Sign recall in a fixed-base simulator as a measure of fitness-to-drive

Sophia Vardaki[1*], George Yannis[2], Dimosthenis Pavlou[3], Ion N. Beratis[4] and Sokratis G. Papageorgiou[5]

[1] Ph.D, Senior Researcher,
Department of Transportation Planning and Engineering, School of Civil Engineering, National Technical University of Athens,
5, Iroon Polytechniou str, Zografou Campus, GR-15773, Athens, Greece,
tel. +30-210-77231282, fax +30-210-7721327, e-mail: sophiav@central.ntua.gr

[2]Associate Professor,
Department of Transportation Planning and Engineering, School of Civil Engineering, National Technical University of Athens,
5, Iroon Polytechniou str., Zografou Campus, GR-15773, Athens, Greece,
tel. +302107721326, fax +302107721454, e-mail: geyannis@central.ntua.gr

[3] Civil Engineer, Researcher
Department of Transportation Planning and Engineering, School of Civil Engineering, National Technical University of Athens,
5, Iroon Polytechniou str., Zografou Campus, GR-15773, Athens, Greece,
tel. +302107721376, fax +302107721454, e-mail: dpavlou@central.ntua.gr

[4] Msc, PhD, Neuropsychologist
2nd Neurological Department, University of Athens,
Attikon General University Hospital
1 Rimini Str, GR-12462 Haidari, Athens, Greece.
e-mail: ionas96@hotmail.com

[5]Assistant Professor
Attikon General University Hospital
University of Athens Medical School
Department of Neurology
75 Mikras Asias str., GR-11527, Athens, Greece
tel: +302107289404, fax: +302107216474, e-mail: sokpapa@med.uoa.gr

*corresponding author

First Submission Date: July 25th, 2013
Revised Submission Date: November 14th, 2013
Word count: 6,000 words + 6tables + 7figures= 9,250

Sign recall in a fixed-base simulator as a measure of fitness-to-drive

ABSTRACT

The goals of this pilot study were firstly to provide evidence of whether there are main effects of health status and time elapsed between presentation and recall of sign information as well as interactions between these variables on drivers' recall of traffic safety messages; and secondly, in the absence of a main effect of time, to determine whether varying levels of operational and tactical driving task demands would differentially affect healthy versus medically at-risk older drivers in their message recall. Study participants included a "medically at-risk" group of drivers diagnosed with either Parkinson's disease or mild cognitive impairment and a control group of drivers with no pathological conditions. Two separate experiments were carried out using a fixed-base driving simulator. In the first experiment it was found that there was a significant main effect of health status on the recall of safety information presented on a sign, with the medically at-risk subjects performing worse than controls; and, that a longer versus shorter delay before message recall had no significant effect on either group. In the second experiment it was found that increasing the level of driving task demand between message presentation and recall resulted in a disproportionally greater drop in recall performance for the medically at-risk group than for the controls, although this effect was not statistically significant; also a statistically significant main effect for task demand was found which had an inverse impact on recall performance across both groups of study participants. Although the conclusions drawn are tentative, they are encouraging with regard to the use of a fixed-base driving simulator to identify performance differences related to medical conditions that have clear implications for fitness-to-drive.

INTRODUCTION

Medical conditions, such as neurodegenerative disorders, affect visual factors, cognitive processes and physical abilities which can reduce driver performance and potentially lead to elevated crash risk. Health professionals may be requested to determine medical fitness-to-drive of a patient for licensing purposes or responding to the requests of patients or their families. If drivers with a diagnosed medical condition that may impair driving performance recognize their limitations and adapt their driving behavior by self-regulation, it is not certain that they will experience a crash. Older driver characteristics such as awareness of one's limitations, good judgment, caution, strategic thinking, enhanced anticipation and risk perception are positive safety aspects of driving behavior. On the other hand, individuals with dementia or mild cognitive impairment (MCI) are characterized by reduced capacity to self-regulate. It is widely recognized that in determining fitness-to-drive, it is the diminished visual, perceptual-cognitive and physical abilities themselves that are of principal concern, and not the chronological age or the underlying medical conditions (a particular diagnosis) that may have produced a functional loss (*1*), (*2*).

Working memory is a cognitive ability of key importance to driving; it allows a driver to remember—and apply when needed—navigational directions and rules for traffic operations, even as s/he is processing and responding to the real-time demands of steering, anticipating and avoiding conflicts, and performing other second-to-second vehicle control tasks (*1*), (*2*). The modal model of the mind portrays the mind as containing three types of memory stores, namely sensory memory, working (or short-term) memory and long-term memory, conceived of as places where information is held (*3*). According to the modal model, the processing of information within stores and the movement of information from one store to another is regulated by the control processes of attention, rehearsal, encoding and retrieval (remembering). Although some cognitive psychologists ascribe somewhat different meanings to the terms working memory and short-term memory, there is no consistency in such differential use and others use them as synonyms. Both terms refer to the content of conscious perception and thought and to the mental processes that operate on that content (*3*). In 2010 BC (British Columbia) Guide in Determining Fitness-to-drive *(4)*, short-term and working memory are differentially defined. Short-term memory or passive memory refers to the temporary storage of information or the brief retention of information that is currently being processed in a person's mind. Working memory (the active component of short-term memory) refers to the ability to manipulate information with time constraints/taking in and updating information. Executive functions including decision-making, impulse control, judgment, task switching and planning strongly interact with working memory, and with attention, which operates on the contents of working memory (*5*). Anecdotally, the loss of short-term memory is one of the most common complaints of older people.

The ability to recall directions and information from signs and other traffic control devices is an important element in avoiding the confusion that can lead to accidents. Not only does it make sense that those drivers with working memory problems are more likely to become lost and/or confused, and to respond inappropriately to unusual or unexpected traffic situations, research has shown that (age-related) impairments in working memory are a significant predictor of at-fault crashes (*6*). Performance on the delayed recall measure (short-term recall) from the Mini-Mental Status Examination (MMSE) has been shown to relate to at-fault crashes (*1*). It is noted that MMSE, although it measures multiple cognitive domains (including orientation, registration and short-term recall, attention and concentration, language, and visuospatial function), does not cover executive functions.

On their review of driving simulation studies on driving performance assessment of people with neurodegenerative disorders including Parkinson disease and Alzheimer's disease, Uc and Rizzo (*7*) recognize the potential usefulness of the simulators in fitness-to-drive assessment (*5*). Findings of studies on driving performance of drivers with Parkinson's disease (PD) indicate that although PD is most often associated with motor symptoms, it is impairments in cognition and visual perception that are the main determinants of performance and safety of drivers with PD (*7*). On the other hand, mild cognitive impairment (MCI) often represents an intermediate stage between normal aging and Alzheimer's disease. It has been stressed in research that it is critical for clinicians to have guidelines for clinical decision-making on fitness-to-drive in persons with PD (*8*). Researchers have underlined the "need for increased vigilance among clinicians, family members and individuals with MCI for initially benign changes in driving that may become increasingly problematic over time" (*9)* and also that clinicians may fail in their judgment particularly in drivers with mild-cognitive decline (*7*).

