κυκλώστε)**;**

8. Πόσες διαδρομές πραγματοποιείτε την ημέρα ως οδηγός (κυκλώστε)**;**

9. Υποδείξτε το μέσο μήκος των διαδρομών σας σε χιλιόμετρα (κυκλώστε)**:**

10. Σε σχέση με πέντε χρόνια πριν η οδήγησή σας (κυκλώστε)**:**

11. Πόσο συχνά οδηγήσατε το τελευταίο εξάμηνο στις παρακάτω συνθήκες:

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**Καθόλου**	**Τουλάχιστον μια φορά το δίμηνο**	**Τουλάχιστον μια φορά τον μήνα**	**Τουλάχιστον μια φορά τη βδομάδα**	**Τουλάχιστον δύο φορές τη βδομάδα**	**Τουλάχιστον τέσσερις φορές τη βδομάδα**
Q1.11.1	Νύχτα	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.2	Σε ώρες κυκλοφοριακής αιχμής	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.3	Με βροχή	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.4	Σε αυτοκινητόδρομους	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.5	Σε άγνωστες περιοχές	(1)	(2)	(3)	(4)	(5)	(6)

Q1.11.6	Εκτός πόλης	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.7	Εντός πόλης	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.8	Κοντά στην περιοχή κατοικίας	(1)	(2)	(3)	(4)	(5)	(6)
Q1.11.9	Διανύοντας μεγάλες αποστάσεις (>2ώρες)	(1)	(2)	(3)	(4)	(5)	(6)

12. Πόσες φορές το τελευταίο εξάμηνο αποφύγατε επισκέψεις ή άλλες δουλειές με το αυτοκίνητό σας επειδή ανησυχείτε για την οδήγηση σας (κυκλώστε);

Q1.12	Ποτέ (1)	Σπάνια (2)	Μερικές φορές (3)	Πολλές φορές (4)

Β. ΑΥΤΟΑΞΙΟΛΟΓΗΣΗ ΟΔΗΓΟΥ

13. Ποιά είναι τα <u>αδύνατα</u> και ποιά τα <u>δυνατά</u> σημεία σας στην οδήγηση;

**Σημειώστε με √ το κουτάκι της επιλογής σας*		**Αδύνατο**	**Λίγο αδύνατο**	**Μάλλον δυνατό**	**Δυνατό**
Q1.13.1	Να οδηγείτε μακρινές αποστάσεις	(1)	(2)	(3)	(4)
Q1.13.2	Να αντιλαμβάνεστε άμεσα τους κινδύνους της κυκλοφορίας	(1)	(2)	(3)	(4)
Q1.13.3	Να οδηγείτε σε ολισθηρό δρόμο	(1)	(2)	(3)	(4)
Q1.13.4	Να αλλάζετε λωρίδα κυκλοφορίας με άνεση	(1)	(2)	(3)	(4)
Q1.13.5	Να παίρνετε γρήγορες αποφάσεις όταν οδηγείτε	(1)	(2)	(3)	(4)
Q1.13.6	Να παραμένετε ψύχραιμοι σε αγχωτικές καταστάσεις όταν οδηγείτε	(1)	(2)	(3)	(4)
Q1.13.7	Να ελέγχετε απόλυτα το αυτοκίνητο	(1)	(2)	(3)	(4)
Q1.13.8	Να αφήνετε αρκετή απόσταση από το μπροστινό αμάξι	(1)	(2)	(3)	(4)
Q1.13.9	Να προσαρμόζετε την ταχύτητά σας ανάλογα με τις οδικές καταστάσεις	(1)	(2)	(3)	(4)
Q1.13.10	Η προσπέραση, αν χρειάζεται	(1)	(2)	(3)	(4)
Q1.13.11	Να παραχωρείτε την προτεραιότητα σας όταν υπάρχει ανάγκη	(1)	(2)	(3)	(4)
Q1.13.12	Να τηρείτε τα όρια ταχύτητας	(1)	(2)	(3)	(4)
Q1.13.13	Να παρκάρετε με την όπισθεν	(1)	(2)	(3)	(4)
Q1.13.14	Να προσέχετε τα άλλα οχήματα στο δρόμο	(1)	(2)	(3)	(4)
Q1.13.15	Να οδηγείτε γρήγορα, αν χρειάζεται	(1)	(2)	(3)	(4)
Q1.13.16	Να οδηγείτε στο σκοτάδι	(1)	(2)	(3)	(4)
Q1.13.17	Να προσέχετε τους πεζούς και τους ποδηλάτες	(1)	(2)	(3)	(4)

