DRIVING DIFFICULTIES AS REPORTED BY ELDERLY DRIVERS WITH MCI AND WITHOUT NEUROLOGICAL IMPAIRMENT: IMPLICATIONS FOR ROAD DESIGN

Sophia Vardaki[1], George Yannis[1], Dimosthenis Pavlou[1], Ion Beratis[2], Nikolaos Andronas[2] and Sokratis G. Papageorgiou[2]

[1] Department of Transportation Planning and Engineering, National Technical University of Athens, Athens, Greece
[2] Department of Neurology, National and Kapodistrian University of Athens, Athens, Greece

sophiav@central.ntua.gr
geyannis@central.ntua.gr
dpavlou@central.ntua.gr
ionas96@hotmail.com
nikos_andronas@yahoo.gr
sokpapa@med.uoa.gr

Abstract
The purpose of this study was to explore the factors determining driving difficulties as seen from the viewpoint of thirty elderly MCI drivers and thirty age-matched controls without cognitive impairment, using data from an extensive questionnaire. The analysis revealed that two factors underlie MCI perceptions of driving difficulties, representing (i) difficulties associated with late detection combined with slowed response to relevant targets in the peripheral field of view, and (ii) difficulties associated with divided attention between tasks requiring switching from automatic to controlled responses, particularly of long duration. The analysis for healthy controls revealed three factors representing (i) difficulties in estimating speed and distance of approaching vehicles in complex (attention-dividing) high-information-load conditions; (ii) difficulties in moving head, neck and feet; and (iii) difficulties in switching from automatic to controlled processing in new or unexpected situations. The exposure pattern of both groups is generally consistent with their concerns. The results underline the ability of elderly drivers' (with MCI and without cognitive impairment) to indicate probable impairments in various driving skills. The patterns of difficulties identified may provide us with indications about roadway situations that are associated with perceived demands by each group; these patterns might be important to consider when auditing or designing improvements to accommodate aging road users, as well as the most vulnerable subgroup of elderly drivers who might still be able to drive.

Keywords: *older drivers, road safety, self perceptions, cognitive impairment, driver behavior, driving task demand*

1.Introduction

As drivers age, they are more likely to experience medical conditions that affect their ability to control a motor vehicle safely. Most notably, functional deficiencies resulting from impaired cognition, particularly in the case of neurological diseases such as dementia, mean that the risk of older people being involved in a collision is greater than for other drivers (Hakamies-Blomqvist, 2004; Sims, McGwin, Allman, Ball, & Owsley, 2000).However, individuals with mild cognitive impairment (MCI) as well as those in the earliest stages of a progressive, dementing illness, may be able to continue driving safely for some time (Lundberg et al., 1997). Researchers have underlined the importance of identifying drivers with early dementia or MCI, what Wadley et al. (2009) call 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". This is made all the more necessary by the reduced capacity of such drivers to self-regulate (Staplin, 2012; Staplin, Lococo, Gish & Decina, 2003). The driving performance of patients with MCI has not been widely been studied (Carr & Ott, 2010).
Wadley et al. (2009) examined the driving performance of 59 cognitively normal older adults and 46 persons with MCI (43 amnestic and 3 nonamnestic) using an on-road driving assessment. The groups were not matched on age (the MCI group was significantly older) or gender (the MCI group had fewer females), but there were no differences between the groups in terms of race, education or visual acuity. Differences in mean driving performance ratings were small, with participants in both groups receiving high mean ratings. The MCI patients were significantly more likely to receive a less-than-optimal rating on left turns, lane control and global ratings. The authors discussed specific difficulties in left turn negotiation and maintaining lane control among MCI patients in relation to greater demands in executive function associated with these maneuvers.
A study by Frittelli et al. (2009) examined the impact of Alzheimer's disease (AD) and mild cognitive impairment (MCI) on driving ability using a low-cost, personal-computer-based interactive driving simulator (STISIM Driving Simulator). The study included 20 patients with mild AD (CDR = 1), 20 individuals with MCI (CDR = 0.5) and 19 neurologically normal aged controls. The drivers with AD were rated as significantly worse than both the MCI subjects and the healthy elderly drivers on three driving behaviors: length of the run (sec), mean time to collision and number of off-road events (defined as occurring when the centre of the car's hood crossed the lateral border of the road). The only statistically significant difference between the MCI patients and the healthy controls was a shorter mean time to collision for the MCI subjects.