There is evidence that driving simulators have enabled a better understanding of driving impairments and driver error and their relationships with the type and degree of functional impairments, and enable researchers to distinguish between controls and drivers with Parkinson's disease (*7*). A review of relevant studies (*10*) has shown the need to investigate the ability of individuals (including cognitively impaired individuals) to appropriately prioritize particular aspects of performance and especially whether basic driving abilities are challenged in complex tasks or in concurrent task conditions. The simulators provide the possibility to measure (the limits of) performance in control (operational tasks) which involve time-pressured behaviors in a safe and controlled way (such as acceleration, lane position, braking and maneuvering to avoid crashes, and steering control) that may be challenged in emergency or unexpected situations. Tactical tasks take more time to complete and refer to more complex situations involving interactions with other road users. They relate to risk perception, risk taking, gap acceptance, choice of lane, choice of speed, space management, visual search behavior, visual attention and allocation. Intersections, yielding right of way, driving with a secondary task, passing and overtaking, merging and lane changing are included in experiments designed to assess driving performance. In tactical tasks, the occurrence of safety errors in the execution of these tasks are more probable and would allow the assessment of the specific mechanisms in question. Scenarios that have been used in persons with a variety of medical impairments include run-off-road on curves, car-following and rear-end collisions, intersection incursion avoidance, interaction with emergency vehicle/pedestrians, and merging with the potential for side impact collisions (*5*), (*7*), (*10*).

The performance of older drivers with and without mild cognitive impairment (MCI) when approaching intersections was compared using a portable driving simulator with an established relative validity for some operations (*11*). Preliminary findings suggested that drivers with MCI performed less well than age-matched healthy controls when approaching controlled intersections and critical light-change intersections (*11*). The impact of Alzheimer's disease (AD) and mild cognitive impairment (MCI) on driving ability was also examined using a low-cost, personal-computer-based interactive driving simulator (*12*). The study included patients with mild AD, individuals with MCI (CDR=0.5) and neurologically normal aged controls. The groups were matched in terms of age, level of education and years of driving experience. Drivers with AD were rated as significantly worse than MCI subjects and healthy elderly drivers on length of run (sec), mean time to collision and number of off-road events. The only statistically significant difference between MCI patients and healthy control subjects was in the shorter mean time to collision of MCI subjects (*12*).

Driving simulation studies on PD using fixed-base simulators have shown decreased performance in various performance measures including poor steering, slower reaction times, reduced speed adaptation and curve navigation, increased variability of lane position, late deceleration when approaching traffic signals with and without the presence of concurrent tasks. The decrease in driving performance in the simulator was predicted by measures of attention, perception, response selection (which depends on memory and decision-making), response implementation (executive functions), and awareness of cognitive and behavioral performance (metacognition). Importantly, researchers also note that the side effects of medication is an issue of serious concern in driving performance assessment of PD patients (*7*), (*13*).

In a driving simulator study (*14*), one of the cognitive abilities associated with crash occurrence in a sample of older drivers was working memory. Performance in driving tasks involving working memory was measured with a recall task. According to the results of a logistic regression analysis, after adjusting for age, each added point on the working memory scale (recall) was associated with a 45% decrease in risk (*14*). Based on the findings of a recent review of studies on driving performance (on-road tests and simulators) in PD for outcome measures (*8*), the authors propose a framework of risk factors to help clinicians determine when drivers with PD are at risk. The authors found that cognitive deficits may be present in the early stages of PD; also, simulated driving performance in drivers with PD tend to be worse in low contrast conditions, which may possibly be predicted by deficits of contrast sensitivity. They also determined the MMSE to be possibly predictive of simulated driving performance (although they note that MMSE has been shown to be a poor predictor of on-road performance in drivers with PD). In a validation study (*15*) of a screening battery to predict driving fitness decisions (pass-fail) in PD drivers, the inclusion of driving simulation increased the accuracy of the clinical model, suggesting that driving simulation is strongly associated with actual on-road performance in PD.

Although driving simulators may provide a platform for the assessment of driving abilities of drivers who are at increased risk for a variety of conditions such as AD or PD predictions of crash risk and driver safety depend on understanding patterns of various complex factors of real-world driving (*5*). Important challenges that researchers commonly face in performance assessment with the use of driving simulators relate to limitations of the simulators, scenario validation and participant adaptation. Certain limitations of fixed-base driving simulators raise questions about their application for measuring behaviors such as gap judgment (e.g., for left turns, passing maneuvers, etc.); the detection/recognition of hazards (as well as intentional information sources) that rely on a human's full dynamic range for visual contrast sensitivity; and especially for any driver decision or response that depends on how the 'feel' of the simulator – the feedback the driver receives in terms of acceleration, braking and lateral *g* forces – compares to his/her own vehicle (*5*), (*10*), (*16*). Working memory for temporary traffic control information may be studied effectively using these platforms, notwithstanding these limitations. A research question that may be addressed is how different levels of demand for operational (vehicle control) and tactical driving tasks between presentation and recall of such information affects healthy versus medically at-risk older drivers; specifically, those with potential cognitive impairment.

Because healthy versus cognitively impaired drivers may adjust their driving speed differently to accommodate their processing of higher versus lower levels of demand for driving tasks, a potential confounding factor in any experiment seeking to measure the impact of this variable is the actual amount of time between the presentation and recall of the traffic safety message. In this pilot study using a fixed-base driving simulator, we first sought to determine whether there are main effects of health status and time elapsed (between presentation and recall of sign information), and/or interactions between these variables, in the recall of traffic safety messages. Next, in the absence of a main effect of time, we wished to explore how varying levels of operational and tactical driving task demands might differentially affect healthy versus medically at-risk older drivers in their message recall. Study findings and their implications for future research are presented and discussed below.

