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Design of an on-road driving experiment on assessing driving behavior of older drivers

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Abstract

Driving is a complex activity, which requires a combination of motor and mental skills. The deterioration of many mental functions critical to driving (i.e. memory, attention, visual-spatial perception, executive functions), either due to physiological aging, due to a neurological disease (i.e. mild cognitive impairment, mild dementia, etc.), or due to relevant medication may significantly affect driving performance. The goal of this study is to present the design of a large on road driving experiment which aims to assess the driving ability of older drivers through an innovative methodology. In order to achieve the above goal, a system for recording and evaluating the driving behavior of the elderly, by using driving data, which are collected through OSeven smartphone application is developed. For the purpose of this study, 100 elderly active drivers (over 60 years old) will take part in an on road driving experiment, on a specific route, which will include road sections inside and outside urban area, in the region of Attica. The data that will be collected are: a) objective driving data continuously recorded through the OSeven smartphone application, which collects a variety of driving behavior parameters continuously and b) driving behavior assessment through a specific driving behavior checklist. The collected data will be processed with appropriate algorithm development methods and a series of different statistical analyses will take place aiming to analyze the impact of advanced age and other factors on driving behavior parameters. The benefits of this study are both scientific and socio-economic. The final outcome concern a toolbox for the evaluation and possible improvement of the driving ability and safety of older drivers namely a complete protocol for assessing the driving ability and safety of the elderly, and specific indicators of their driving behavior and safety.

Keywords: *on-road driving experiment, older drivers, driving behavior, driving assessment, smartphone application.*

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1. Introduction

Driving is one of the most multifaceted, complex and potentially hazardous tasks that people encounter every day [1]. It requires a combination of motor and mental skills as well as the execution of several sub-tasks and simultaneous environmental cues in a safe way. According to Roenker et al. [2], driving skills refer to strengths and weaknesses of the individual's driving performance, that is the execution of the ensemble of driving's sub-tasks (e.g. reaction time, steering wheel) which improves with practice. It should be noted that the driving style or driving performance corresponds to the way people choose to drive based on habits consolidated over years (e.g. speeding, aggressiveness), influenced by attitudes toward driving and the individual's values.

A number of parameters, acting alone or connected, could cause road traffic crashes, such as vehicle (e.g. tire pressure), road (e.g. road type, traffic volumes) and environmental (e.g. weather conditions, time of the day) factors [3]. Moreover, human factors (e.g. cognitive failures, inexperience), which are considered the cause of more than 70% of road crashes refer to an individuals' driving skills, personality measures and cognitive abilities [4]. In addition, the deterioration of many mental functions critical to driving (i.e. memory, attention, visual-spatial perception, executive functions), either due to physiological aging, due to a neurological disease (i.e. mild cognitive impairment, mild dementia, etc.), or due to relevant medication may significantly affect driving performance [5, 6].

The ageing process is usually accompanied by several changes in mental and physical capacities. Those changes are thought to affect, at a smaller or larger extent, the ability to perform flawlessly daily tasks. Driving behavior can change with age under the influence of alterations in perceptual-motor, sensory, cognitive abilities or accumulated experience [7]. More specifically, recent epidemiological data state that older drivers have increased risk to be engaged in motor crashes, and that road fatalities in the elderly represent the 27% of all life losses from car crashes in the EU [8]. What is more, according to accumulated research findings, the presence of cognitive dysfunction due to the ageing process, especially in the case of neurocognitive disorders of high prevalence, such as Alzheimer' s disease (AD), may critically compromise fitness to drive. In the next five years, it is expected that 32% of patients with Mild Cognitive Impairment (MCI) are going to develop Alzheimer's disease [9]. It should be noted that in driving, patients with AD are more likely to commit at-fault driving errors and get involved in a car crash than healthy elderly drivers.

