Assessing Driving Performance of Older Drivers – A Literature Review

Dimosthenis Pavlou[1*], George Yannis[1]

[1]National Technical University of Athens, Department of Transportation Planning and Engineering, 5 Heroon Polytechniou str., GR-15773, Athens, Greece

Abstract

Driving requires the ability to receive information, process it and make the right and timely judgment and appropriate response. Various difficulties (motor, visual, cognitive or perceptual etc.) can affect the driving performance. These difficulties arise due to advanced age and can lead to a significant deterioration in driving ability and an increased risk of road crash. While today, over 20% of road crash fatalities involve drivers of more than 60 years of age in Europe, it is expected that by 2050 the rate of elderly road crash fatalities will increase to 43%. The goal of this study is to examine and present the most critical parameters that can assess and predict the driving performance of older drivers. For that purpose, an extended literature review was extracted in order to investigate the most crucial indicators which are examined in the scientific field. Methods of assessing driving, including on-road trials, driving simulator experiments, driving behavior questionnaires, neurological and neuropsychological tests or a combination of them and related results of the literature are provided. Several studies examining driving parameters that could predict and assess the driving behavior of older drivers were reviewed based on specific selection criteria. In this framework, the respective driving performance measures were recorded with the aim to investigate which ones are the most promising and in which way they are analyzed. The literature review highlights the need for further research for diagnostic tools assessing driving behavior and safety in order to support decision makers to assess fitness (or not) – to – drive for the elderly.

Keywords: *Older Drivers, Driving Behavior, Assessment, Fitness to Drive for the Elderly, Literature Review.*

[1] Corresponding author. Tel.: +30-6973807692;
E-mail address: dpavlou@central.ntua.gr

1. Introduction

Driving is a complex task that requires the utilization of a wide range of individual skills as well as practical and psychological abilities. Drivers should have good spatial perception and well-coordinated control in order to manage multiple stimuli simultaneously, make timely judgments or responses and react quickly in case of an emergency when completing the driving processing [1]. The normal aging process is associated with increasing motor, cognitive, visual, perceptual and sensory impairments. In particular, specific changes include motor skills such as physical strength, manual dexterity or neck flexibility [2], cognition such as processing speed, selective and divided attention, fluid intelligence or executive functioning [3], vision such as contrast sensitivity, visual acuity or sensitivity to glare [4], perception such as reaction time or motion perception [5] and sensory function, such as acuity and contrast sensitivity [6]. The aforementioned difficulties can affect various domains, some of which are closely related to driving performance. Due to advanced age, a functional decline in the memory, physical fitness and flexibility needed for safe driving can lead to a significant deterioration in driving ability and an increased risk of road crash.

Older adult drivers are more likely to experience not only complicated conditions but also challenging driving situations that can directly affect their ability to control a motor vehicle safely [7]. It should be mentioned that the age-group refers to as older adult drivers is the one of 75 years and above. According to European Commission [8], older drivers have the second highest fatality rate in traffic of all age-groups. At the same time, they do not consist so much a risk to others, but they are at risk themselves due to their vulnerability and frailty to the increased injury severity or risk of death in the event of a crash involvement. Population ageing is a global phenomenon with lasting and continued impacts on sustainable development. In general, the average age of road crash fatalities is on the rise. In the upcoming years, the problem's magnitude may further increase due to the expected increase in the total number of people more than 65 years of age, the mobility of elderly people as well as the rates of licensed older drivers. While today, over 20% of road crash fatalities involve drivers aged 60 years and above in Europe and it is expected that by the year 2050, the rate of elderly road crash fatalities will increase to 43% [9]. Similar growth is also expected to be achieved in the driving population. In particular, in 2011, the percentage of older drivers in the total population was 16% and by 2025, one in five drivers (20%) will be at least 65 years of age [10].

To date, no systematic review exists that synthesizes the literature on which are the most crucial parameters that affect driving behavior, nor how older adults assess their perception and their driving abilities. Within, the above framework, the aim of the current research is to identify the critical driving parameters that can assess and predict the driving performance. To achieve this objective, a comprehensive literature search on driving performance of older people was conducted in order to investigate the most important indicators examined in the scientific field of driver behavior. Identified measurement methods and associated techniques were assessed based on pre-defined criteria, such as title of the paper, published in scientific journals, recent research and quantitative results, etc.

The paper is structured as follows. In the beginning, the theoretical background and the objective of this paper is outlined. Subsequently, the methodological approach of the current research is provided. Then, an extended literature review is carried out regarding all the critical parameters and the available experiment types of assessing driving performance of older drivers. A review of on-road experiments and driving simulator studies on driver behavior is presented, based on specific selection criteria. This is followed by a section, in which, the results of the literature review pertaining to older drivers and their driving performance and a synthesis of the most critical parameters are highlighted. In the next step, evaluated similarities and differences between the studies are also presented. The research gaps in the knowledge base as well as suggested areas for future research exploration are provided. Finally, overall conclusions to assist researchers and practitioners and brief policy recommendations that can promote road safety are proposed.

2. Methodological Background

The current research endeavors to complement the qualitative outputs of the literature by exploiting meta-analytic technique which is used to acquire quantitative estimates of the most influencing parameters on driving performance. Studies have to fulfil specific study selection criteria in order to be included in the meta-analysis.