RESEARCH METHODS

Participants

This driving simulation study was conducted at the Department of Transportation Planning and Engineering of the School of Civil Engineering at the National Technical University of Athens (NTUA) in Athens, Greece, using a FOERST Driving Simulator FPF. The driving simulator consists of 3 LCD screens, each 40'' wide, with driver's seat and controls, and support base. Display resolution for the LCD screens was full HD (1920x1080pixels). Later figures illustrate the simulator configuration used during data collection.
This study was part of a large driving simulator experiment (*17*) designed for the purposes of two research projects, the DriverBrain project ("Analysis of the performance of drivers with cerebral diseases") and the

DISTRACT project ("Analysis of causes and impacts of driver distraction"). The large experiment, which is currently in progress, aims to assess the effect of cerebral diseases (Alzheimer's disease, Parkinson's disease and mild cognitive impairment) on driver performance. Participants in the large experiment are current drivers with a cerebral pathological condition (neurological disease) recruited through the 2nd Department of Neurology, University of Athens Medical School, at ATTIKON University General Hospital, Haidari, Athens, and drivers with no known pathological condition. All participants hold a valid driving license; and they have to meet certain criteria: they must have driven for more than 3 years; they must have driven more than 2500km during the last year; they must have driven at least once a week during the last year; they must have driven at least 10km/week during the last year; they must have CDR<2; they must not have a significant psychiatric history of psychosis; they must not have any significant kinetic disorder that prevents them from basic driving moves; they must not suffer dizziness or nausea while driving, either as a driver or as a passenger; they must not be pregnant; they must not be alcoholic or have any other drug addiction; they must not have any significant eye disorder that prevents them from driving safely; and they must not have any disease of the central nervous system.

TABLE 1 Comparison of Medically-at risk group (patients with Parkinson's disease and MCI) and Control group Using Wilcoxon Rank Sum Test. Values Represent Mean±SD (Median)- Demographic information

	MAR group (MCI or PD)	Control group	P-values
Driving experience[a]	46.8±11.7(43)	30.1±6.5(32)	0.002
Driving exposure			
Days/week	4.0±1.9(3.5)	5±1.7(5)	0.336
Kilometers driven/week[a]	53.1±48.0(40.0)	102.9±48.7(85.0)	0.029
Accidents (2 years)	0.3±0.7(0.0)	0.3±0.5(0.0)	0.694
CDR[b]	0.6± 0.5(1.0)	0.00± 0.00(0.00)	0.071
Parkinsonism(n=5)			
Disease duration	10±5.6(13)		
UPDRS[c]	12.8 ±6.3(14)		
H&Y[d]	1.8±0.4(2)		

[a] Statistically significant between-group difference at the 0.05 level
[b] Clinical Dementia Rating
[c] Unified Parkinson's disease Rating Scale – motor scores
[d] Hoehn & Yahr stage

Two groups of drivers participated in the present study, a medically at-risk group and a group of controls. The medically at-risk (MAR) group included nine subjects with a mean age of 70.3 years (s.d.=12.1), all males, 5 with Parkinson's disease and 4 with mild cognitive impairment. The control (C) group consisted of seven subjects, 4 men and 3 women, who were medically evaluated and found to have no pathological condition, with a mean age of 55.6 years (s.d.=12.5). The difference in age between the two groups is statistically significant at the 0.05 level (p=0.031); the groups were not statistically different in terms of years of education (mean number of years of education 14.7 (s.d.=2.9) and 15.7 (s.d.=2.7) for medically at-risk and controls respectively. In Table 1 the between-group comparisons in driving experience, driving exposure, accidents in the past two years and in the Clinical Dementia Rating (CDR) are presented.

The differences in driving experience and in the number of kilometers driven per week between the two groups, were statistically significant at the 0.05 level (p=0.031). The two groups were not statistically different in terms of frequency of driving (number of days they drive per week) and number of recent accidents (within the last two years). The drivers with PD had mild to moderate disease severity as indicated by the indices of Parkinsonism (Table 1).

All subjects completed a series of neuropsychological tests at the ATTIKON University General Hospital, before their participation in the driving simulation experiment. In Table 2 the between-group comparisons in performance measures in neuropsychological tests are presented. Statistical differences between groups were found in Frontal Assessment Battery (FAB), Hopkins Verbal Learning Test-Revised Trial 1(HVLT-1), Hopkins Verbal Learning Test-Revised Trial 2, (HVLT-2), Brief Visuospatial Memory Test Delayed Recall (BVMTDR), Trail Making Test Part A (TMTA), Trail Making Test Part B (TMTB), Spatial Span Backward (SSp.Back), Symbol Digit Modalities Test Oral (SDMTo), Symbol Digit Modalities Test Written (SDMTw) and Spatial Addition Test (Sp. Addition).

On the basis of diagnoses and differences in functional abilities, we assumed that those drivers in the medically at-risk group had higher potential for working memory impairment than drivers in control group.

TABLE 2 Comparison of patients with Parkinson's disease and MCI Using Wilcoxon Rank Sum Test. Values Represent Mean±SD (Median)-Functional tests

	MAR group (MCI or PD)	Control group	P-values
General cognitive state			
MMSE	27.8±2.2(29.0)	29.4±0.8(30)	0.071
Cognitive screening			
Clock Drawing Test	6.0±1.7(7.0)	7.0±0.00(7.00)	
Semantic fluency Test	16.2±2.8(17.0)	17.9±0.4(18.00)	0.071
Phonemic Fluency	9.0± 4.5(11.0)	13.3± 3.6()	0.055
Frontal Assessment Battery[a] (FAB) (executive-related)	12.6±4.2(14)	16.7±1.4(17.0)	0.023
Upper limb apraxia screening Test	16.2±2.8(17.0)	17.9±0.4(18)	0.142
Learning and memory			
Hopkins Verbal Learning Test-Revised Trial 1[a] (HVLT-1)	4.3±1.2(4)	6.9±1.8(7.0)	0.012
Hopkins Verbal Learning Test-Revised Trial 2[a] (HVLT-2)	5.6±1.2(6.0)	8.3±1.8(8.0)	0.003
Hopkins Verbal Learning Test-Revised Trial 3 (HVLT-3) (immediate recall of verbal information)	6.78±2.0(6.0)		0.055
Hopkins Verbal Learning Test-Revised Delayed Recall (HVLTDR)	4.2±3.7(5.0)	6.4±3.6(5)	0.408
Brief Visuospatial Memory Test –Trial 1 (BVMT1)	2.78±2.4(2.0)	5.0±2.6(4.0)	0.114
Brief Visuospatial Memory Test –Trial 2 (BVMT2)	5.3±3.3(4.0)	8.6±2.6(9.0)	0.091
Brief Visuospatial Memory Test –Trial 3 (BVMT3) (immediate recall of visuospatial material)	6.8±3.7(6.0)	10.1±2.9(11.0)	0.055
Brief Visuospatial Memory Test Delayed Recall[a] (BVMTDR) (delayed recall of visuospatial material)	5.2±3.8(6.0)	10.0±2.0(11.0)	0.008
Executive functions			