Devlin et al. (2012) examined the performance of older drivers with and without mild cognitive impairment (MCI) when approaching intersections, testing fourteen male and female older drivers with MCI and fourteen age-matched, healthy drivers, using a portable driving simulator. The results indicated that the drivers with MCI exhibited behaviors that were less situationally appropriate than those of the controls when approaching stop controlled intersections and critical light-change intersections. Specifically, the healthy drivers demonstrated a greater number of foot hesitations on their approach to stop-controlled and critical light change intersections compared to the MCI group; this behavior was interpreted as a strategy to improve readiness in the event of rapid braking being required. A large variation in cognitive ability amongst the drivers with MCI was found.

O'Connor, Edwards, Wadley & Crowe, (2010) used data from a longitudinal study to examine psychometrically defined MCI at baseline and predict levels and rates of change in four aspects of mobility: life space, driving space, driving frequency and driving difficulty. Three-hundred and four older adults with MCI and 2051 healthy controls (2355 participants in total) participated in the study. All participants underwent physical and visual examination and were assessed for depression and overall health status. Self-report questionnaires were used to assess the four aspects of mobility. The MCI group was classified as amnestic (n = 82), non-amnestic (n = 140) and multidomain (n = 82). In general, the MCI group had lower baseline rates for life space, driving space and driving frequency and higher baseline rates for driving difficulty compared to the control group, and also showed a greater decline in driving frequency and increase in rates of driving difficulty for a five-year period. There was no significant difference between the MCI subgroups in terms of their initial rates of mobility, although these differed thereafter. One conclusion of the study was that the functional status of MCI drivers may deteriorate over time.

In a cross sectional study by O’Connor, Edwards & Bannon (2013), older adults with MCI (n = 41), dementia (n = 40) and normal cognition (n = 43) self-reported on driving status, driving frequency and driving behaviors, in particular their avoidance of situations such as driving in bad weather, at night, in unfamiliar areas or on busy roads, as well as making left turns. Similar levels of driving status and frequency were reported by each group. However, the dementia and MCI groups avoided unfamiliar areas and busy roads more often than the group with normal cognition.

In their study investigating awareness of functional difficulties in MCI, Okonkwo et al. (2009) found a tendency in MCI patients to overestimate their driving abilities (as revealed by the discrepancy between self-report and objective performance), although this trend was not statistically significant. The study suggested that patients’ awareness of their functional deficiencies varies according to the functional domain, and that self-reports of functional abilities made by MCI patients are probably no less accurate than those made by older adults with normal cognition.

The indication of the studies reviewed is that MCI patients experience difficulties in driving and that in comparison with healthy controls, they exhibit lower ratings on driving performance in demanding tasks associated with intersection approach, time-to-collision and left turns, whether assessed on a simulator or by an on-road test. Moreover, MCI individuals are more likely than cognitively normal individuals to experience difficulties with driving and avoid unfamiliar areas and busy roads .

A Danish study (Meng & Siren, 2012) investigated the perceived changes in driving skills, the discomfort experienced in driving, and the self-regulation of driving as measured by the avoidance of certain driving situations by older drivers with different levels of self-rated cognitive problems using a structured telephone interview. The results showed that the recognition of cognitive problems was associated with a perceived improvement in higher level driving

skills and a decline in lower level driving skills; cognitive problems recognized by drivers were associated with discomfort in, and avoidance of, specific driving situations.
The lower functioning group was more likely to report improvement in the higher level skills that rely on cumulative experience, strategic thinking and crystallized intelligence, which are abilities known to generally improve with age, such as 'avoidance of unnecessary risks in traffic'. This group was also more likely to report a decline in the lower level skills, indicating that they acknowledged negative changes in their driving. This group was also much more likely to report discomfort in all driving situations. The driving situations that showed the largest difference in avoidance between the two groups (lower functioning and higher functioning groups) were 'dark', 'dense traffic', and 'times and places with many cyclists', situations that are all cognitively demanding as well as relatively easy to avoid. On the other hand, a large difference between the groups was not found in all of the cognitively demanding situations, for example left turns, which are much more difficult to avoid. The authors conclude that driving-related discomfort is an important factor in the self-regulation of driving, a finding which is in line with previous research indicating a link between driving-related stress, the self-regulation of driving, and driving cessation.

In this paper we investigate the perceptions that drivers with MCI and age-matched controls without measurable cognitive impairment have of driving difficulties, using data from an extensive questionnaire. Samples of drivers diagnosed with MCI and age matched controls were asked to report the frequency with which they experienced driving difficulties related to functional deficits and knowledge of new traffic rules and traffic signs.