It is worth mentioning that approximately 15-20% of the general population aged 65 years and older in the OECD countries may have MCI [10]. A transitional stage between normal aging and dementia with none or only minimal impairment in everyday activities was observed [11]. From the research available, it seems that drivers with MCI, appear to present a slightly increased rate of driving errors in comparison to their healthy counterparts. Indicatively, patients with MCI present increased difficulties regarding positioning their vehicle on the road, left-hand turns, reaction time and mean time to collision as well as maintaining proper speed while driving [12]. Another recent study by Shimada et al. [13] revealed that, the older the participants with MCI were, the higher the number of unsafe driving acts, while at the same time, the higher the number of unsafe driving tasks, the lower the processing speed. In addition, Anstey et al. [14] indicated that older adults with MCI had similar performance during an on-road driving assessment with healthy older adults, although the overall performance of the participants with MCI were lower both in on-road and in the off-road evaluation.

Taking into account the consequences that possible inaccurate decisions may impose on an individual's and their surrounding environment quality of life, the goal of this research is to present the design of a large on-road driving experiment which aims to assess the driving ability of older drivers through an innovative methodology. In order to achieve the above goal, a system for recording and evaluating the driving behavior of the elderly, by using driving data, which are collected through OSeven smartphone application is developed.

The structure of the paper is as follows. In the beginning, the conceptual framework and the objective of this paper is outlined. Subsequently, an extended literature review is carried out regarding all available experimental process of assessing driving behavior of older drivers. More specifically, studies that examine driver performance of elderly people through on-road driving trials were included. In the next step, the methodological overview and the system which has been developed and implemented to record and evaluate the driving behavior of the elderly using real time driving data is detailed described. Finally, some concluding remarks are provided and recommendations for future research directions are also highlighted.

2. Theoretical Background

In a very short amount of time, with the rapid evolution of technology, the automotive telematics market is growing steadily and a few driver monitoring systems and innovative telematics have been introduced in our daily life. To date, more and more older drivers look for new services which can provide more options in order to adjust their driving style and techniques, reward their progress, identify their weaknesses and promote maximum road safety for everyone. Automotive telematics technology receive information from vehicles, including sensors, radars, Global Positioning System (GPS) coordinates, wireless internet connections, engine diagnostics, touch screens as well as cameras inside and outside the vehicle and send it to a centralized server where it is then analyzed using an appropriate fleet management software. In this paper, studies which refer to the driver behavior through technological devices adapted to the car's brain are presented. Particular emphasis is given to surveys which were conducted in order to assess driving performance of older adults using data from state-of-the-art technologies with focus on key risk indicators (e.g. speeding, harsh events).

In many studies taken place internationally, a device-agnostic platform has been developed with the ability to collect naturalistic driving data from different sources such as smartphones, on-board diagnostics (OBDs) and 4G/5G connected cars. To begin with, a validation study involved 33 drivers whose vehicles were instrumented with an in-vehicle data recorder (IVDR), called DriveDiagnostics was conducted [15]. The IVDR collected driving indicators, such as speed, harsh accelerations, hash brakings, lane change, position estimated through GPS, etc. It also recorded the movement of the vehicle and used this information in order to indicate overall trip safety. This system has been designed in order to monitor and analyze driver behavior not only in crash or near-miss events but also in normal driving situations.

Smartphone sensors have been widely used for the research of traffic monitoring, mining driving routes and recognition of aggressive driving behaviors [16]. More specifically, Gu et al. [17] proposed a smartphone-based Driving Data Recorder (DDR). The aforementioned technology had the functions of accurate speed estimation and intelligent traffic scene understanding. This DDR was used to store the relevant driving data and provided feedback on driver behavior for crash analysis or other insurance issues and vehicle speed was directly detected from the gyroscope and the accelerometer of a smartphone. In addition, Mohan et al. [18] used the accelerometer, microphone, GSM radio and GPS sensors in the smartphone for reporting the relevant location and detecting speed, braking, harsh acceleration, bumps and potholes.

Furthermore, estimation of road conditions using smartphone sensors, such as tri-axial accelerometer and a gyroscope, has been proposed by Allouch et al. [19]. In particular, the goal of this research was to derive a road quality recognition system which can identify, detect, analyze and predict the state of road segments. A naturalistic driving experiment, lasted for about 3 weeks, was implemented and drivers installed the RoadSense application on their smartphone. It should be noted that the application was run by the driver in real-driving environments. The drivers were asked to drive just as how they normally do. This application detected in real-time the road quality as well as the road location trace on a geographic map and some useful information including the speed of the vehicle, the percentage of smooth type on the travelled road, the number of potholes and the distance travelled were also provided. What's more, an interesting study aiming to provide a real-time system for detecting potholes was presented [20]. The proposed technology employed Android OS based smartphones having simple algorithms and accelerometer sensors so as to detect harsh events from acceleration data. Experimental results indicated that there was a true positive rate equal to 90%. Nevertheless, one of the main drawbacks of that work was that the system used only accelerometer sensors and data were collected through specialized hardware.