14. Πως θα αξιολογούσατε την οδήγησή σας σήμερα σε σχέση με πέντε χρόνια πριν (κυκλώστε);

Q1.14	Χειρότερη (1)	Λίγο χειρότερη (2)	Ίδια (3)	Λίγο καλύτερη (4)	Καλύτερη (5)	Δεν ξέρω (6)

15, 16, 17. Πιο συγκεκριμένα, πως θα αξιολογούσατε την οδήγησή σας στις παρακάτω συνθήκες:

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**15. Σε σχέση με 5 χρόνια πριν:**			**16. Το αποφεύγετε;**				**17. Αν το αποφεύγετε, για ποιό λόγο γίνεται αυτό; (Αν δεν το αποφεύγετε μην**		
		Σημαντική επιδείνωση	**Μικρή επιδείνωση**	**Καμία διαφορά**	**Πάντα**	**Συχνά**	**Μερικές φορές**	**Ποτέ**	**Δεν έχετε κάποιο συγκεκριμένο λόγο**	**Επειδή διστάζετε ή φοβάστε**	**Επειδή η οικογένειά σας/ οι δικοί σας το αποθαρρύνουν**
Q1.15.1 Q1.16.1 Q1.17.1	Ήπια κίνηση – ήσυχος δρόμος	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.2 Q1.16.2 Q1.17.2	Πόλη με μεγάλη κυκλοφορία	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.3 Q1.16.3 Q1.17.3	Δρόμος ταχείας κυκλοφορίας	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.4 Q1.16.4 Q1.17.4	Αυτοκινητόδρομος	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.5 Q1.16.5 Q1.17.5	Νύχτα	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.6 Q1.16.6 Q1.17.6	Έντονη βροχόπτωση	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.7 Q1.16.7 Q1.17.7	Οδήγηση σε βρεγμένο οδόστρωμα	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.8 Q1.16.8 Q1.17.8	Δρόμος με πολλές στροφές	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.9 Q1.16.9 Q1.17.9	Άγνωστη περιοχή	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.10 Q1.16.10 Q1.17.10	Αλλαγή λωρίδας	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.11 Q1.16.11 Q1.17.11	Μεγάλες αποστάσεις (>2 ώρες)	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.12 Q1.16.12 Q1.17.12	Αριστερές στροφές	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.13 Q1.16.13 Q1.17.13	Οδήγηση ενώ είστε κουρασμένος/η	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.14 Q1.16.14 Q1.17.14	Οδήγηση μόνος στο αυτοκίνητο	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.15 Q1.16.15 Q1.17.15	Συζήτηση με συνεπιβάτη	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.16 Q1.16.16 Q1.17.16	Συνομιλία στο κινητό τηλέφωνο	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.17 Q1.16.17 Q1.17.17	Διασταυρώσεις χωρίς σηματοδότες	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)
Q1.15.18 Q1.16.18 Q1.17.19	Προσπέραση σε υπεραστικές οδούς δύο λωρίδων κυκλοφορίας	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(1)	(2)	(3)

18. Ποια από τα παρακάτω και πόσο συχνά θεωρείτε ότι σας χαρακτηρίζουν στην οδήγηση;

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**Ποτέ**	**Σπάνια**	**Μερικές φορές**	**Συχνά**	**Πάντα**
Q1.18.1	Δυσκολίες στον επιμερισμό της προσοχής σας σε διάφορες ενέργειες ταυτόχρονα	(1)	(2)	(3)	(4)	(5)
Q1.18.2	Δυσκολίες στην εκτίμηση της απόστασης και της ταχύτητας των άλλων οχημάτων	(1)	(2)	(3)	(4)	(5)
Q1.18.3	Δυσκολίες στην αντίληψη οχημάτων και πεζών που πλησιάζουν ξαφνικά μπροστά σας από πλευρική κατεύθυνση	(1)	(2)	(3)	(4)	(5)
Q1.18.4	Δυσκολίες στην επικέντρωση της προσοχής στα σήματα κυκλοφορίας σε περιβάλλον όπου υπάρχουν και άλλες πινακίδες	(1)	(2)	(3)	(4)	(5)
Q1.18.5	Δυσκολίες συγκέντρωσης και διατήρησης της προσοχής	(1)	(2)	(3)	(4)	(5)
Q1.18.6	Καθυστέρηση αντίδρασης σε περίπτωση αναγκαστικού φρεναρίσματος	(1)	(2)	(3)	(4)	(5)
Q1.18.7	Δυσκολίες στην ευελιξία χεριών, ποδιών και αυχένα	(1)	(2)	(3)	(4)	(5)
Q1.18.8	Μη επαρκής γνώση των κανόνων κυκλοφορίας και των νέων σημάτων κυκλοφορίας	(1)	(2)	(3)	(4)	(5)
Q1.18.9	Δυσκολίες προσαρμογής σε περιπτώσεις που ξαφνικά εμφανίζονται αλλαγές στις κυκλοφοριακές ρυθμίσεις σε μια συνηθισμένη διαδρομή σας	(1)	(2)	(3)	(4)	(5)