Trail Making Test Part A[a] (TMTA) (psychomotor speed, visual search)	73.9±42.2(59.0)	34.6±8.9(35.0)	0.002
Trail Making Test Part B[a] (TMTB) (mental flexibility, executive-related)	157.2±76.5(137)	75.4±33.2(64.0)	0.008
Spatial Addition Test[a] (visuospatial working memory)	6.0±1.2(6.0)	14.1±4.9(16.0)	0.001
Visual and Spatial Perception			
Judgment of Line Orientation Test (visuospatial perception)	14.8±3.8(16.0)	17.0±3.3(19.0)	0.252
Short-term & Working Memory tests			
Spatial Span Forward (visuospatial working memory)	6.4±2.8(7.0)	8.4±1.4(8.0)	0.174
Spatial Span Backward[a] (visuospatial working memory)	5.0±2.2(5.0)	6.1±2.2(6.0)	0.031
Attention			
Symbol Digit Modalities Test Oral[a] (SDMTo)	23.2±17.2(22.0)	49.4±11.2(52.0)	0.005
Symbol Digit Modalities Test Written[a] (SDMTw) (information processing speed)	22.8±11.9(26.0)	48.0±10.9(51.0)	0.001

[a] Statistically significant between-group difference at the 0.05 level

Procedure

The drivers with PD were tested during periods of optimal symptom control. Experimenters were blind to the results of the neuropsychological tests. All subjects gained a degree of familiarity with the simulator through participation in a prior experiment that lasted approximately 45 minutes. Subjects were afforded a rest period of at least 15 minutes between their experience in the prior experiment and their participation in the present study. This prior experience allowed participants to practice all their driving skills (distance judgment, pedal and steering control) and also served as a screen for susceptibility to simulator adaptation syndrome (SAS) for the study sample. None were so affected.

The two study aims noted above were addressed in two different experiments, both completed in a single laboratory session. Each experiment used repeated measures for the MAR and C subjects during simulator drives of approximately two minutes' duration. Studies on (interchange) information messages indicate that drivers may forget advance information messages if the time span between the advance notification and the exit ramp exceeds the memory limit and that short-term memory span is between 0.5 and 2 min (*18*).

Experiment 1 used two test conditions, TC1 and TC2, to measure the effect of varying the delay between the presentation and recall of safety information on a message sign--holding constant a low level of demand for intervening, operational-level driving tasks--for drivers with and without medical risk factors. In TC1 this delay was 10 seconds, while in TC2 it was 80 seconds; this was achieved by presenting the sign information either near the end or near the beginning of the simulator drive. The order of presentation of TC1 and TC2 was counterbalanced, with half of the subjects randomly assigned to each order.

Experiment 2 included two conditions, TC3 and TC4. This experiment measured the effect of different levels of intervening driving task demand (i.e., between message presentation and recall) on the recall of the sign information by the MAR and C subjects, while the amount of time between the presentation and recall of the safety message was roughly equivalent across conditions. Driving task demand increased from test condition TC3 to TC4 as explained in the following paragraphs; TC3 and TC4 were presented in this (fixed) order to all subjects.

FIGURE 1 Example message sign indicating border crossing 6 km ahead where drivers should stop for inspection

In both experiments and before each of the four drives in the simulator, subjects were instructed to respond to traffic control information and always maintain safe gaps with other vehicles just as they would when actually driving. They were also instructed to maintain a constant speed at the posted speed limit unless they encountered the road section where barriers were present. Specifically, they were told to try to "*maintain a constant speed at the maximum posted speed limit for the roadway throughout the entire drive, unless you encounter road conditions where you must reduce speed to avoid hazards. In this situation, drive at what you feel is the maximum safe speed for conditions*." They were also told by the experimenter, "*At some point during this drive you will see a sign with a safety message displayed in white letters on a blue background. I will ask you to recall it at the end of the drive*." An example is shown in Figure 1.

The safety message was presented using a letter size calculated on the basis of legibility specifications to provide a viewing time within the range of 5 to 7.5 seconds (*19*). Alternate messages were constructed for use in each test condition, each with three units of information, indicating the *type of situation ahead*, *distance* and a *driver action* that is required (*19*) using standard wording (*20*). The information units conveyed in the example in Figure 1 indicate a *Border crossing* (one unit, indicating the situation/problem ahead*)*, *6 km* (one unit, indicating the distance to the situation ahead), where the driver must *stop for inspection* (one unit, indicating what the driver is required to do). The other messages presented were: *Road construction*, *3km*, *deviation* (TC1); *Tunnel*, *5 km*, *reduce speed* (TC2) and *Ice on the road*, *4 km*, *use chains* (TC3).

All driving scenarios involved driving along straight sections and gentle curves on a limited access, divided roadway. By avoiding sharp curves or frequent stops (*21*) we tried to reduce the incidence of simulator adaptation syndrome. Across all test conditions, the driving scenario began with a period of low-demand driving, requiring minimal steering input and with the only other traffic being a lead vehicle a safe distance ahead of the driver. These conditions persisted throughout TC1 and TC2, which, as noted above, differed only according to when the message sign was presented. In test conditions TC3 and TC4, however, after the initial period of low-demand driving, the level of demand was varied by imposing different types of operational and tactical driving tasks on subjects, as described below.

- Level 1. In TC3, drivers made a double lane change that involves driving through a road work section containing large blocks (barriers) on each side of the road. These blocks caused the road to progressively narrow, representing a tapering lane closure (1:20 taper ratio) that ultimately required the driver to negotiate a single lane only 3m wide.

- Level 2. In TC4, drivers met the same steering requirements as in TC3, and were also required to execute a lane change in response to a discriminative stimulus (activation of the flashers on the lead vehicle).

The research design thus required subjects to remember and apply rules for car following and lane changes throughout the drives. In the high demand condition (TC4), the demand on the working memory is different from the other test conditions. It should be noted that, lane changes of the lead vehicle (that occur in everyday driving), is also present in the other conditions. The discriminative stimulus in TC4 is a lane change of the car ahead after activating the emergency flashers.

Figures 2 and 3 show a subject in the simulator during a drive under test condition TC3. The early part of the driving scenario is shown in Figure 2, where the subject was confronted by an open road; the blocks/barriers of the road work section are just visible in the distance. In TC1 and TC2, the driver experienced only the open road condition that is visible immediately ahead of the driver in Figure 2. In Figure 3, the subject is negotiating the road work section, as the lane width tapers to its narrowest dimension.

FIGURE 2 Test condition TC3, with open road immediately ahead of the driver.

FIGURE 3 Test condition TC3, as barriers narrow the road to a single lane.

Immediately after the end of each drive, subjects were asked to recall the safety message presented on the corresponding sign. The experimenter then assigned a score 0-3, indicating none, 1, 2 or all 3 information units that are recalled. With the exception of the distance unit, the accuracy of recall was assessed on the basis of the meaning of the message information, rather than the exact wording.