2.1 Literature Search

This paper examines and presents the most critical parameters that can assess and predict the driving performance of older drivers. In order to perform a comprehensive literature review, a systematic search of relevant scientific literature was carried out using the key terms: “older drivers” OR “driving performance” OR “driving behavior”

OR “driving assessment” OR “driving” OR “elderly” OR “fitness to drive for the elderly” OR “on-road trial” OR “simulator” OR “questionnaire” “neurological tests” OR “neuropsychological tests”. Prioritization criteria for the inclusion of studies in the literature review specified as follows:

- Studies published from 2000 and onwards
- Most recent and high-quality meta-analyses
- Studies including information on driving performance of older drivers in the title or abstract
- Importance: number of citations
- Language: studies published in English
- Source: peer-reviewed journals before peer-reviewed conference papers

The search was conducted using scientific databases and repositories, such as ScienceDirect, Scopus, ResearchGate, Google Scholar, PubMed, Medline and Cochrane which provided access to scientifically rigorous studies in indexed and reputable journals and conferences. It should be noted that journal papers were preferred over conference papers. Nevertheless, highly informative conference papers were accepted and included in the analysis when they were of considerable overall quality. No “grey” literature (e.g. government reports, lecture notes, newsletters, presentations) was examined. In the next step, publications were deduplicated, screened by title and then by abstract. Relevant literature was documented and summarized and the most relevant findings were overviewed for final refinement.

2.2 The PRISMA Procedure

This review was carried out during December 2021 and adhered to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) steps [11] to identify relevant research articles. The initial search was performed in October 2021 and all databases were last accessed in December 2021. To begin with, the search resulted in a total of 23,218 papers with 2,759 duplicates. Two reviewers independently screened all papers utilizing a general inclusion/exclusion assessment which was similar to the approach followed by Hawker et al. [12]. In case that older adults were not included in the studies examined, these papers were excluded. A total of 77 articles were selected for full-text review, including full papers suggested from a subject matter expert. It should be noted that no articles were identified during a legacy search. After the full paper review, an additional 52 articles were excluded for not meeting the inclusion criteria (e.g., papers did not thoroughly discuss nor explore driving performance indicators of elderly drivers). In total, 25 papers were included in the final review. The PRISMA flowchart and the search strategy is depicted in Figure 1.

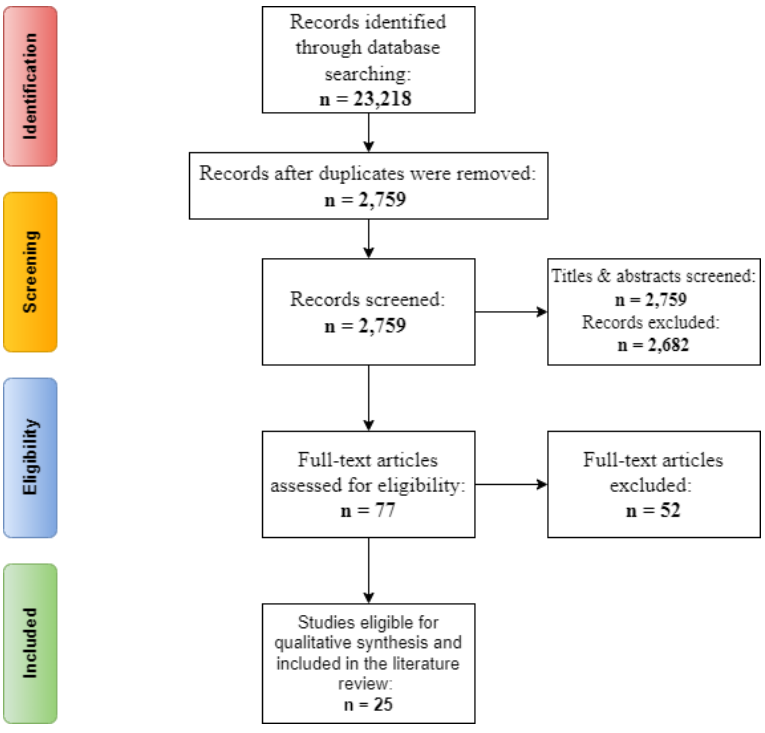

Figure 1: PRISMA flowchart of the systematic literature review

3. Results of the Comprehensive Literature Review

3.1 On-Road Trials

Several naturalistic driving experiments have been conducted so far in order to examine the most critical factors that affect driver performance of older people. To begin with, an interesting study aiming to identify driving characteristics in older drivers was implemented and 80 drivers aged 70 years or older performed an on-road driving assessment [13]. Participants also filled in a questionnaire regarding their personal and driving data. The most crucial driving performance measures which were taken into consideration was speed, lane position, braking, attention and maneuver. During the on-road evaluation, driving too fast was the item reported most often, followed by problems with the manual gearbox and attention to signs, road lines and traffic lights. Overall, the results revealed that the older the driver, the more driving errors were reported during the real-time driving assessment. An on-road driving study collected objective driving information over a two-week period was implemented using an in-vehicle monitoring device from 36 older drivers with mild cognitive impairment (MCI) and 35 older drivers without MCI [14]. It was found that the majority of speeding events (82.61%) were by older male drivers and occurred in 60-70km/h speed zones. In older male drivers, suspected MCI was associated with a significantly higher rate of speeding events, while increasing age was associated with a lower rate of speeding events.

Another naturalistic driving experiment was conducted and 74 drivers aged 67-94 years were participated [15]. After the end of the experimental processing, participants filled in a self-constructed questionnaire and provided valuable information about their crash history, critical traffic events and driving behavior within the previous year (e.g., number of crashes, personal injuries, and question of guilt). Results indicated that the combination of cognitive and non-cognitive risk parameters had a significant effect on driving skills, fitness to drive and the occurrence of prospective minor at-fault crashes not only in healthy older drivers but also in drivers with MCI. Furthermore, an open-traffic experiment which lasted 40 to 50 min was carried out for 145 older drivers aged above 70 years [16]. Driving performance (i.e. visual exploration, feedback control, speed adaptation, anticipation) was assessed by the “Test Ride to Investigate Practical Fitness to Drive” (TRIP) rated by an observation grid completed by the experimenter during the drive, successfully used in previous driving studies [17]. The results showed that 34% of participants overestimated, 45% correctly estimated, and 21% underestimated their driving ability, while there was a significant relationship between cognitive and driving self-awareness profiles.