2.Methods

2.1 Participants

Samples of drivers diagnosed with MCI and controls without measurable cognitive impairment were recruited to participate in this study. This study was part of a large driving simulator experiment (Yannis et al., 2013), from which current participants were drawn. All participants in this research held a valid driving license and met certain criteria (Yannis et al., 2013; Vardaki et al., 2015) such as current minimum driving activity, as well as exclusion criteria, e.g., kinetic disorders that prevent them from basic driving movements and eye disorder that prevents them from driving safely.
All MCI subjects were classified with amnestic MCI. The control group consisted of 30 subjects, who were medically evaluated and found to have no pathological condition, with a mean age of 62.2 years (s.d. = 7.0). The MCI group consisted of 30 participants with a mean age of 65.4 (s.d. = 7.6). Table 1 displays between-group comparisons for driver age, gender, driving experience and driving exposure (number of days driven per week). None of the differences were statistically significant at 0.05 level.

Table 1 – Comparison of the group of patients with MCI and the control group without neurological history on various demographics with the use of the Wilcoxon Rank Sum Test

	MCI group N = 30	Control group N = 30	Pvalues[a]

Age, mean±SD (median; IQR)	65.4±6.6 (66; 60.8-74)	62.2±7.0 (60; 56.5-75)	0.052
Gender, n, M/F	30, 18/12	30, 17/13	0.795
Driving experience, mean±SD (median)	39.6±8.2 (40.0; 33.8-48.9)	33.1±6.0 (36.0; 34-46)	0.144
Days/week, mean±SD (median; IQR)	4.8± 2.2 (5.5, 2.8-7)	5.8±1.7 (7, 5-7)	0.755

a. Level of statistical significance for between-group difference p = 0.05

The diagnosis of mild cognitive impairment was based on the criteria of Petersen et al. (2005), which involve complaints about memory impairment by the patients or a family member, verified impairment on at least one cognitive domain but with preserved functional abilities of daily living and absence of dementia. For participants in this study, exclusion criteria involved a score on the Clinical Dementia Rating Scale equal to or greater than one, premorbid history of neurologic or psychiatric disorders, and the presence of significant depression.

Table 2- Descriptives and t-test analysis for the control group and the MCI group on measures of functionality and cognition

	Control Group	MCI Group	Control Group	MCI Group		
	Mean	SD	Mean	SD	t	p
MMSE	29.07	.94	28.18	1.72	2.41	.020
CDR	.0	.0	.5	.0	-	-
IADLmen	5.0	.0	5.36	.63	1.58	1.30
IADLwomen	8.0	.0	8.0	.0	-	-
FAQ	.23	.44	.88	1.59	1.44	.160
CDT	6.80	.48	6.45	1.40	1.28	.210
FAB	15.57	2.08	13.69	3.42	2.54	.015
HVLT-Total	22.93	3.65	18.48	4.99	3.90	<.001
HVLT-Delayed	7.20	2.43	4.79	4.45	2.59	.012
TMT-A	40.78	13.14	55.90	23.50	3.07	.003
TMT-B	102.80	52.62	143.86	85.39	2.22	.032
LNS	9.67	2.50	8.10	2.88	2.23	.030
SDMT	43.70	8.86	32.79	12.90	3.77	<.001
Sem. Fluency	19.60	5.56	17.31	5.83	1.55	.128
UFV1	235100	127631	770400	1266200	1.88	.075
UFV2	984900	910089	1647000	1321600	1.96	.057
UFV3	2264000	1129800	3164000	1282900	2.47	.018

Note. MMSE = Mini Mental State Examination; CDR = Clinical Dementia Rating; IADL = instrumental activities of daily living; FAQ = functional assessment questionnaire; CDT = Clock Drawing Test; FAB = Frontal Assessment Battery; HVLT = Hopkins Verbal Learning Test; TMT = Trail Making Test; LNS = Letter Number Sequencing; SDMT = Symbol Digit Modalities Test; UFV = Useful Field of View

The analysis (Table 2) revealed significant differences between the control group and the MCI group in measures of general cognitive functioning (MMSE), in specific executive cognitive function impairments (FAB), in measures of verbal episodic memory (Hopkins Verbal Learning Test), information processing speed (SDMT), psychomotor speed (TMTA), mental flexibility (TMTB), working memory (LNS) and selective attention (UFV3).