RESULTS

A two-way mixed ANOVA (using SPSS) was conducted for the dependent variable (recall) for two groups, i.e., the medically at-risk group and the control group, to analyze the data from each of the two experiments in this pilot study. For the analysis the dependent variable (recall scores) was expressed as percentages of the information units that are recalled, on a scale of 0 to 100 (100% indicating all three information units, 67% two information units and 33% indicating one information unit and 0% indicating none).

Experiment 1

In Experiment 1 (Test Conditions 1 and 2) a 2x2 analysis tested for main effects of medical status (between-subjects variable) and amount of delay (within-subjects variable) on recall of the safety information, and for a possible two-way interaction between these variables. Table 3 provides descriptive statistics for the two levels of each independent variable. From the table we can see that on average, the recall score is slightly higher under longer delay than under shorter delay conditions. This effect was not significant ($F\ (1,14)=0.49$, $p=0.497$). However, there was a significant main effect of group membership on safety message recall ($F\ (1,14)=21.03$, $p<0.001$). Thus, without regard to the amount of delay, medically at-risk subjects performed worse in the recall of safety information than controls. The absence of any significant interaction between the independent variables is suggested by the nearly-parallel lines shown in Figure 4. The

ANOVA confirmed that the interaction effect was non-significant (F<1, p=0.936). Figure 5 shows the standard error bars that denote one standard error around the mean of recall scores in Experiment 1.

TABLE 3 Descriptive Statistics of Recall Scores in Experiment 1

Descriptive Statistics				
	Group	Mean	Std. Deviation	N
Delay Level 1 (shorter)	Controls	66.71	38.54	7
	Medically at-risk	14.78	24.24	9
	Combined	37.50	40.20	16
Delay Level 2 (longer)	Controls	76.14	31.84	7
	Medically at-risk	22.22	37.31	9
	Combined	45.81	43.72	16

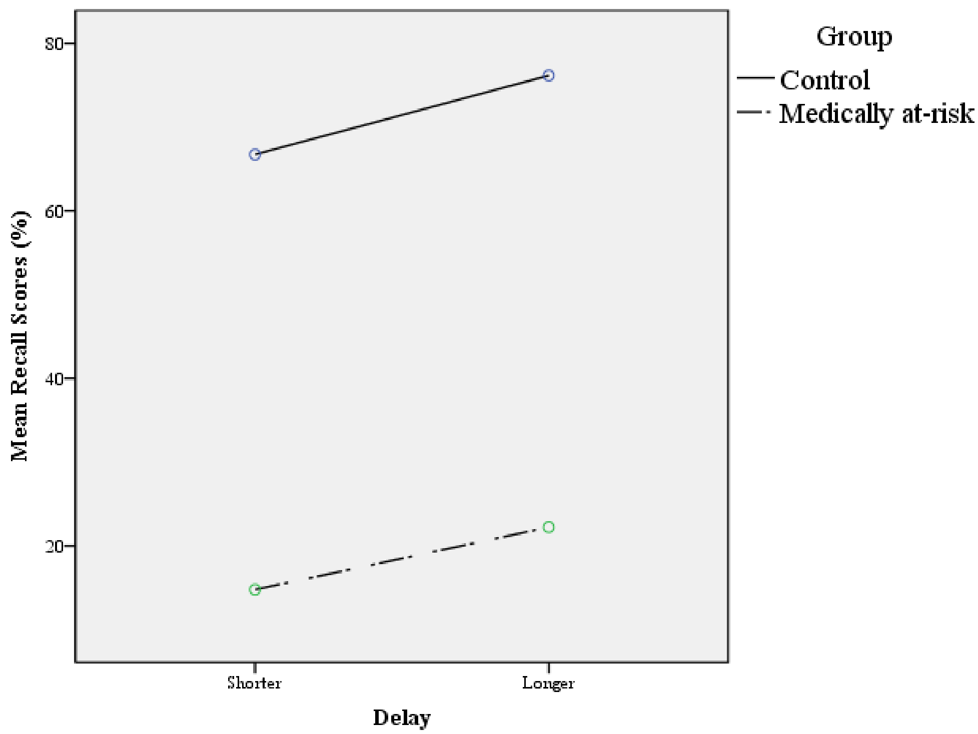

FIGURE 4 Mean recall scores for each group under longer and shorter delay

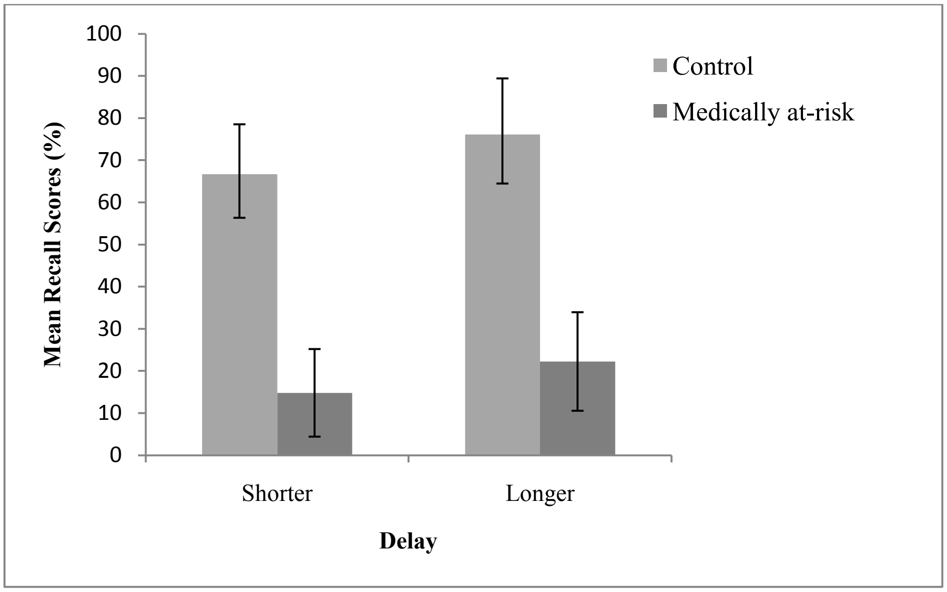

FIGURE 5 Error bars denoting one standard error around the mean of recall scores for each group under longer and shorter delay

Table 4 provides the mean speeds and standard deviations for TC1 and TC2. The difference in speeds between TC1 (shorter delay condition) and TC2 (longer delay condition) is statistically different (Wilcoxon test for repeated measures was used for comparisons) for the medically at-risk group at the 0.05 level (p=0.021). Speed of the medically at-risk group is lower than speed of control group in both conditions, although these differences are not statistically significant (Wilcoxon rank sum test was used for comparisons) (Table 5).