An interesting study was conducted in order to clarify how older drivers evaluate their driving performance [18]. More specifically, drivers aged 70 years or older (N = 181) were asked to assess their own driving performance by questionnaire and then to drive on a public road while wearing an electronic device that measured their actual driving behavior. It was showed that older drivers’ self-assessments, including overall rating, maneuver, speed and lane position were significantly higher than the experts’ assessments of their driving performance. In addition, drivers with a greater rating discrepancy were likely to drive faster around an intersection with a stop sign. This discrepancy was also related to a low entropy rate (e.g. low randomness in head rotation) around a signalized T-junction. These findings based on on-road driving assessments provide credible evidence of performance overestimation by older drivers. Moreover, the vehicles of 29 drivers, whose age ranged from 65 to 82 years, were instrumented with an on-board diagnostic device for a four-month period in order to record their routes driven as well as their risky driving behavior events [19]. Driving indicators such as distance, speed, harsh acceleration or braking and crash risk were used to assess the elderly driving performance. Generalized mixed effects regression models were implemented and results showed that older drivers were less likely to drive a suggested low-risk route when they were more familiar with the alternate routes. Overall, important insights on the influence of familiarity on route choice, preferences, and driving behaviors of older drivers were provided.

In order to validate a laboratory-based driving simulator in measuring on-road driving performance, 129 older drivers, 60-88 years old, were evaluated with both the simulator and a naturalistic driving experiment [20]. The participants’ driving performance was gauged by appropriate and reliable age-specific assessment criteria (e.g. driving speed, error detection, working memory, maneuvers, lane position), which were found to be negatively correlated with age. Driving data from 344 older drivers aged 75–94 years living in the suburban outskirts of Sydney, Australia, were used to determine the proportion of drivers involved in speed events, and examine the most important parameters that may influence their behavior [21]. It was revealed that the majority of participants (78%) were involved in a speed event, while rural residents were more likely to be involved in speed events when they had not been a driver involved in a crash during the previous year compared to those involved in a crash. In addition, measures of visual and cognitive function did not predict involvement with speed events per distance.

A functional neuropsychological ability test, an on-road driving experiment and a simulated driving trial was carried out for 136 older drivers over 70 years old [22]. The most influencing factors related to fitness-to-drive

were chosen based on the correlation between the outcome measure of each test and the pass/fail outcome of the on-road driving test. In particular, visual, motor, and cognitive function tests were used to assess driving ability. Data collected from both on-road and simulator experiment were used to measure the driving behavior of older adults. Average speed, standard deviation of lateral position (SDLP), lane changing, time to collision (TTC), deceleration, detection and reaction time to road hazard were used as performance parameters. In this respect, different assessment combinations were considered, and various modeling techniques were applied. The results indicated that the on-road driving test offered a valuable reference for those unfit-to-drive older drivers to either adjust their driving performance or cease driving.

3.2 Driving Simulator

Simulated driving experiments allow researchers to study complex driving behaviors in a controlled, realistic and safe driving environment, which might be impractical, hazardous, or risky under real driving conditions [23]. 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 compared with on-road experiments. Many studies have concluded that driving simulators can provide accurate observations on drivers' behaviors and functions [24]. First of all, a driving simulator experiment aiming to evaluate the driving performance of older drivers with cerebral diseases was implemented [25]. 60 older drivers (i.e. 30 with MCI and 30 age-matched controls without cognitive impairment) were participated and data from an extensive questionnaire were also used. With regards to the MCI group, it was revealed that there were difficulties associated with late detection combined with slowed response to relevant targets in the peripheral field of view. The results for healthy controls revealed that there were difficulties in moving head, neck, and feet and in estimating speed and distance of approaching vehicles in complex (attention-dividing) high-information-load conditions. It should be noted that both group analyses represented difficulties in switching from automatic responses to needing to use cognitive processing in new or unexpected situations, particularly of long duration. These findings underlined the ability of older drivers (with MCI and without cognitive impairment) to indicate probable impairments in various driving skills.

Another interesting study carried out by Pavlou et al. [26] aimed in investigating the driving performance of drivers with brain pathologies (e.g. Alzheimer's Disease (AD), Parkinson's Disease (PD), MCI). 114 drivers above 55 years of age participated in a driving simulator experiment, in which healthy participants and patients drove in different driving scenarios. The driving scenarios included driving in rural area in low and high traffic volumes. Various driving performance measures were examined, such as mean speed, lateral position, steering angle, headway, reaction time at unexpected events, crash probability etc. and the driving performance of drivers impaired by the brain pathologies was compared to that of healthy controls by means of descriptive statistics. The results showed that there were significant differences between the two examined groups. Impaired drivers drove at significantly lower speeds, presented higher lateral position variability, kept larger headways as well as demonstrated larger reaction times than the control group.