2.2 Perceived Driving Difficulties

To collect the data required for this investigation, 30 older drivers with MCI and 30 healthy age-matched controls were asked to report the frequency with which they experienced difficulties related to functional deficits and knowledge of new traffic rules and traffic signs. The functional abilities underlying these difficulties include visuo-perceptual abilities, useful field of view, reaction time, selective attention, divided attention, sustained attention, psychomotor performance, knowledge (of new traffic rules and signs) and mental flexibility (Ball et al., 1998; De Raedt, 2000; Hakamies-Blomqvist, Sirén & Davidse , 2004; Knoblauch, Nitzburg & Seifert, 1997). We chose the specific functional abilities because of the following attributes: they are important in safe driving and decrease as a result of the ageing process (De Raedt & Ponjaert-Kristoffersen, 2000). Furthermore, the abilities were selected on the basis that the related driving problems could be described in a clear and simple way. We used a limited the number of questions to avoid a possible overload of respondents as a result of an extended use of investigating questions. It should be noted that although older people are not always aware of visual problems (Eby et al., 2003; Holland, 2001), we assumed no sensory or hearing deficit. A four-point scale (always; often; sometimes; never) was used to rate frequency.

"Which of the following are true for you, and with what frequency?"

Q1. I have difficulty concentrating on more than one action at the same time (e.g. keeping the vehicle centered in the lane and concentrating on the position of other vehicles)

Q2. I have difficulty judging the distance and speed of approaching vehicles

Q3. I am surprised by vehicles and pedestrians appearing from the sides very close to me

Q4. I have difficulty focusing my attention on traffic signs where there are other signs

Q5. I have difficulty concentrating and maintaining attention

Q6. My reactions are delayed when I have to perform an emergency stop

Q7. I have difficulty moving my hands, feet and neck

Q8. My knowledge of new traffic rules and new traffic signs is not good enough

Q9. I have difficulty adapting to sudden changes in traffic control on one of my usual routes

2.3 Driving in Specific Situations

Drivers were asked how often they drive in specific situations/conditions including driving at night, in heavy traffic, in urban roads, in heavy rain, on freeways, on unfamiliar roads, on rural roads, on urban roads, in the proximity of their homes and long distances. A six-point scale (never; at least once every two months; at least once a month; at least once a week; at least twice a week; at least four times a week).

3.Results

3.1 Factor Analysis of Drivers' Perceptions of their Driving Difficulties
To investigate the factors determining driving difficulties, as perceived by elderly drivers with MCI and age-matched controls, a factor analysis was performed using SPSS.

3.1.1 MCI Group

A principal component analysis (PCA) was initially conducted on nine items with oblique rotation. The preliminary analysis revealed that variables Q2 (difficulty in judging the distance and speed of other vehicles) and Q8 (inadequate knowledge of traffic rules and new traffic signs) did not correlate well with other variables (correlation coefficients < 0.3) and thus they were eliminated. Seven variables were included in the PCA for the MCI group. The suitability of this approach was considered by use of the Bartlett's test of sphericity and the Kaiser-Meyer-Olkin index (KMO). The KMO measure verified the sampling adequacy for the analysis, KMO = 0.763 > 0.5, and all KMO values for individual items were above the acceptable limit of 0.5. Bartlett's test of sphericity χ^2 (21) = 94.412, p < .001, indicated that correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Two components had eigenvalues over Kaiser's criterion of 1 and in combination explained 68.79% of the variance. Given the convergence of the scree plot and the Kaiser's criterion, two components were retained in the final analysis. Table 3 shows the factor loadings after rotation. The items that cluster on the same components suggest that factor 1 represents difficulties related to late detection and slowed response to relevant stimuli/targets in the peripheral field of view, explaining 54.1% of the variance, and factor 2 represents difficulties related to divided attention between automatic and controlled processing in high-information-load conditions and long duration tasks explaining 14.7% of the variance.
For interpretative purposes, we used the cut-off point of 0.5 for loadings. To identify the construct that each factor represents we looked at the common themes among highly loading questions. The variables that load highly on factor one, ordered by their factor loadings, are Q3, Q7 and Q4. The variables that load highly on factor two, ordered by their factor loadings, are Q1, Q9 and Q5.