TABLE 4 Mean (SD) Driving Speed in Experiment 1

	Descriptive statistics	
Group	TC1 (Shorter delay)	TC2 (Longer delay)
Controls (n=7)	64.40(19.82)	61.32(16.82)
Medically at-risk[a] (n=9)	54.26(15.43)	47.68(14.82)

[a] Statistically significant within-group difference at the 0.05 level

Experiment 2

In Experiment 2 (Test Conditions 3 and 4) a 2x2 analysis tested for main effects of medical status (between-subjects variable) and level of demand for intervening driving tasks (within-subjects variable) on the recall of the safety message, and for a possible two-way interaction between these variables. Table 5 provides descriptive statistics for the two levels of each independent variable. From the table we can see that on average, in Level 1 of intervening driving task demand (a steering task) the recall score is higher than the recall score in Level 2 (where a steering task was followed by a lane change contingent upon a discriminative stimulus).

TABLE 5 Descriptive Statistics of Recall Scores in Experiment 2

Descriptive Statistics				
	Group	Mean	Std. Deviation	N
Demand Level 1	Controls	76.14	31.84	7
	Medically at-risk	70.44	42.30	9
	Combined	72.94	36.99	16
Demand Level 2	Controls	57.29	16.59	7
	Medically at-risk	40.89	32.57	9
	Combined	48.06	27.32	16

In Experiment 2, the effect of group membership on recall is non-significant (F (1,14)=0.48, p=0.499). However, the ANOVA indicates that differences in recall performance associated with the level of intervening task demand were reliable (F (1,14) = 25.36, p<0.001). In other words, disregarding group membership, subjects performed worse in the recall of safety information under a higher versus a lower level of driving task demand following message presentation.

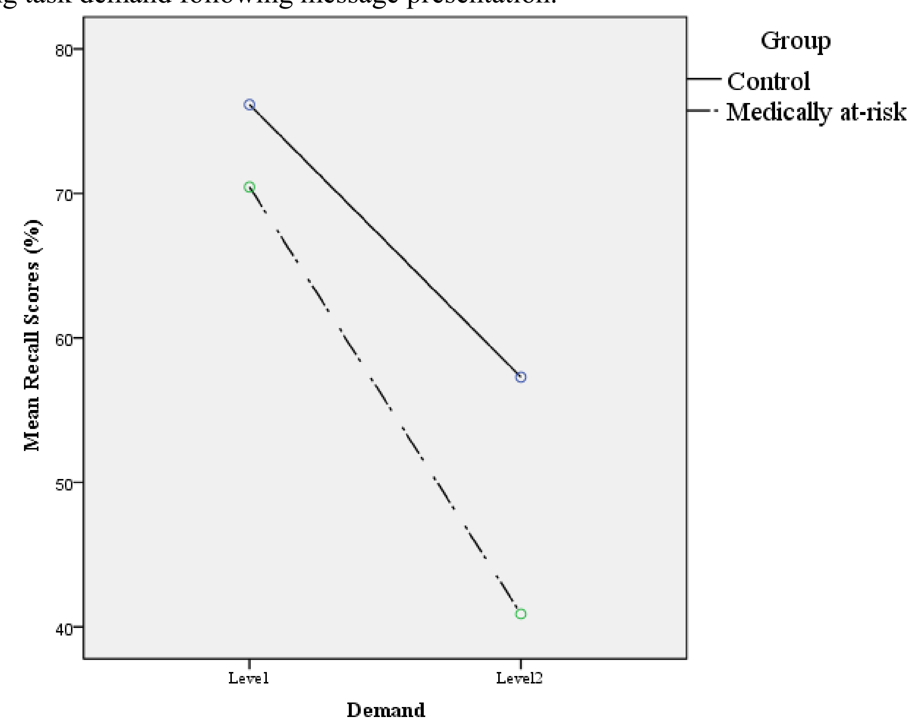

FIGURE 6 Mean recall scores for each group with varying levels of task demand.

Figure 6 illustrates the nature of the interaction between medical status and intervening task demand. This figure shows that scores decreased for both groups from task demand Level 1 to Level 2, and they dropped more sharply for the medically at-risk drivers. However, this interaction was not statistically significant (F (1,14)=1.24, p=0.285). Figure 7 shows the standard error bars that denote one standard error around the mean of recall scores in Experiment 2.

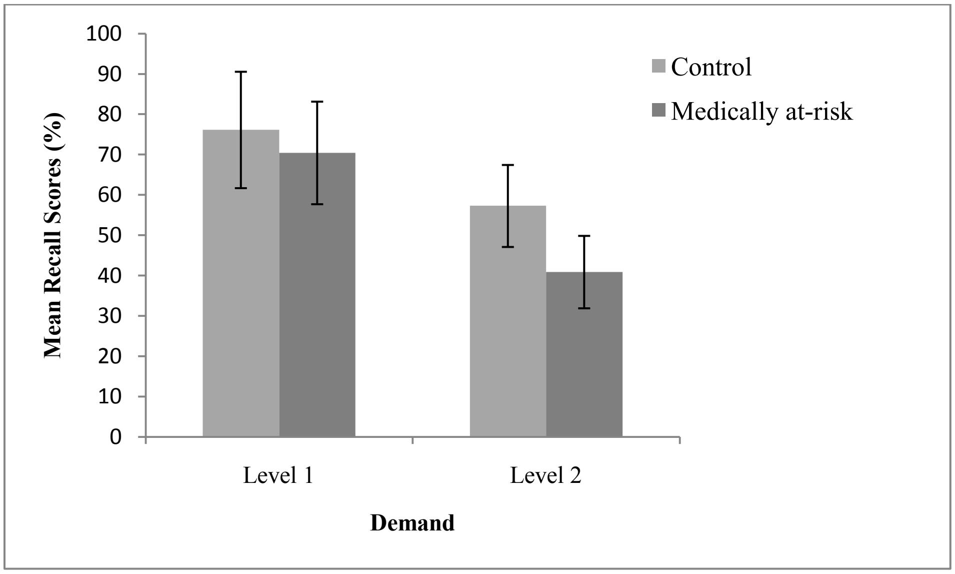

FIGURE 7 Error bars denoting one standard error around the mean of recall scores for each group with varying levels of task demand

Table 6 provides the mean speeds and standard deviations for TC3 (Level 1 of intervening task demand (driving through a road work section)) and TC4 (Level 2 of intervening task demand (where the steering task was followed by the execution of a lane change in response to a discriminative stimulus). Speed in TC3 is not statistically different than speed in TC4 (comparisons made using Wilcoxon test for repeated measures) at the 0.05 level (p=0.021) for both groups. It is noted that although the speed between conditions are not significantly different, subjects in both groups performed worse in the recall of safety information under a higher (TC4) versus a lower level (TC3) of driving task demand. The small increase in speed from TC3 to TC4 might be due to the order the two conditions are presented to the subjects, that is TC4 always follows TC3. Speed of the medically at-risk group is lower than speed of control group in both conditions, although the differences are not statistically significant (Wilcoxon rank sum test was used for comparisons) (Table 8).