Park et al. [27] examined the association between the cognitive-perceptual problems of older drivers and unsafe driving performance during simulated automobile driving in a virtual environment. For that purpose, 55 drivers aged 65 years or older participated in a driving simulator experiment and they were also asked to fill in a specially designed questionnaire. Cognitive-perceptual function was evaluated with the Cognitive Perceptual Assessment for Driving (CPAD). During simulated driving, a significantly greater number of older drivers experienced car crashes and unsafe performance in controlling speed, braking, steering, vehicle positioning, making lane changes, and making turns was observed. Results also demonstrated that older drivers who did not pass the CPAD test were 4 times more likely to experience a car crash, 3.5 times more likely to make errors in steering, 2.8 times more likely to make errors in vehicle positioning, and 6.5 times more likely to make errors in lane changes than are drivers who passed the CPAD test. In addition, driving performance of 53 volunteer older adults was assessed by the driving simulator and gauged by age-specific assessment criteria [28]. The simulated driving test covered a total distance of 15 km and was divided into three speed zones of 60 km/h, 70 km/h and 100 km/ h. The assessment criteria used in this study were cognitive functions required in making decisions based on past driving experience and ever-changing driving conditions. The Pearson coefficient was applied to investigate the correlation between examined performance indicators (i.e. total run length, speed violation, proper signaling, divided attention task, off-road crash, lane position) and the age of participants. It was showed that senior drivers had been involved in less crashes, used indicators more frequently in changing lanes and committed less speed violations than advanced age senior drivers. Furthermore, the senior drivers drove faster than advanced age senior drivers and were observed to be travelling at a speed appropriate to the traffic conditions.

Henderson et al. [29] tried to capture an age-related deficit in the drivers' ability to respond to challenging driving situations. To that aim, 25 older drivers aged 65-83 years participated in the driving simulator study. All

participants reported good mental and physical health with no history of neurological, psychiatric or substance abuse problems, and all were tested with their normal visual correction. Three variables of interest (i.e. crash rate, minimum distance of approach to all hazards, and lane deviation time) were examined. The thresholds proposed in this research were found to be correlated with the total lane deviation time, suggesting a deficiency in processing of peripheral flow and delayed detection of adjacent cars. Moreover, Urlings et al. [30] examined the relationship between reinforcement sensitivity and driving in older drivers at risk of diminished driving ability. 136 drivers above 70 years of age participated in this study and driving was assessed by an on-road driving experiment, a simulated driving task and self-report measures (i.e., driver behavior questionnaire). Both general driving as well as specific aspects of driving (i.e. average speed, speeding, standard deviation of lateral position and reaction time to unexpected events, road hazard detection, anticipation behavior at intersections) were considered. Lastly, Doroudgar et al. [31] investigated the differences in reaction times and driving outcomes via the STISIM Drive driving simulator for 38 older adults, aged 60 years and above. Driving performance parameters included lane position, mean speed, car-following delay, car-following modulus, car-following coherence, off-road crashes, collisions, pedestrians hit and traffic light tickets. The results indicated that older drivers experienced significantly slower reaction times, had more collisions, drove slower, deviated less in speed, and were less able to maintain a constant distance behind a pace car compared to younger people.

3.3 Questionnaires

A systematic review was conducted to synthesize the literature concerning the self-perception of driving performance and abilities in older age through an extensive questionnaire assessment. To begin with, Son and Park [32] aimed to assess potential risks induced by visual and auditory secondary tasks while driving. To fulfill this objective, 15 older aged 60 ~ 69, were recruited, completed a questionnaire and asked to drive in a simulator. They conducted two driving sessions, one for visually distracted driving and the other for cognitive distraction. The order in which secondary tasks were presented was counter-balanced. Behavior data and driving performance indicators were collected continuously using multiple measurement devices for vehicle speed, lane position, electrocardiogram and gaze pattern. The results revealed that the effect of interaction types, i.e., visual and auditory, on older drivers' performance was significant, while more difficult secondary task created greater age difference in driving performance. Eye movement and physiological responses were found to be less significant. Findings could suggest older drivers' lower risk awareness of cognitive distraction.

Similarly, a group of 104 older drivers, aged between 60 and 92, completed a questionnaire about driving habits and attitudes along with an on-road driving test [33]. A measure of self-regulation was derived from drivers' self-reported avoidance of difficult driving situations. The on-road driving test involved a standard assessment used to determine fitness to drive. Driving test scores were based on the number of errors committed in the driving tests, with weightings given according to the seriousness of the errors. According to responses on the driver behavior questionnaire, the most commonly avoided difficult driving situations were parallel parking and driving at night in the rain, while the least avoided situation was driving alone. Results indicated that poorer performance on the driving test was not related to overall avoidance of difficult driving situations, while higher relationship was identified found between driving ability and avoidance of specific difficult driving situations. Pavlou et al. [34] analyzed the self-reported driving behavior of elderly people with and without brain pathologies affecting cognition, in order to explore possible differences in self-perception of driving performance through a driving behavior questionnaire evaluation. In particular, the questionnaire was answered by 137 drivers with similar demographic characteristics (aged 60 years and over), out of which 44 were healthy individuals and 93 had a brain pathology. Participants provided valuable information with regards to their driving routines, possible avoidance of driving, distraction as well as their emotions and behaviors while driving. The findings showed that patients tended to report to be more likely to avoid using their vehicle because they were afraid of their driving abilities compared to healthy drivers. With respect to distraction, patients claimed that it was too dangerous to converse with a passenger and even more so, to use the mobile phone and thus, they reported avoiding to do so. Additionally, patients with brain pathologies reported being quite calm while driving.