Γ. ΟΔΗΓΗΣΗ ΜΕ ΑΠΟΣΠΑΣΗ ΠΡΟΣΟΧΗΣ

19, 20. Όταν οδηγείτε στις παρακάτω συνθήκες θεωρείτε ότι είναι επικίνδυνο να συνομιλείτε με συνεπιβάτη ή να χρησιμοποιείτε κινητό τηλέφωνο;

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**19. Συνομιλία με συνεπιβάτη**				**20. Χρήση κινητού τηλεφώνου**			
		Καθόλου επικίνδ	**Λίγο επικίνδυνο**	**Αρκετά επικίνδυνο**	**Πολύ επικίνδυνο**	**Καθόλου επικίνδ**	**Λίγο επικίνδυνο**	**Αρκετά επικίνδυνο**	**Πολύ επικίνδυνο**
Q1.19.1 Q1.20.1	**Εντός** πόλης - με **μεγάλη** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Q1.19.2 Q1.20.2	**Εντός** πόλης - με **μικρή** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Q1.19.3 Q1.20.3	**Εκτός** πόλης - με **μεγάλη** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Q1.19.4 Q1.20.4	**Εκτός** πόλης - με **μικρή** κυκλοφορία	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)

21. Τον τελευταίο μήνα πόσο συχνά συνομιλείτε με κάποιον συνεπιβάτη κατά την οδήγηση (κυκλώστε);

Q1.21	Ποτέ (1)	Σπάνια (2)	Μερικές φορές (3)	Πολλές φορές (4)

22. Τον τελευταίο μήνα πόσο συχνά χρησιμοποιείτε κινητό τηλέφωνο κατά την οδήγηση (κυκλώστε);

Q1.22	Ποτέ (1)	Σπάνια (2)	Μερικές φορές (3)	Πολλές φορές (4)

23. Με ποιόν τρόπο και πόσο συχνά αλλάζετε την οδηγική σας συμπεριφορά όταν <u>συνομιλείτε με συνεπιβάτη κατά την οδήγηση</u>;

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**Ποτέ**	**Σπάνια**	**Μερικές φορές**	**Συχνά**	**Πάντα**
Q1.23.1	Μειώνω ταχύτητα και οδηγώ πιο προσεκτικά	(1)	(2)	(3)	(4)	(5)
Q1.23.2	Προσπαθώ να έχω μεγαλύτερη απόσταση από το προπορευόμενο όχημα	(1)	(2)	(3)	(4)	(5)
Q1.23.3	Οδηγώ πιο δεξιά, επί του οδοστρώματος	(1)	(2)	(3)	(4)	(5)
Q1.23.4	Συμπληρώστε κάποιον άλλον τρόπο αλλαγής της οδηγικής σας συμπεριφοράς_____	(1)	(2)	(3)	(4)	(5)

24. Με ποιόν τρόπο και πόσο συχνά αλλάζετε την οδηγική σας συμπεριφορά όταν <u>κάνετε χρήση κινητού τηλεφώνου κατά την οδήγηση</u>; (αν δεν χρησιμοποιείτε κινητό τηλέφωνο κατά την οδήγηση περάστε στην ερώτηση 25)