Table 3 - Summary of Exploratory Factor Analysis results for Perceived Driving Difficulties by the Group of Drivers with MCI

	Rotated Factor Loadings	
Question	**Factor 1**	**Factor 2**
I am surprised by vehicles and pedestrians appearing from the sides very close to me (Q3)	.852	.081
I have difficulty moving my hands, feet and neck (Q7)	.838	-.185
I have difficulty focusing my attention on traffic signs where there are other signs (Q4)	.757	.273
My reactions are delayed when I have	.579	.268

to perform an emergency stop (Q6)		
I have difficulty concentrating on more than one action at the same time (Q1)	-.121	.944
I have difficulty adapting to sudden changes in traffic control on one of my usual routes (Q9)	.073	.720
I have difficulty concentrating and maintaining attention (Q5)	.210	.701
Eigenvalues	3.79	1.03
%variance	54.11	14.68

FACTOR 1- The variables that make up the first factor represents difficulty in detecting peripheral stimuli (visuo-spatial attention) and in responding to spatial and temporal information from the environment, in moving head, neck and feet (motor performance), and in selecting relevant signs (or information in the broad sense) and ignoring irrelevant ones (selective attention).

The first factor represents driving difficulties associated with late detection and slowed response to relevant stimuli/targets in the peripheral field of view.

The visual field does shrink as people age, producing increasing insensitivity to peripheral signals. More recent work on peripheral vision has generally combined measures of peripheral vision with peripheral attention (Holland, 2001; De Raedt, 2000). Age-related changes of vision combined with cognitive changes affecting 'pre-attention' contribute to a decreased probability of detecting a moving or stationary object in the outer regions of the visual field. Visual localization limitations might be a problem at junctions, complicated due to the numerous directions of approaching traffic or the presence of cyclists, motorcyclists and pedestrians approaching from the sides. Restrictions in turning the head and body to monitor position or to look to the rear or to the sides for changes in traffic are common with increasing age. These difficulties affect the ease and frequency of head movements at junctions, resulting in late detection of other users and objects (cars, signs, pedestrians, cyclists) in the periphery. Selective attention refers to the ability to select relevant information, ignore irrelevant information and focus attention on particular stimuli for a given task De Raedt, 2000). A particular problem for older people relates to the fact that too much attention is paid to irrelevant stimuli. It is more difficult for the elderly to perceive traffic signs in very cluttered surroundings, where attention has to be paid to stimuli appearing suddenly in unknown places, often located in the periphery of the visual field. These problems can become severe for this age group, particularly in urban areas and at complex junctions with many sources of information where advertisements and directional signs are also commonly found.

FACTOR 2 - The variables that load on the second factor refer to capacity to divide attention between several tasks skills and to switch from automatic to controlled processing in new or unexpected situations (mental flexibility) and the ability to maintain attention to a task (sustained attention).

The second factor refers to driving difficulties associated with divided attention between tasks requiring switching from automatic to controlled responses, particularly of long duration.

During driving, the car must be kept on the road in a correct lateral position, while road signs and the position of other road users must always be noted. In essence, driving is a real world divided-attention task (De Raedt, 2000). Divided attention involves monitoring two or more stimulus sources simultaneously, but more commonly it includes the combination of any two tasks that have to be performed simultaneously. Divided-attention ability is particularly important in relation to in-car information systems, car-phones, etc (Holland, 2001). In experienced – older – drivers, some task components have become highly automized with practice, and an extensive number of overlearned automized responses have been built up over many years of driving. This allows them to compensate for age-related limitations in cognitive capabilities. However, in more demanding driving conditions, dual tasks impose high divided-attention demands, requiring controlled processes. In high-information-load conditions where drivers scan and monitor many sources of information simultaneously, unexpected new situations require switching from automatic to controlled actions.
The ability to adapt to new or unexpected situations and implement a new strategy suppressing automatic actions is related to adaptive skills and tactical compensation mechanisms and in this sense is very important for the safe behavior of older drivers (De Raedt, 2000).
Drivers might have difficulty in adapting their speeds when leaving a freeway after a long period of driving to enter a lower-speed arterial road. Other examples of such difficulties involve driving in unknown surroundings, altered traffic regulations and changes to the traffic infrastructure.
Sustained attention refers to the ability to maintain attention to a task and involves long-duration tasks. However, different tasks impose different requirements for vigilance. Vigilance is required in high density traffic in complex urban areas where there is high information load, while (a different) vigilance is also required in long distance monotonous drives where the information processing load is light (Holland, 2001).
Examples of conditions where all these abilities may come into play include: busy junctions or intersections involving long waiting for gaps into traffic; merging to highways with high volumes of traffic while in addition the driver performs a way-finding task; searching for the directional signs to find the appropriate exit on a highway with closely spaced exits and performing lane changes to enter the exit ramp; driving in unfamiliar areas with intersections where drivers are unfamiliar with the traffic control; encountering sudden changes due e.g. to the occurrence of road works after driving in a low-demand environment (relatively straight alignment); entering an area with side activities requiring adaptation to lower speeds when driving in an unfamiliar rural area.