Another approach aiming to assess a model of personality-attitudes-risky driving in a large sample of active older drivers was carried out [35]. More specifically, a cross-sectional design was implemented and structured questionnaires were completed by 485 older Italian drivers, aged 60 to 90 years. The driving performance indicators included personality traits, attitudes toward traffic safety, risky driving (errors, lapses, and traffic violations), as well as self-reported crash involvement in the last 12 months. Structural equation modeling (SEM) revealed that personality traits predicted both directly and indirectly traffic violations, errors, and lapses. It was also found that more positive attitudes toward traffic safety negatively predicted risky driving. In turn, risky driving was positively correlated to self-reported crash involvement. Moreover, Chen et al. [36] examined the accuracy of older drivers' self-awareness of driving ability in their everyday driving environment by determining the

concordance between the perceived and actual driving performance. To achieve this objective, 50 older drivers 75 years of age and older participated in an on-road trial and completed a structured questionnaire. The type of traffic sign or light, maneuvers, vehicle or lane position, speed limit, gap acceptance and traffic volumes were the environmental variables recorded at each intersection, while critical driving errors were noted when the participant was involved in a crash or near-crash. Using the clinical functioning and demographic information, an ordinal regression revealed that two factors were related to the accuracy of self-awareness: older drivers with better visual-motor processing speed and fewer self-reported comorbid conditions tended to overestimate their driving ability.

3.4 Neurological and neuropsychological tests

Previous studies established a fitness-to-drive assessment method by combining a neuropsychological tests, clinical interviews, on-road trials and simulated driving experiments [37]. Neuropsychological and neurological tests are often utilized to predict driving abilities and fitness in clinical practice [15]. Although several meta-analyses and review articles provided evidence for robust correlations between driving behavior and these tests, the aforementioned tests alone are not sufficient to accurately differentiate between fit and unfit drivers. Hence, multifactorial approaches are increasingly recommended by experts [38]. Wadley et al. [39] examined the driving performance of well-characterized samples of 105 older adults, aged 65 years and above (i.e. 59 cognitively normal and 46 with MCI) using an on-road driving assessment. All participants went through a neurological and neuropsychological examination and a visual screening. Relevant driving history variables were assessed with self-report questionnaires. Participants' driving behavior was rated on a 5 point Likert scale and included several driving performance indicators (i.e. 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.

The objective of another research [40] was to gain understanding of the parameters relating to car driving problems and aging. The research sample consisted of 84 drivers aged between 65 and 96 years, who were referred for a general fitness-to-drive evaluation. The relationship between several specific neuropsychological tests and self-reported crashes was examined. The most crucial driving performance measures which were taken into account was speed, lateral position on the road, lane position change, distance from the car in front, anticipation visual behavior and communication and crash risk. The initial results of this study indicated the relevance of a cognitive/neuropsychological approach to the driving ability of older people. Nevertheless, the link with crash risk seemed to be more complex. Similarly, a very interesting study was carried out and 90 drivers (54 females and 36 males) aged from 60 to 91 took part in a series of visual, cognitive psychological and physical tests, and a standardized on-road driving experiment [41]. A computerized test of visual attention, devised specifically for this research, was the best predictor of on-road driving performance. Contrast sensitivity and visuospatial memory were some of the basic abilities that made independent contributions to the prediction of driving behavior. The two aforementioned functional abilities provided a better prediction of driving performance than chronological age, reinforcing the argument that drivers should only have their driving tested when their functional abilities decline, rather than when they reach a particular age.

Shen et al. [22] aimed to assess the driving-related risk factors of older drivers through the validation of the screening tool Safety Advice For Elderly drivers (SAFE). To that aim, 74 older drivers aged 65 years and above, recruited from the general population, were included in this prospective observational study. An on-road driving evaluation was accompanied by a driving instructor and a traffic psychologist (the latter had a special qualification). Some basic risk indicators for impaired driving fitness including anamnestic, sensory and medical factors were assessed by a physician within a face-to-face examination. At the same time, cognitive (e.g. memory, attention) risk factors were assessed by a neuropsychologist. It was found that the inclusion of additional evidence-based risk factors, such as age, annual mileage, speed, attention and number of prescription drugs into the SAFE improved the prediction of driving fitness.

4. Discussion

To the best of the authors' knowledge, previous studies on older adult drivers have never compared actual on-road driving performance with simulated driving performance, questionnaires, neurological and neuropsychological tests. Each study was ordered based on the year of the publication and information regarding participants (i.e. age, number of volunteers and grouping criteria where applicable), the type of assessment (i.e. subjective measures based on surveys/questionnaires and neurological and neuropsychological tests or objective measures such as on-road trial, driving simulator experiment) and the main findings from the study are provided. Table 1 provides a summary of the 25 studies evaluated in the current review.

Overall, after examining the 25 studies, the critical driving performance measures of older drivers, were: speed (i.e. average speed, speeding or its variability) in 21 studies, crash risk in 16 studies, lane position in 14 studies, attention/distraction in 9 studies, driving errors, maneuvers and fitness-to-drive in 8 studies, reaction time in 6 studies and acceleration or deceleration in 4 studies, while headway, time to collision, confusion or disorientation or seat-belt use were found to be less significant. It is worth mentioning that not all driving performance measures presented above were examined in all 25 studies. Results indicated that older drivers had different acceleration/deceleration habits and thus, different turning time, which also varied depending on whether the vehicle on the main road came from the left or the right. It should be highlighted that distraction, inattention, visuospatial skills and executive functions have been noted as the most critical parameters for safe driving in several studies, as they appeared to affect important driving tasks, such positioning and maneuvering the vehicle, predicting the development of driving situations, judging distances, adapting speed or estimating crash risk.