Another naturalistic driving study was conducted in order to classify different driving styles based on data collected from smartphones [21]. The proposed approach classified the driving styles into three levels: normal, aggressive and very aggressive driving, based on the rotation rate and acceleration. To achieve this objective, a novel system which used a Dynamic Time Warping (DTW) and a smartphone based sensor-fusion (i.e. accelerometer, magnetometer, gyroscope, GPS, video) was used to identify and record these actions without external processing. Similarly, motion sensors (i.e. accelerometer and GPS receiver) embedded on a smartphone were used in an on-road trial and twelve types of driving events such as, sudden turning or sudden lane changing were detected [22]. The proposed pattern matching algorithms classified whether or not these events were aggressive based on raw data from various on-board smartphone sensors. Thiagarajan et al. [23] proposed a system, called vTrack, which monitored the traffic conditions and predicted the traveling time based on the report from GPS and WiFi position sensors in massive users' smartphones.

Particular focus is put on research that endeavours on the assessment of driving behavior of older drivers through an on-road driving experiment. First of all, Festa et al. [24] analyzed in-car video recording of naturalistic driving of 18 older adults with questionable or mild Alzheimer disease (AD) and 20 age-matched controls in order to characterize self-regulatory behaviors engaged by older drivers and evaluate how driving performance changes with cognitive impairment. Participants' vehicles were equipped with four small cameras so as to record two weeks of driving behavior. In particular, one camera faced the driver, another faced forward, and the rest of the cameras (two back cameras) faced diagonally forward to capture the environment along the sides of the vehicle. It should be noted that video from the cameras was automatically downloaded to a portable digital video recording device which was placed under the passenger seat. Results revealed that older drivers with AD displayed further restrictions of driving performance beyond those of healthy elderly individuals, indicating additional regulation on the basis of cognitive status.

Additionally, another on-road driving experiment was conducted and 33 healthy individuals aged 65 years above were recruited [25]. For the purpose of this study, an instrumented automatic vehicle with charge-coupled device cameras, data recorders and dual brake controls was used. The equipment was placed on the windshields, pedal box and front dashboard. Vehicle information, such as the acceleration, braking, speed, surrounding traffic, lanes, position and location of the vehicle as well as driver-related characteristics, such as participant's face, gaze and footwork were provided. All participants took an on-road driving test and drove the instrumented vehicle on the same course in an urban environment around a driving school for a 30-minute duration. It should be highlighted that in order to ensure participant's safety, a driving instructor was in the car while each participant drove.

An elaborate assessment approach aiming to investigate and measure older drivers' visual behavior was developed [26]. More specifically, the empirical data came from 38 elderly people aged 60 to 81 years, who completed an on-road driving trial recorded by vehicle movement and eye tracking. Their visual attributes were extracted from eye tracking video frames and linked to vehicle positions. Driving data, driving section and drivers' cognitive condition were encapsulated into an integrated database which allowed interrogating multi-faceted driver-vehicle-environment interactions. The results of the exploratory analysis revealed that older drivers' appeared to have different visual search patterns at intersection manoeuvres and roundabout, while older adults with better executive function skills performed more frequent eye fixations inside vehicle features, and especially on the curves.

Eramudugolla et al. [27] aimed to investigate the differences on the on-road error profiles of drivers with MCI compared to cognitively normal older adults. To that aim, drivers aged 65 years and older participated in an on-road driving experiment for a 50-minute open-road assessment in an automatic vehicle with dual-brake controls fitted. The route was predetermined, located in an urban environment which included a range of controlled and uncontrolled intersections, residential areas, highway driving, school zones, shopping strips, stop/give-way intersections, car parks, and roundabouts. The aforementioned route was approximately 20 km and was divided into 164 possible manoeuvres or locations to assist with scoring. Driving performance was scored following a standard and validated protocol and participants were classified as safe or unsafe based on a validated on-road safety scale of 1 to 10 (where higher scores indicated higher safety). Driving performance indicators, such as speed control, lane position, indication, blind-spot checking, or gap selection were provided. It was found that compared with safe cognitively normal drivers, unsafe cognitively normal drivers were more likely to make errors in speed control, observation, lane position and curved driving. At the same time, unsafe MCI participants had additional difficulties at roundabouts, intersections, straight driving, parking and under self-navigation conditions.