TABLE 6 Mean (SD) Driving Speed in Experiment 2

	Descriptive statistics	
Group	TC3 (Demand Level1)	TC4 (Demand Level 2)
Controls (n=7)	34.27(12.87)	36.95(11.37)
Medically at-risk (n=9)	27.72(10.79)	28.88(4.36)

CONCLUSIONS AND DISCUSSION

The goals of this pilot study were firstly to provide evidence of whether there are main effects of health status and time elapsed between presentation and recall of sign information as well as interactions between these variables on drivers' recall of traffic safety messages; and secondly, in the absence of a main effect of time, to determine whether varying levels of operational and tactical driving task demands would differentially affect healthy versus medically at-risk older drivers in their message recall.

Two separate experiments were carried out using a fixed-base driving simulator, in a single laboratory session. Study participants included a "medically at-risk" group of drivers diagnosed with either Parkinson's disease (PD) or mild cognitive impairment (MCI), having a mean age of 70.3 years, and a control group of drivers with pathological conditions, having a mean age of 55.6 years. Functional performance measured in cognitive tests of drivers in the medically at-risk group was statistically different than the functional performance of the control group (as measured in these tests). On the basis of diagnoses and differences in functional abilities, we assumed that those drivers in the medically at-risk group had higher potential for working memory impairment than controls.

In the first experiment, we found a significant main effect of health status on the recall of safety information presented on a sign, with the medically at-risk subjects performing worse than controls. At the same time, we found that a longer versus shorter delay before message recall had no significant effect on either group. In the second experiment, we found that increasing the level of driving task demand between message presentation and recall (while holding delay roughly equal) resulted in a disproportionally greater drop in recall performance for the medically at-risk group than for the controls, but this effect did not reach statistical significance. The only significant effect demonstrated in Experiment 2 was a main effect for task demand, which had an inverse impact on recall performance across both groups of study participants.

The conclusions that can be drawn from this study are tentative, given various limitations. The evidence presented here is encouraging, however, with regard to the use of a fixed base simulator to identify performance differences related to medical conditions that have clear implications for fitness-to-drive. With an understanding of its limitations, such driving simulation in combination with functional assessment batteries measuring physical, visual and cognitive abilities could comprise the off-road component of a multi-tiered system to evaluate medical fitness-to-drive. Reliable evaluation procedures will become more important as the number of older drivers increases in the years ahead, producing a higher prevalence among motorists of declines in specific cognitive abilities that predict crash risk, such as working memory. This increasing prevalence may be anticipated because of changes due to normal aging and the various age-related pathologies that are more common among older adults, and the medications used to treat them.

At the same time, there are some important qualifications to these conclusions. Our future research agenda is driven by a need to meet these challenges, as discussed below.

Not only were the study participants few in number, but the medically at-risk group consists of drivers with different pathologies. Furthermore, the medically at-risk drivers were not matched with controls in respect to age, gender, driving experience or driving exposure in terms of kilometers driven per week (*22*). Because these are individual characteristics associated with driving competence, these differences raise serious methodological concerns. Since the aging process is associated with declines in working memory, the difference in performance in the recall task between the average age of the MAR group and the control group, may be confounded by the relationship between age and recall performance. Other confounding factors might be the differential driving experience (years since acquisition of driving license) and driving exposure (kilometers driven per week). Experienced drivers possess cognitive driving skills such as anticipation and hazard recognition; healthy older (experienced) drivers possess these cognitive skills and they are characterised by strategic thinking and safety orientation (*23*) that might enable them to compensate for age-related functional decline. However, compensation is also subject to functional limitations.

Furthermore, drivers with functional declines may drive less and avoid driving in difficult. Without regular practice, older drivers may have to use controlled processes to carry out tasks that were once automatic (*21*). Difference in gender between the two groups of participants is also an issue of concern due to gender's relationship to driving habits and experience. It has been suggested that women's different accident patterns are due to quantitatively and qualitatively different driving experience (*24*), (*25*).

In respect to the study design, another problem is the lack of control over the time the message is displayed to the subjects, i.e. subjects' exposure to the sign information. It is probable that due to limitations in display resolution or vision limitations, some subjects may need to be closer to the sign and/or reduce speed to read it. This means that the available time to view and read the sign (which affects the comprehension and the legibility distance) information may be differentiated among subjects. Furthermore, in order to avoid the confounding factor relating to the detection of the sign, before each drive subjects were told that they would need to recall a safety message presented on a sign. However, an issue that raises questions regarding the external validity of our experiment relates to the fact that the particular experimental condition (i.e., drivers are told they will need to look for a specific sign) does not resemble a usual driving situation, with possible implications regarding the external validity of the experiment.

Next, there is a broad consensus that it is the diminished visual, perceptual-cognitive and physical abilities themselves, not the associated medical conditions that may have produced a functional loss, that are of principal concern in determining fitness-to-drive (*26*). When the analysis of the pilot data took place, preliminary measures of functional profiles of the present study sample had been obtained; Preliminary analysis of performance in cognitive tests revealed between-group differences in visual search, motor speed spatial skills, verbal learning and memory, visuospatial working memory, executive control, and speed of information processing (comparisons not adjusted for demographic variables). Group assignment based on diagnoses and group differences in performance measured in these tests, were assumed to provide for contrasting health/functional status among participants, such that those in the "medically at-risk" group had higher potential for working memory impairment. Being unable to analyze the extent to which performance differences may be attributed to actual differences in functional abilities of vision and cognition underlines the tentative nature of our results.

Evidence reported by Cox et al. (*27*) that learning to use a simulator can be especially difficult for (older) drivers with dementia, even when given time to adapt to it, also deserves mention. This might explain why recall scores for the medically at-risk group in the present study actually improved for the test condition where drivers were required to steer between barriers (TC3), relative to the earlier, 'open road' conditions (TC1 and TC2) – even though demand increased, they benefited from additional practice. A further complication of using a simulator to assess skills in older drivers is that they are more likely to experience simulator sickness (*28*). Finally, driving skills that are overlearned by older persons with a lifetime of experience are perhaps less likely to be manifested by individuals with cognitive impairment than by same-age healthy controls under the artificial conditions of a simulator.

REFERENCES

1. Staplin, L., Lococo, K. H., Gish, K. W., Decina, L.E. (200. Model Driver Screening and Evaluation Program. Final Technical Report. Volume 2: Maryland Pilot Older Driver Study. Washington, D.C., National Highway and Traffic Safety Administration. http://www.nhtsa.dot.gov/people/injury/olddrive/modeldriver/

2. Staplin, L. Choosing Among Measures of Driver Cognitive Status that Predict Crash Risk. Maryland Older Driver Symposium. May 2012.