Concerning the on-road trials, the 15 studies that were reviewed indicated that driving performance of older drivers on naturalistic driving experiments was consistently worse than that of cognitively intact individuals. In addition, 10 studies assessed the critical driving indexes with the use of a driving simulator. The initial results from experiments using driving simulators indicated that different driving tasks involved different driving abilities and cognitive constructs. Undoubtedly, driving simulators were ideally suited for testing the effects of distraction on older adults, which has not been done in the literature. The finding that elderly people assigned high ratings to their driving abilities was also highlighted by 18 studies, in which driving behavior questionnaires were conducted, and subjective ratings were compared to driving simulator and on-road driving performance. With regards to the neuropsychological literature the 6 studies that were assessed suggested that driving indicators on tests measuring selective visual attention, sleeping abnormalities, motor fitness, visuospatial abilities, and, to a lesser extent executive functioning and working memory, may predict the ability to drive safely. The aforementioned neurological/neuropsychological measures could be helpful in detecting individuals with questionable or problematic driving ability. Nonetheless, neuropsychological and neurological tests should be viewed as one part of the screening process that is accompanied when necessary by simulated or on-road driving assessment.

4.1 Limitations

Throughout this systematic review method, there are some limitations that should be acknowledged. Firstly, there was a risk of retrieval bias. More specifically, peer-reviewed journal and conference articles were only searched for and included in the review; thus, information in the gray literature such as dissertations, reports, theses and proceedings, may be missing from the final synthesis. Similarly, included articles were written only in English, which may have, therefore, resulted in language bias. Nevertheless, given that aging is a global phenomenon, research on driving performance indicators of older people could also have been included in non-English publications and materials. What's more, even though a systematic search procedure was used, there was a possibility that some relevant studies and articles were missed. Lastly, it is worth mentioning that none of the papers included a group of younger participants compared to older drivers. Although the aim of most of these studies was not to compare age-related differences in driving performance, these aspects could be also taken into consideration. This is especially important given that previous studies, that have employed similar measurement techniques, revealed that younger adult drivers (especially novice drivers) faced other difficulties compared to the older ones [42].

4.2 Future Research Directions

Future work should include the participation of novice, younger or middle-aged drivers in same study designs in order to delineate more precisely additional factors and covariates that influence driving performance. These studies may also consider the use of complementary qualitative research methodologies to more holistically examine the underlying reasons for overestimation. The results of this study must be investigated with other types of cerebral diseases. Additional research should also address prospective prediction of other significant indicators of driving competence in those rated as safe or marginal on-road driving experiments, such as future crashes or violations (which may be considered by some as better index of true (i.e. real-time) driving abilities). While this review provides valuable knowledge and assessment with regards to the driving performance of elderly people, future work should examine improved subjective and additional objective assessment tools, even or other factors, such as comfort in driving that may also help to explain how aging population determines their own driving skills. Finally, particular emphasis could be given on self-perception (e.g., self-assess, self-rate, and self-awareness) as well as the particular methods used for measuring driving abilities will promote a higher quality of research. Ultimately, this will ensure that cohesive findings are available for human factors researchers and safety experts who develop practical solutions for maintaining the road safety of elderly population.

Table 1: Summary of studies included in review

A/A	Author	Year	Sample Characteristics				Methodology				Driving Performance Measures								
			Sample size	Males	Females	Age	On-road trial	Driving simulator	Questionnaire	Neurological/ Neuropsychological tests	Speed	Attention/ Distraction	Maneuvers	Reaction time	Lane position	Acceleration/ Deceleration	Driving errors	Crash risk	Fitness to drive
1	Toepper et al.	2021	74	47	27	67 – 94	x		x	x								x	x
2	Feng et al.	2021	71	40	31	≥ 65	x		x		x							x	
3	Son & Park	2021	15	15	0	60 – 69		x	x		x	x			x				
4	Kosuge et al.	2021	191	184	7	> 70	x		x		x		x		x				
5	Schulz et al.	2020	74	48	26	≥ 65	x			x	x	x							x
6	Shen et al.	2020	136	102	34	> 70	x	x		x	x			x	x	x		x	x
7	Paire-Ficout et al.	2020	145	96	49	> 70	x		x		x	x		x					x
8	Chen et al.	2019	50	34	16	74 – 96	x		x		x		x		x		x	x	
9	Vardaki et al	2019	60	35	25	60 – 70		x	x		x	x		x					
10	Urlings et al.	2018	136	97	39	> 70	x	x	x		x			x	x			x	
11	Payyanadan et al.	2018	29	14	15	65 – 82	x		x		x					x	x	x	
12	Willstrand et al.	2017	80	48	32	72 – 83	x		x		x	x	x		x	x	x		x
13	Doroudgar et al.	2017	38	20	18	≥ 60		x			x			x	x			x	
14	Pavlou et al.	2017	114	72	42	≥ 55		x			x			x	x			x	
15	Pavlou et al.	2017	137	82	55	≥ 60			x			x					x		x
16	Chevalier et al.	2016	344	204	140	75 – 94	x				x							x	
17	Lucidi et al.	2014	485	297	188	60 – 90			x		x						x	x	
18	Park et al.	2011	55	40	15	≥ 65		x	x		x		x		x	x		x	
19	Wadley et al.	2009	105	50	55	≥ 65	x		x	x	x				x			x	
20	Baldock et al.	2007	90	36	54	60 – 91	x		x	x	x	x					x		x
21	Baldock et al.	2006	104	39	65	60 – 92	x		x								x	x	x
22	Henderson et al.	2005	25	17	8	65 – 83		x					x		x			x	
23	Lee et al.	2003	129	100	29	60 – 88	x	x	x		x	x	x		x		x		
24	Lee et al.	2002	53			65 – 85		x			x	x	x		x			x	
25	De Raedt & Ponjaert-Kristoffersen	2000	84	60	24	65 – 96			x	x	x		x		x			x	
						Total	**15**	**10**	**18**	**6**	**21**	**9**	**8**	**6**	**14**	**4**	**8**	**16**	**8**

5. Conclusions

The aim of the current research was to identify the critical factors that can assess and predict the driving performance of elderly people. In order to fulfill this objective, a comprehensive literature search on driving performance of older people was conducted in order to investigate the most important indicators examined in the scientific field of driver behavior. Methods of assessing driving, including on-road trials, driving simulator experiments, driving behavior questionnaires, neurological and neuropsychological tests or a combination of these and related results of the literature were provided. All in all, the driving performance measures of older drivers were found to be: speed, crash risk/ probability, lateral position of the vehicle, attention/distraction, driving errors, maneuvers, fitness-to-drive as well as acceleration or deceleration, while headway, time to collision, confusion or disorientation or seat-belt use were found to be less significant.