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**Ποτέ**	**Σπάνια**	**Μερικές φορές**	**Συχνά**	**Πάντα**
Q1.24.1	Μειώνω ταχύτητα και οδηγώ πιο προσεκτικά	(1)	(2)	(3)	(4)	(5)
Q1.24.2	Σταματάω το όχημα σε ασφαλές σημείο	(1)	(2)	(3)	(4)	(5)
Q1.24.3	Προσπαθώ να έχω μεγαλύτερη απόσταση από το προπορευόμενο όχημα	(1)	(2)	(3)	(4)	(5)
Q1.24.4	Οδηγώ πιο δεξιά, επί του οδοστρώματος	(1)	(2)	(3)	(4)	(5)
Q1.24.5	Συμπληρώστε κάποιον άλλον τρόπο αλλαγής της οδηγικής σας συμπεριφοράς_____	(1)	(2)	(3)	(4)	(5)

Δ. ΣΥΝΑΙΣΘΗΜΑΤΑ ΚΑΙ ΣΥΜΠΕΡΙΦΟΡΑ ΟΔΗΓΟΥ

25. Πόσες φορές τον τελευταίο χρόνο βιώσατε ένα διαπληκτισμό με συνεπιβάτη σας καθώς οδηγούσατε (κυκλώστε);

Q1.25	0	1	2	3	4	5	6	7	8	9+

26. Πόσες φορές τον τελευταίο χρόνο βιώσατε ένα διαπληκτισμό με οδηγό άλλου οχήματος (κυκλώστε);

Q1.26	0	1	2	3	4	5	6	7	8	9+

27. Πόσες φορές τον τελευταίο χρόνο «ήρθατε στα χέρια» με οδηγό άλλου οχήματος (κυκλώστε);

Q1.27	0	1	2	3	4	5	6	7	8	9+

28. Χρησιμοποιείτε τη ζώνη ασφαλείας (κυκλώστε); Q1.28	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)	Πάντοτε (5)

29. Οδηγείτε υπό την επήρεια αλκοόλ όταν είστε έξω με τους φίλους σας (κυκλώστε); Q1.29	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)

30. Οδηγείτε επικίνδυνα για εσάς και τους άλλους όταν είστε έξω με τους φίλους σας (κυκλώστε); Q1.30	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)

31. Σε γενικές γραμμές πόσο συχνά οδηγείτε χωρίς να είστε συγκεντρωμένος-η (κυκλώστε); Q1.31	Καθόλου (1)	Σπάνια (2)	Μερικές φορές (3)	Πολύ συχνά (4)

Ε. ΚΛΙΜΑΚΑ ΕΚΦΡΑΣΗΣ ΘΥΜΟΥ ΚΑΤΑ ΤΗΝ ΟΔΗΓΗΣΗ

32. Πόσο συχνά συμβαίνουν τα παρακάτω γεγονότα, καθώς οδηγείτε;

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**Σχεδόν ποτέ**	**Σπάνια**	**Συχνά**	**Σχεδόν πάντα**
Q1.32.1	Φωνάζω επικριτικά σχόλια, όπως «Νύχτα πήρες το δίπλωμα;»	(1)	(2)	(3)	(4)
Q1.32.2	Βρίζω τον άλλο οδηγό δυνατά	(1)	(2)	(3)	(4)
Q1.32.3	Βρίζω τον άλλο οδηγό χαμηλόφωνα	(1)	(2)	(3)	(4)
Q1.32.4	Αγριοκοιτάζω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.5	Κουνάω το κεφάλι μου αποδοκιμαστικά στον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.6	Σκέφτομαι πράγματα όπως «Νύχτα πήρες το δίπλωμα;»	(1)	(2)	(3)	(4)
Q1.32.7	Προσπαθώ να βγω από το αυτοκίνητο και να βρίσω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.8	Προσπαθώ να εξωθήσω τον άλλο οδηγό στη άκρη του δρόμου	(1)	(2)	(3)	(4)
Q1.32.9	Κάνω άσεμνες χειρονομίες με το χέρι στον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.10	Προσπαθώ να τρομάξω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.11	Παθαίνω κρίση πίσω από το τιμόνι	(1)	(2)	(3)	(4)
Q1.32.12	Μουντζώνω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.13	Οδηγώ κατευθείαν στον προφυλακτήρα του άλλου οδηγού	(1)	(2)	(3)	(4)
Q1.32.14	Προσπαθώ να βρεθώ μπροστά από τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.15	Ακολουθώ τον άλλο οδηγό ακριβώς από πίσω του για πολλή ώρα	(1)	(2)	(3)	(4)
Q1.32.16	Αναβοσβήνω τα φώτα μου στον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.17	Επίτηδες εμποδίζω τον άλλο οδηγό να πάει εκεί που θέλει	(1)	(2)	(3)	(4)