3.1.2 Group without cognitive impairment
A principal component analysis (PCA) was initially conducted on nine items with oblique rotation. The preliminary analysis revealed that Q8 (inadequate knowledge of traffic rules and new traffic signs) did not correlate well with other variables (correlation coefficients < 0.3) and thus it was eliminated. Eight variables were included in the PCA for the group of drivers without cognitive impairment. The suitability of this approach was considered by use of the Bartlett's test of sphericity and the Kaiser-Meyer-Olkin index (KMO). The KMO measure verified the sampling adequacy for the analysis, KMO = 0.748 > 0.5 , and all KMO values for individual items were above the acceptable limit of 0.5. Bartlett's test of sphericity χ^2 (28) = 85.294, $p < .001$, indicated that

correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Three components had eigenvalues over Kaiser's criterion of 1 and in combination explained 74.84% of the variance. Given the convergence of the scree plot and the Kaiser's criterion, three components were retained in the final analysis. Table 4 shows the factor loadings after rotation. The items that cluster on the same components suggest that factor 1 represents difficulties in estimating speed and distance of approaching vehicles in complex (attention-dividing) high-information-load conditions (extracting important information from signs), explaining 47.2%, of the variance, factor 2 represents difficulties in moving head, neck and feet (motor performance), explaining 15.1% of the variance, and factor 3 represents difficulties in switching from automatic to controlled processing in new or unexpected situations (mental flexibility) and reacting to sudden unforeseen hazards, explaining 12.6% of the variance. The variables that load highly on factor one, ordered by their factor loadings, are Q2, Q1, Q4 and Q5. The variable that loads highly on factor two is Q7. The variables that load highly on factor three are Q9 and Q6. This analysis seems to reveal that perceived driving difficulties by the cognitively intact group is composed of three constructs.

Table 4 - Summary of Exploratory Factor Analysis results for Perceived Driving Difficulties by the Group of Drivers without Cognitive Impairment

	Rotated Factor Loadings		
Question	**Factor 1**	**Factor 2**	**Factor 3**
I have difficulty judging the distance and speed of approaching vehicles (Q2)	.913	-.146	.020
I have difficulty concentrating on more than one action at the same time (Q1)	.864	.061	.003
I have difficulty focusing my attention on traffic signs where there are other signs (Q4)	.857	-.122	.113
I have difficulty concentrating and maintaining attention (Q5)	.559	.384	.379
I have difficulty moving my hands, feet and neck (Q7)	-.249	.939	.016
I am surprised by vehicles and pedestrians appearing from the sides very close to me (Q3)	.339	.460	.011
I have difficulty adapting to sudden changes in traffic control on one of my usual routes (Q9)	.325	.181	.767
My reactions are delayed when I have to perform an emergency stop (Q6)	.548	.383	-.615
Eigenvalues	3.78	1.2	1.01
%variance	47.17	15.10	12.57

FACTOR 1 - The variables that load on the first factor represent speed and distance judgment of approaching vehicles, the ability to divide attention between several tasks and to select relevant signs (or information in the broad sense) and to ignore the irrelevant ones (selective attention).

Factor 1 represents difficulties in estimating speed and distance of approaching vehicles in complex (attention-dividing) high-information load-conditions .

Limitations in perceiving closure rates of oncoming vehicles could lead to erroneous gap judgments/selection of inappropriate gaps in oncoming traffic. Relevant situations involve left turns in stop- and yield-controlled intersections and also overtaking maneuvers on two-lane roadways where sensitivity to speed changes of oncoming cars are crucial. Uncontrolled intersections that impose attention-dividing demands involving speed and distance judgments, i.e. left and right turns, are examples of such situations where attention to signs/devices conveying messages of traffic control and or directions is also important. Another case where these abilities come into play are exiting maneuvers where drivers in a way-finding task search for appropriate directional signs while simultaneously attempting lane changes involving gap selection in adjacent lanes. In addition, it is important while exiting to detect stopped or slow-moving vehicles ahead on the exit ramp terminal (AASHTO, 2010).

FACTOR 2 - We found one variable that loads highly on the second factor, which represents the ability to move head, neck and feet (motor performance).