The findings from this review may help to inform policy recommendations in order to keep older drivers safe on the roadway. For instance, if dangerous/risky driving behavior is found to persist, then the development and promotion of interventional programs may be warranted. These programs can make elderly people more aware of, and appreciate, their actual driving abilities, and could help them to (re)calibrate their perceptions in order to become more aligned with reality. According to the National Highway Traffic Safety Administration, many states have existing provisions and lows that provide specific licensing requirements for elderly adults drivers. Nevertheless, further instructions and educational programs that either require senior participants or that engage senior drivers in training using a real-world driving or driving simulation, may be considered as part of (re)licensing in older age. Finally, policy makers should also support legislation that require all automobiles, produced after a certain year, to be equipped with minimum assisted-driving and safety features and technologies which will significantly benefit older drivers. Advanced Driver Assistance Systems (ADAS) can compensate for limitations of older drivers by assisting the driver in directing attention to relevant information, drawing their attention to approaching traffic, signaling road users located in the driver's blind spot, and providing prior knowledge on the next traffic situation.

Acknowledgments

This research is co-financed by Greece and the European Union (European Social Fund – ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Strengthening Human Resources Research Potential via Doctorate Research – 2nd Cycle" (MIS-5033021), implemented by the State Scholarships Foundation (IKY).

References

1. De Oliveira, R. F., & Wann, J. P. (2012). Driving skills of young adults with developmental coordination disorder: Maintaining control and avoiding hazards. Human movement science, 31(3), 721-729.
2. Schwebel, D. C., Ball, K. K., Severson, J., Barton, B. K., Rizzo, M., & Viamonte, S. M. (2007). Individual difference factors in risky driving among older adults. Journal of safety research, 38(5), 501-509.
3. Bakhtiari, R., Tomczak, M. V., Langor, S., Scanlon, J. E., Granley, A., & Singhal, A. (2020). Application of tablet-based cognitive tasks to predict unsafe drivers in older adults. Transportation research interdisciplinary perspectives, 4, 100105.
4. Selander, H., Thorslund, B., & Henriksson, P. (2021). The affect of visual acuity on driving ability: a simulator study.
5. Biernacki, M. P., & Lewkowicz, R. (2021). How do older drivers perceive visual information under increasing cognitive load? Significance of personality on-road safety. Accident Analysis & Prevention, 157, 106186.
6. Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. Clinical psychology review, 25(1), 45-65.
7. Carr, D. B., & Ott, B. R. (2010). The older adult driver with cognitive impairment: "It's a very frustrating life". Jama, 303(16), 1632-1641.
8. European Commission (2018). Older Drivers. Directorate General for Transport.
9. European Commission (2021). Road safety: 4,000 fewer people lost their lives on EU roads in 2020 as death rate falls to all-time low. Accessed 20/12/21. Retrieved from: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1767
10. McElligott, M. (2015). Balanced Approach to a Growing Problem: How Congress Can Keep Roads Safe and the Elderly Population Happy. Elder LJ, 23, 191.

11. Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS medicine, 6(7), e1000097.
12. Hawker, S., Payne, S., Kerr, C., Hardey, M., & Powell, J. (2002). Appraising the evidence: reviewing disparate data systematically. Qualitative health research, 12(9), 1284-1299.
13. Willstrand, T. D., Broberg, T., & Selander, H. (2017). Driving characteristics of older drivers and their relationship to the useful field of view test. Gerontology, 63(2), 180-188.
14. Feng, Y. R., Meuleners, L., Stevenson, M., Heyworth, J., Murray, K., Fraser, M., & Maher, S. (2021). The impact of cognition and gender on speeding behaviour in older drivers with and without suspected mild cognitive impairment. Clinical interventions in aging, 16, 1473.
15. Toepper, M., Schulz, P., Beblo, T., & Driessen, M. (2021). Predicting on-road driving skills, fitness to drive, and prospective accident risk in older drivers and drivers with mild cognitive impairment: the importance of non-cognitive risk factors. Journal of Alzheimer's disease, 79(1), 401.
16. Paire-Ficout, L., Lafont, S., Hay, M., Coquillat, A., Fabrigoule, C., & Chavoix, C. (2021). Relationships between cognitive and driving self-awareness in older drivers. The Journals of Gerontology: Series B, 76(6), 1077-1085.
17. Ranchet, M., Paire-Ficout, L., Uc, E. Y., Bonnard, A., Sornette, D., & Broussolle, E. (2013). Impact of specific executive functions on driving performance in people with Parkinson's disease. Movement disorders, 28(14), 1941-1948.
18. Kosuge, R., Okamura, K., Nakano, Y., & Fujita, G. (2021). Characteristics of driving self-assessments and factors related to inaccurate self-assessment in Japanese older adults. Accident Analysis & Prevention, 159, 106235.
19. Payyanadan, R. P., Sanchez, F. A., & Lee, J. D. (2018). Influence of familiarity on the driving behavior, route risk, and route choice of older drivers. IEEE Transactions on Human-Machine Systems, 49(1), 10-19.
20. Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: on-road versus simulated driving. Accident Analysis & Prevention, 35(5), 797-803.
21. Chevalier, A., Coxon, K., Chevalier, A. J., Wall, J., Brown, J., Clarke, E., ... & Keay, L. (2016). Exploration of older drivers' speeding behaviour. Transportation research part F: traffic psychology and behaviour, 42, 532-543.
22. Shen, Y., Zahoor, O., Tan, X., Usama, M., & Brijs, T. (2020). Assessing fitness-to-drive among older drivers: a comparative analysis of potential alternatives to on-road driving test. International journal of environmental research and public health, 17(23), 8886.
23. Calhoun, V. D., & Pearlson, G. D. (2012). A selective review of simulated driving studies: combining naturalistic and hybrid paradigms, analysis approaches, and future directions. Neuroimage, 59(1), 25-35.
24. Papantoniou, P., Papadimitriou, E., & Yannis, G. (2015). Assessment of driving simulator studies on driver distraction. Advances in transportation studies, (35).
25. Vardaki, S., Dickerson, A. E., Beratis, I., Yannis, G., & Papageorgiou, S. (2019). Driving difficulties as reported by older drivers with mild cognitive impairment and without neurological impairment. Traffic injury prevention, 20(6), 630-635.
26. Pavlou, D., Beratis, I., Papadimitriou, E., Yannis, G., Golias, J., & Papageorgiou, S. G. (2017). Driving performance profiles of drivers with brain pathologies in rural roads. International Journal of Transportation, 5(3), 17-28.
27. Park, S. W., Choi, E. S., Lim, M. H., Kim, E. J., Hwang, S. I., Choi, K. I., ... & Jung, H. E. (2011). Association between unsafe driving performance and cognitive-perceptual dysfunction in older drivers. PM&R, 3(3), 198-203.
28. Lee, H. C., Drake, V., & Cameron, D. (2002). Identification of appropriate assessment criteria to measure older adults' driving performance in simulated driving. Australian Occupational Therapy Journal, 49(3), 138-145.
29. Henderson, S., Woods-Fry, H., Collin, C. A., Gagnon, S., Voloaca, M., Grant, J., ... & Allen, W. (2015). A brief peripheral motion contrast threshold test predicts older drivers' hazardous behaviors in simulated driving. Accident Analysis & Prevention, 78, 1-7.
30. Urlings, J. H., van Beers, M., Cuenen, A., Brijs, K., Brijs, T., & Jongen, E. M. (2018). The relation between reinforcement sensitivity and self-reported, simulated and on-road driving in older drivers. Transportation research part F: traffic psychology and behaviour, 56, 466-476.
31. Doroudgar, S., Chuang, H. M., Perry, P. J., Thomas, K., Bohnert, K., & Canedo, J. (2017). Driving performance comparing older versus younger drivers. Traffic injury prevention, 18(1), 41-46.
32. Son, J., & Park, M. (2021). The Effects of Distraction Type and Difficulty on Older Drivers' Performance and Behaviour: Visual vs. Cognitive. International journal of automotive technology, 22(1), 97-108.
33. Baldock, M. R. J., Mathias, J. L., McLean, A. J., & Berndt, A. (2006). Self-regulation of driving and its relationship to driving ability among older adults. Accident Analysis & Prevention, 38(5), 1038-1045.
34. Pavlou, D., Papantoniou, P., Papadimitriou, E., Vardaki, S., Economou, A., Yannis, G., & Papageorgiou, S. G. (2017). Self-assessment of older drivers with brain pathologies: reported habits and self-regulation of driving. Journal of Transport & Health, 4, 90-98.
35. Lucidi, F., Mallia, L., Lazuras, L., & Violani, C. (2014). Personality and attitudes as predictors of risky driving among older drivers. Accident Analysis & Prevention, 72, 318-324.
36. Chen, Y. T., Gélinas, I., Mazer, B., Myers, A., Vrkljan, B., Koppel, S., ... & Marshall, S. C. (2019). Personal and clinical factors associated with older drivers' self-awareness of driving performance. Canadian Journal on Aging/La Revue canadienne du vieillissement, 40(1), 82-96.
37. Fuermaier, A. B., Piersma, D., de Waard, D., Davidse, R. J., de Groot, J., Doumen, M. J., ... & Tucha, O. (2017). Assessing fitness to drive—a validation study on patients with mild cognitive impairment. Traffic injury prevention, 18(2), 145-149.
38. Pavlou, D., Beratis, I., Fragkiadaki, S., Kontaxopoulou, D., Yannis, G., Economou, A., & Papageorgiou, S. (2017b). Which are the critical parameters assessing the driving performance of drivers with cerebral diseases? A literature review. Transportation research procedia, 25, 4338-4354.
39. Wadley, V. G., Okonkwo, O., Crowe, M., Vance, D. E., Elgin, J. M., Ball, K. K., & Owsley, C. (2009). Mild cognitive impairment and everyday function: an investigation of driving performance. Journal of geriatric Psychiatry and Neurology, 22(2), 87-94.

40. De Raedt, R., & Ponjaert-Kristoffersen, I. (2000). The relationship between cognitive/neuropsychological factors and car driving performance in older adults. Journal of the American Geriatrics Society, 48(12), 1664-1668.
41. Baldock, M. R. J., Mathias, J., McLean, J., & Berndt, A. (2007). Visual attention as a predictor of on-road driving performance of older drivers. Australian Journal of Psychology, 59(3), 159-168.
42. Martinussen, L. M., Møller, M., & Prato, C. G. (2017). Accuracy of young male drivers' self-assessments of driving skill. Transportation research part F: traffic psychology and behaviour, 46, 228-235.