All in all, as can be understood from the previous paragraphs, no study has assessed the driving performance of older drivers through an innovative smartphone application. As a result, a gap in the literature exists that the current paper hopes to fill by designing a toolbox for the evaluation and possible improvement of the driving ability and safety of older drivers. In order to evaluate the driving behavior of elderly people, an on-road driving experiment is deemed the most appropriate method and, therefore, a review of the literature was also conducted on methodological issues. Several published papers have used the corresponding variables in order to estimate the driving behavior indicators.

3. Methodological Overview

For the purpose of this study, 100 elderly active drivers (over 60 years old) will take part in a naturalistic driving experiment, on a specific route with a duration of at least 45 minutes, which will include road sections inside and outside urban area, in the region of Attica. A system will be implemented to record and evaluate the driving behavior of the elderly using real time driving data. An on-road driving experiment will be performed using objective driving data that will be collected through the OSeven smartphone application and a driving behavior assessment through a specific driving behavior questionnaire will be provided.

Participants will use the same vehicle and the driving evaluation expert will serve as a co-passenger for conducting the specialized assessment according to a standardized set of criteria. The specialized driving evaluation checklist will be completed by a specialized driving evaluator expert. This framework is expected to provide important help for filling the existing gap of the current evaluation process of elderly drivers by enhancing the accuracy of the recommendations regarding the driving ability for the elderly and by this way to improve their quality of life.

3.1 Experimental process

Driving behavior analytics will be recorded, using smartphone device sensors (i.e. accelerometer, gyroscope, magnetoscope, etc.). An innovative data collection system using a smartphone application that has been developed by OSeven will be exploited. More specifically, a set of sophisticated and personalized interactive tools will be applied by OSeven, powered by breakthrough technology, smart algorithms and reliable metrics. In particular, an app interfacing between hardware sensors of the smartphone device and its user will be developed and a variety of APIs to read sensor data recorded and store it to smartphone’s database will be exploited. The app will be capable of transmitting data to the central database transmitted through Wi-Fi or cellular network (e.g. 3G/4G network). Through this process data is being filtered and cleaned and the composition of several significant safety indicators is taking place. Valuable critical information such as metrics, features, highlights and driving score will be produced in order to evaluate driving profile and performance.

The most advanced Machine Learning techniques have been implemented to detect the most crucial driving performance indicators, identify the trip transport mode and recognize whether the user is a driver or a passenger. Consequently, the OSeven platform helps drivers understand their weak points and motivates them to improve their driving behavior. A schematic overview of the standard procedure followed every time a new trip is recorded by the app, is provided in Figure 1.