	**Σημειώστε με √ το κουτάκι της επιλογής σας*	**Σχεδόν ποτέ**	**Σπάνια**	**Συχνά**	**Σχεδόν πάντα**
Q1.32.18	Κάνω στους άλλους οδηγούς ό,τι έκαναν σε μένα	(1)	(2)	(3)	(4)
Q1.32.19	Οδηγώ ταχύτερα απ' ό,τι πριν	(1)	(2)	(3)	(4)
Q1.32.20	Επιβραδύνω για να εκνευρίζω τον άλλο οδηγό	(1)	(2)	(3)	(4)
Q1.32.21	Αφήνω τα μεγάλα φώτα να φωτίζουν στον καθρέφτη του άλλου οδηγού	(1)	(2)	(3)	(4)
Q1.32.22	Ξεσπάω τον θυμό μου στους συνεπιβάτες μου	(1)	(2)	(3)	(4)
Q1.32.23	Δεν μπορώ να ηρεμήσω και παραμένω θυμωμένος /η όλη την ώρα	(1)	(2)	(3)	(4)
Q1.32.24	Εκτονώνω τον θυμό μου σε άλλους αργότερα	(1)	(2)	(3)	(4)
Q1.32.25	Σκέφτομαι πρώτα προτού αντιδράσω	(1)	(2)	(3)	(4)
Q1.32.26	Προσπαθώ να σκεφτώ θετικές λύσεις για να αντιμετωπίσω την κατάσταση	(1)	(2)	(3)	(4)
Q1.32.27	Δίνω ακόμα περισσότερη προσοχή στο δρόμο, προς αποφυγή ατυχημάτων	(1)	(2)	(3)	(4)
Q1.32.28	Αποφασίζω να μην πέσω στο επίπεδό τους	(1)	(2)	(3)	(4)
Q1.32.29	Λέω στον εαυτό μου ότι δεν αξίζει να εμπλακώ	(1)	(2)	(3)	(4)
Q1.32.30	Απλά προσπαθώ να αποδεχτώ ότι υπάρχουν και κακοί οδηγοί στον δρόμο	(1)	(2)	(3)	(4)
Q1.32.31	Απλά προσπαθώ να αποδεχτώ ότι υπάρχουν καταστάσεις που προκαλούν	(1)	(2)	(3)	(4)
Q1.32.32	Ανοίγω το ραδιόφωνο ή βάζω μουσική για να ηρεμήσω	(1)	(2)	(3)	(4)
Q1.32.33	Κάνω πράγματα όπως βαθιές αναπνοές για να ηρεμήσω	(1)	(2)	(3)	(4)
Q1.32.34	Σκέφτομαι πράγματα που με αποσπούν από τον εκνευρισμό στον δρόμο	(1)	(2)	(3)	(4)

ΣΤ. ΙΣΤΟΡΙΚΟ ΣΥΜΒΑΝΤΩΝ

33. Πόσα ατυχήματα <u>συνολικά</u> είχατε ως οδηγός (κυκλώστε);

Q1.33	0	1	2	3	4	5	6	7	8	9+

34. Πόσες φορές <u>τα τελευταία δύο χρόνια</u>, αποφύγατε «την τελευταία στιγμή» ένα ατύχημα (κυκλώστε);

Q1.34	0	1	2	3	4	5	6	7	8	9+

35. Πόσα <u>ατυχήματα μόνο με υλικές ζημιές</u> είχατε <u>τα τελευταία δύο χρόνια</u> με το αυτοκίνητο(κυκλώστε);

Q1.35	0	1	2	3	4	5	6	7	8	9+

36. Πόσα <u>σοβαρά ατυχήματα με τραυματισμό</u> είχατε <u>τα τελευταία δύο χρόνια</u> με το αυτοκίνητο(κυκλώστε);

Q1.36	0	1	2	3	4	5	6	7	8	9+

37. Πόσες φορές <u>τα τελευταία δύο χρόνια</u>, <u>παραβιάσατε</u> τον Κώδικα Οδικής Κυκλοφορίας ενώ οδηγούσατε (κυκλώστε);

Q1.37	0	1	2	3	4	5	6	7	8	9+

38. <u>Τα τελευταία δύο χρόνια,</u> <u>πόσες κλήσεις</u> είχατε για παραβάσεις του Κώδικα Οδικής Κυκλοφορίας (κυκλώστε);

Q1.38	0	1	2	3	4	5	6	7	8	9+

… you can do it._