3. Grey P., *Psychology*, 4th Ed., Worth Publishers, New York, 2002.

4. *2010 British Columbia Guide in Determining Fitness to Drive*. Ministry of Public Safety and Solicitor General. Office of the Superintendent of Motor Vehicles. 2010 (Revised.2013).

5. Rizzo M. Medical Disorders. *Handbook of Driving Simulation for Engineering, Medicine and Psychology*. CRC Press, 2011.

6. Ball, K. K., D. L. Roenker, V. G. Wadley, J. D. Edwards, D. L. Roth, Jr. G. McGwin, R. Raleigh, J. J. Joyce, G. M. Cissell, and T. Dube. Can High-Risk Older Drivers Be Identified Through Performance-Based Measures in a Department of Motor Vehicles Setting?. *Journal of the American Geriatric Society*, Vol. 54(1), 2006, pp. 77-84.

7. Uc, E., and Rizzo, M.. Driving in Alzheimer's Disease, Parkinson's Disease, and Stroke. *Handbook of Driving Simulation for Engineering, Medicine and Psychology*. CRC Press, 2011.

8. Crizzle, A.M, Classen, S., Uc, E. Y.. Parkinson disease and driving. An evidence-based review. *Neurology,*79:2067–2074, 2012.

9. Wadley, V. G., Okonkwo, O., Crowe, M., Vance, D. E., Elgin, J. M., Ball K.K, and C. Owsley. Mild Cognitive Impairment and Everyday Function: An Investigation of Driving Performance. *J Geriatr Psychiatry Neurol*. 22(2): 87–94.June 2009 ; doi:10.1177/0891988708328215

10. Vardaki, S., Yannis, G. and S. Papageorgiou. A Review of Driving Performance Assessment in Simulators, accepted for presentation at the *Road Safety and Simulation RSS013 International Conference*, Rome, October 2013.

11. Devlin, A., McGillivray, J., Charlton, J., Lowndes, G., and Etienne, V.. Investigating driving behaviour of older drivers with mild cognitive impairment using a portable driving simulator, *Accident Analysis & Prevention*, (49) 300– 307, 2012.

12. Frittelli, C., Borghetti, D., Iudice, G., Bonanni, E., Maestri, M., Tognoni, G., Pasquali L. and Iudice, A. Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test, *International journal of geriatric psychiatry*, 24(3), pp. 232-238, 2009.

13. Rizzo, M., Uc, E. Y., Dawson, J., Anderson, S., and R. Rodnitzky. Driving Difficulties in Parkinson's Disease. *Movement Disorders* , Vol. 25, Suppl. 1, pp. S136–S140, 2010.

14. Lee, H. C., Lee,A. H., Cameron, D., Li-Tsang, C.. Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes . *Journal of Safety Research 34 , 453– 459, 2003*

15. Devos, H., Vandenberghe, W., Nieuwboer, A., Tant, M., De Weerdt, W., Dawson, J.D., Uc, E. Y. Validation of a Screening Battery to Predict Driving Fitness in People With Parkinson's Disease. *Movement Disorders*, Vol. 28, No. 5, 2013.

16. Staplin L.. *Safe Driving Tactics: What Role for Low Cost Simulation?.* TRB Annual Meeting 2010.

17. Yannis G., Golias J., Antoniou C., Papadimitriou E., Vardaki S., Papantoniou P., Pavlou D., Papageorgiou S., Andronas N., Papatriantafyllou I., Liozidou A., Beratis I., Kontaxopoulou D., Fragiadaki S., Economou A., Design of a large driving simulator experiment on performance of drivers with cerebral diseases. Proceedings of the *4th International Conference on Road Safety and Simulation*, Rome, October 2013.

18. Staplin, L., Lococo, K., Byington, S. *Older driver highway design handbook*. Federal Highway Administration, Mc Lean ,VA, 1998.

19. Cambell, J. L., Lichty, M. G., Brown, J. L., Richard, C. M., Graving, J. S., Graham, J., Mitchell O' Laughlin, Darren Torbic and Douglas Harwood. *NCHRP Report 600 (Second Edition): Human Factors Guidelines for Road Systems*. Transportation Research Board of the National Academies, Washington D.C, 2012.

20. *Freeway Signing Guidelines*. Hellenic Ministry of Transport and Infrastructure, Athens, 2010.

21. Trick, L. M. and Caird, J. K.. *Methodological Issues When Conducting Research on Older Drivers*. Handbook of Driving Simulation for Engineering, Medicine and Psychology, CRC Press, 2011.

22.Ball, K. K., and M. L. Ackerman. *The Older Driver (Training and Assessment: Knowledge, Skills, and Attitudes)*. Handbook of Driving Simulation for Engineering, Medicine and Psychology. CRC Press, New York, 2011.

23.Breker, S., Henrikson, P., Falkmer, T., Bekiaris, E., Panou, M., Eeckhout, G., Siren, A., Hakamies-Blomqvist, L., Middleton, H., Leue, E. *Aged people Integration, mobility, safety and quality of Life Enhancement through driving (AGILE) Project, Deliverable 1.1: Problems of elderly in relation to the driving task and relevant critical scenarios,* 2003.

24.Sirén, A., Heikkinen, S., Hakamies-Blomqvist, L. *Older female road users: A review*, VTI Rapport 467A, Swedish National Road and Transport Research Institute, Linköping, Sweden, 2001.

25.Hakamies-Blomqvist, L. Safety of Older Persons in Traffic. Proceedings of *Transportation in an Ageing Society. A Decade of Experience,* Transportation Research Board, Washington D.C., pp. 22-35, 2004.

26. Staplin, L., K. Lococo, K. Gish, and J. Joyce. *Functional Assessments, Safety Outcomes, and Driving Exposure Measures for Older Drivers, Report No. DOT HS 811 630*, National Highway Traffic Safety Administration, Washington, D.C., 2012.

27.Cox, D. J., W. C. Quillian, F. P. Thorndike, B. P. Kovatchev, and G. Hanna. Evaluating driving performance of outpatients with Alzheimer disease. *Journal of the American Board of Family Practice,* Vol. 11, 1998, pp. 264-271.

28.Brooks, J. O., R. R. Goodenough, M. C. Crisler, N. D. Klein, R. L. Alley, B. L. Koon, W. C. Logan, J. H. Ogle, R. A. Tyrrell, and R. F. Wills. Simulator sickness during driving simulation studies. *Accident Analysis & Prevention*, Vol. 42(3), 2010, pp. 788-796.