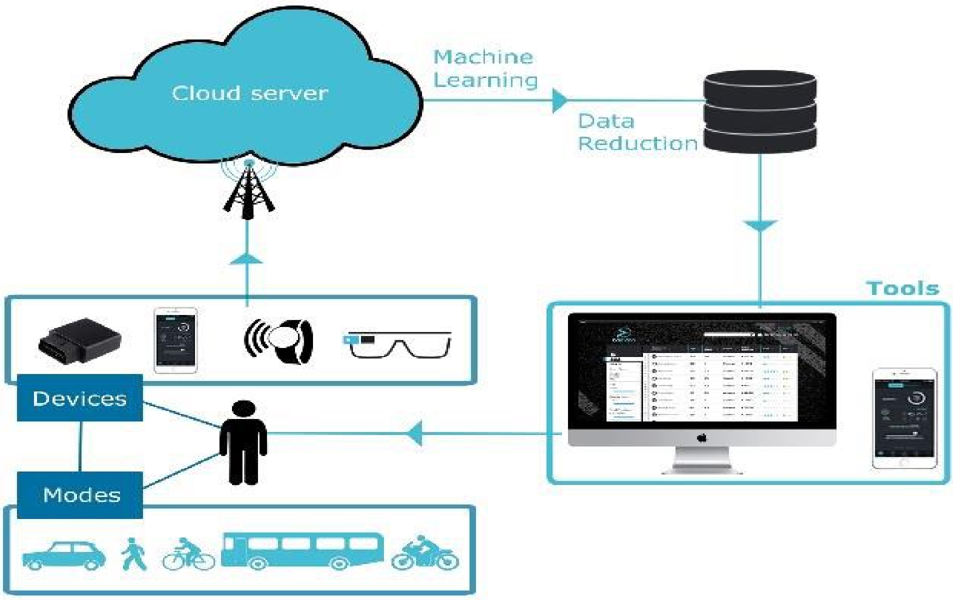

Figure 1: OSeven data handling chart

The large scale data collection and analysis will be ground breaking and will present new challenges by gathering sufficient quantities of data for analysis. The exposure indicators which will be available include indicatively:

- total distance (mileage),
- total duration (seconds),
- type of the road network used (i.e. highway, rural or urban environment), given by GPS position and integration with map providers, such as Google, OSM, etc.,
- time of the day driving (i.e. risky hours, rush hours).

Furthermore, the driving indicators which can reliably quantify the risk associated with a specific driving behavior are the following:

- speeding (i.e. exceedance of the speed limit, time and distance of driving above the speed limit),
- number and severity of harsh events (i.e. acceleration, braking, cornering),
- driver distraction (i.e. caused by mobile phone use while driving, talking, texting),
- driving aggressiveness (i.e. acceleration and braking),
- driving in risky hours (i.e. from 22:00pm to 05:00am).

It should be mentioned that since privacy consist the cornerstone in the field of telematics, the OSeven platform has very clear privacy policy statements for the end users covering the type of data collected, the reason data is collected for, the time that data is stored and the procedures for data security based on encryption standards for data in transit and at rest. All this is done using state-of-the-art technologies and procedures in compliance with the General Data Protection Regulation (GDPR). In this framework, all data has been provided by OSeven in an anonymized format.

At the same time, informed consent will be obtained from all participants by explaining to them that participation is on a voluntary basis. They will be informed on the nature of the study, the duration of their engagement and the type of information that they will be asked to give. Lastly, participants will be ensured about the confidentiality of the procedure and that the use of their background information will involve only research purposes.

3.2 Questionnaire

Before the driving experiment, each participant will fill in a structured questionnaire which will be divided into three distinct sections: a) overall driving data, b) attitude and behavior toward road safety, and c) demographic characteristics. Specifically, drivers are going to provide valuable information such as gender, age, educational level, history of crashes, emotions, or self-assessment driving. They will also apprise other driving behavior indicators, such as speed limit exceedance, traffic violations, harsh events (i.e. brakings or accelerations) and mobile phone usage during driving.

After developing the databases and the data coding, the appropriate analyses will be applied in order to identify the correlation between questionnaires and actual driving behavior that may bear some relationship to crash risk. In parallel, a set of multiple regression analyses will be conducted so as to predict several driving performance variables (e.g. speed, lateral position, variability of steering angle, reaction time, crash probability) by using risk factors (e.g. gender, age, cerebral disease, distraction while driving) and questionnaire answers as independent variables.

4. Discussion

The final outcome concern a toolbox for the evaluation and possible improvement of the driving ability and safety of older drivers. A complete protocol for assessing the driving ability and safety of the elderly and specific driving behavior and safety indicators will be provided by using not only big data analysis tools but also dangerous driving detection tools.

The expected benefits of this study will be scientific, socioeconomic and psychological. The scientific benefits concern the enhancement of the current knowledge regarding the link that exists between the profile of older drivers, including type and severity and the driving performance patterns, by combining the results obtained from the on-road driving evaluation and the self-assessment questionnaires. The proposed study concerning assessment of driving aims at providing helpful information regarding whether an older driver has some indicators that suggest dangerous driving performance.