FACTOR 3 - Factor 3 represents difficulties in switching from automatic to controlled processing in new or unexpected situation.

3.2 Exposure Patterns

Similar patterns of exposure regarding the frequency of driving in certain conditions were found (Table 5). The majority of both groups drive frequently in urban areas, in the proximity of their homes and less frequently over long distances. Interestingly, only 20% (one fifth) of the MCI group drive more often than once a week on freeways, while the corresponding percentage for the control group is 34% (one third). Eighty-six percent of the control group drive more often than once a week on urban roads, compared to 77% of MCI drivers. Less than half of the MCI group (40%) drive more often than once a week in heavy traffic conditions, while it is worth noticing that the corresponding percentage for the control group is higher, at 60% (Table 5). Less than 20% of the MCI group drive more often than once a week on rural roads, while the corresponding percentage for the control group is 27%. Only 10% of both groups drive more often than once a month over long distances, while the majority of both groups (80% in the MCI group and 90% in the control group) drive more often than once a week in the proximity of their homes (Table 5).

Table 5 Frequency of driving in certain driving conditions/situations

	At night %	Heavy traffic, urban roads %	In heavy rain %	Freeways %	Unfamiliar roads %	Rural roads %	Urban roads %	Proximity %	Long distances %

Controls									
Never	6.7	3.3	3.3	10.0	43.3	16.7	0.0	3.3	30.0
At least once every two months	0.0	10.0	20.0	13.3	26.7	30.0	0.0	0.0	43.3
At least once a month	20.0	6.7	20.0	23.3	23.3	23.3	6.7	3.3	16.7
At least once a week	23.3	20.0	26.7	20.0	0.0	3.3	6.7	3.3	6.7
At least twice a week	26.7	33.3	23.3	16.7	3.3	23.3	23.3	33.3	3.3
At least four times a week	23.3	26.7	6.7	16.7	3.3	3.3	63.3	56.7	0.0
MCI									
Never	10.0	6.7	10.0	6.7	30.0	20.0	0.0	3.3	20.0
At least once every two months	10.0	6.7	6.7	13.3	33.3	6.7	0.0	0.0	43.3
At least once a month	30.0	23.3	36.7	43.3	26.7	30.0	13.3	6.7	26.7
At least once a week	16.7	23.3	26.7	16.7	10.0	23.3	10.0	10.0	6.7
At least twice a week	23.3	20.0	10.0	13.3	0.0	13.3	26.7	20.0	0.0
At least four times a week	10.0	20.0	10.0	6.7	0.0	6.7	50.0	60.0	3.3

4. Implications for Road Designers and Road Safety Engineers

As a result of the rise in population age and mobility, designers face the challenge of providing a safe road environment for elderly people with increased mobility needs. Recognizing older drivers' weaknesses and strengths (e.g. driving experience and safety-oriented behavior), road design should accommodate their expectations, their need for more time and information and the possibility of serial execution of driving tasks (Kanellaidis & Vardaki, 2011).

Recent developments in road safety, especially regarding safety and human factors, provide highway designers with guidance for applying specific guidelines and recommendations have been also developed to accommodate older road users; these include the safe system approach to road safety (OECD/ITF), as well as publications with a user-centered approach (safety guides), such as the Highway Safety Manual (AASHTO 2010), the Human Factors Guidelines (Campbell et al. 2012), and the Highway Design Handbook for Older Drivers and Pedestrians (Staplin, Lococo & Byington, 2001).

The Road Safety Audit process in particular, concerns the safety of all road users, especially the vulnerable and elderly, providing a safer road environment (Austroads, 2009; IHT, 2008; FHWA, 2006). It is necessary for road designers to see the road through the eyes of ordinary drivers and understand why, where and when road users make errors. The road safety audit process ensures the design of a safer road environment with no surprises, with a controlled release of relevant information, with repetitive information, especially to emphasize danger, which is forgiving of human errors. Road Safety Audit has been broadly recognized as a successful preventive tool where emphasis was placed on how drivers might perceive or adjust their behavior to the features of the roadway, allowing the identification of any aspects of the roadway where drivers' expectations about the road and traffic might be violated or where the layout fails to give the right message (Austroads, 2009), (Alexander & Lunenfeld, 1986). Issues checked by road Safety Auditors include recognizability, early warning and guidance, particularly at locations where drivers make complex decisions and/or perform complex maneuvers; adequacy of time available to drivers in order to decide and perform maneuvers, the conformity of road layout to driver expectancies (any changes/critical transition points in road and traffic characteristics being indicated clearly and in good time), checking potential violations of expectancies related to roadway design (AASHTO, 2011), (Campbell et al., 2012). Intersections, ramp terminals involving exiting and entering maneuvers, work zones and rural/high speed-urban/low speed transitions are situations that should be considered with priority for conducting road safety audits. The results of this study could be useful when applying positive guidance (Lunenfeld & Alexander, 1990) and task analysis (Fuller & Santos, 2002; Knoblauch, Nitzburg & Seifert, 1997; Campbell et al. 2012), which are indispensable tools for road safety auditors.