The socioeconomic impact concerns the improvement of road safety that may be achieved for the driving population, with the development of a unified, valid and easy to administer procedure with ecologically valid guidelines that can be applied during the license renewal process of older drivers. More specifically, the implementation of an individualized approach to decisions regarding driving cessation is expected to improve overall the major societal problem of road safety by reducing the probability of road fatalities and by alleviating their current social and economic burden both on a personal and a national level. What is more, due to the recent changes in the Greek legislation system under which each driver over the age of 74 is obligated to complete an on-road driving evaluation, it is expected that the load for the driving assessment professional will be significantly increased. Hence, the current research has the capacity to tackle this issue by supporting the work of the driving assessment professionals in a period of time that the effective integration of various sources of information could be of high importance.

Regarding the psychological benefits, elderly people who will be scored as drivers at-risk, will be encouraged to improve their driving skills through driving lessons and serious games methods. In addition, in case that MCI, dementia and other conditions may make it unsafe for elderly people to drive, they will be more willing to use other transportation means for their everyday trips. Consequently, the results of the proposed research will be of particular interest to older drivers, with or without cognitive disorders, as well as to their family environment and caregivers (through public campaigns, dissemination of information, etc.), to physicians or other experts involved in the treatment, monitoring and evaluation of elderly individuals, and especially to road safety policy makers involved in driver licensing and evaluation procedures (medical doctors, Ministry of Transportation, driving examiners, training schools etc.).

4.1 Limitations

The present study has several limitations that must be acknowledged. Firstly, with regards to the original data collection, the integrated approach will obtain a completed dataset for 100 older drivers, aged 60 years and above. The sample size is adequate for the standard assessment but limited the opportunities to split the group into subgroups for more sophisticated analyses. Moreover, vehicle control parameters, such as different stages of roundabout manoeuvres, left and right turns or other driving performance indicators, including reaction time, headway, illegal overtaking are not taken into account. Finally, with regards to the driving behavior, data collection will be provided in their final format by OSeven, but the actual algorithms of obtaining the indicators (e.g. speeding or harsh events) from smartphone sensors are intellectually protected and unknown to the authors; therefore a "black-box" effect exists.

4.2 Future Research Directions

The next steps of the current study include the organization of a following naturalistic driving experiment where a larger sample of drivers with different age groups will be recruited. It is obviously that the more drivers are participated at an on-road driving trial, the more reliable the variables and results are. With respect to research methodologies, there are many different statistical data analysis methods, such as factor analysis, cluster analysis, or time series analysis that can be used in order to exhibit different driving style at any types of road. Furthermore, the correlation of the self-assessment questionnaire answers with the driving behavioral variables from the driving simulator could be also examined. Interestingly, a similar naturalistic driving experiment involving the worst-performing drivers of all ages would be quite impressive to be achieved.

Future research should also focus on the development of a methodology for the prediction of safe driving behavior in the elderly drivers, by applying pass/fail scores in specific neurological and neuropsychological measures. In addition, the participants' psychological status, fatigue, sleepiness, mental health or driving under the influence of alcohol could be also taken into consideration. Lastly, in a subsequent study, of particular interest would be the assessment of driving behavior of older drivers through an On-Board Diagnostic device (OBD-II) connected inside the vehicle for more precise data.

5. Conclusions

The aim of this study is to describe the design of a large on-road driving experiment aiming to assess the driving ability of older drivers through an innovative methodology. In order to fulfil this goal, the participants' driving-behavior profile will be assessed in an innovative and multimodal way. The objective driving data will be obtained by conditions of on-road driving through the integration of state-of-the-art technology and the OSeven smartphone application, which collects a variety of driving behavior parameters continuously. In addition, a driving behavior assessment through a specific questionnaire will be developed.

Findings of this paper can be used for designing more efficient fitness-to-driver assessment. The collected data will be processed with appropriate algorithm development methods and a series of different statistical analyses will take place aiming to analyze the impact of advanced age and other factors on driving behavior parameters. This framework is expected to provide important help for filling the existing gap of the current evaluation process of elderly drivers by enhancing the accuracy of the recommendations regarding the driving ability for the elderly and by this way to improve their quality of life.

It is worth mentioning that when preliminary results are available, the most crucial risk indicators will be extracted in order to be able to support our assumptions and provide significant findings.

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