5. Discussion and Conclusions

The purpose of this study was to explore the factors determining driving difficulties as seen from the viewpoint of elderly MCI drivers and age-matched controls, as well as to assess their relative importance using data from an extensive questionnaire. The study samples included 30 older adults with MCI and 30 age-matched controls without cognitive impairment. The groups were matched in terms of gender, driving experience and driving exposure. The overall pattern of performance indicates that in comparison with the control group, the group of patients with MCI had more difficulties on neuropsychological tests engaging episodic memory operations as well as executive, attentional and working memory resources.

The analysis of questionnaire data of drivers with MCI revealed that two factors underlie MCI perceptions of driving difficulties. The first factor represents difficulties associated with late detection and slowed response to relevant targets in the peripheral field of view; and the second factor refers to difficulties associated with divided attention between tasks requiring switching from automatic to controlled responses, particularly of long duration.

The analysis for healthy controls revealed three factors. The first factor represents difficulties in estimating speed and distance of approaching vehicles in complex (attention-dividing) high-information-load conditions; the second factor represents difficulty in moving head, neck and feet; and, the third factor represents difficulties in switching from automatic to controlled processing in new or unexpected situations.

Difficulties that dominate MCI perceptions relate to late detection of targets in the peripheral view being also worsened/exacerbated by slowed movement and problems in selecting relevant information (that is, a combination of attentional and motor functions). Complex intersections in urban areas with cars, pedestrians, cyclists crossing the driver’s path, with very cluttered surroundings, place high demands on these abilities. Other concern for MCI seem to be difficulties with attention sharing combined with the executive skill of switching from automatic to controlled actions and sustained attention (a combination of attentional and executive resources): driving at busy intersections, merging to highways with high traffic volumes with a way-finding task, workzones, and high-low speed transitions (rural-urban transitions). Improvements in these locations that are associated with demanding situations would benefit MCI drivers.

Difficulties that dominate perceptions of control drivers relate to problems in estimating speed and distance of approaching vehicles combined with problems in attention sharing in high-information-load conditions. Uncontrolled intersections and entering and exiting maneuvers at highways that involve way-finding are examples of demanding situations. The other two factors represent relatively lower concerns related mainly to slowed movements and problems with switching from automatic to controlled actions which, interestingly, are combined with less frequent problems with delayed reactions.

The results might be useful to road designers and road safety engineers e.g., during the task analysis process, to identify the driving task components which are perceived as being difficult, i.e. imposing high workload, by elderly drivers (either MCI or with no cognitive impairment), as well as when applying the principles of positive guidance in the design and audit a road scheme.

A study (Vardaki & Karlaftis, 2011) investigating actual and perceived driving performance and perceptions of elderly drivers 65 to 74, found that more frequent driving problems related to cognitive abilities are correlated to low performance: difficulties in sustaining attention, in flexibility of hands, neck and feet and knowledge are related to driver-stated need for assistance in freeway maneuvers in an on-road trial; more frequent driving problems with side stimuli were also related to driver discomfort experienced in the on-road trial due to other drivers. More frequent (reported) problems with perception of side stimuli combine with less adequate performance in visual searching during all maneuvers on the freeway and especially during exit. The results of the present study are generally consistent with these findings, underlining elderly drivers' ability to indicate probable impairments in various driving skills.

The relation of compensation strategies and self-regulation to self-perception or self-insight (De Raedt, 2000) has been discussed in several studies. The importance of compensation mechanism and self-regulation are well recognized since it accounts for older-driver continued driving ability and in explaining the modest association of specific medical conditions, functional impairments and additional crash responsibility with crash involvement (Hakamies-Blomqvist, 2004). Although self regulation is generally considered a strategy of elderly drivers with self-insight, Broberg &Willstrand (2014) note the inconsistency between driving ability and self-regulation, implying that elderly drivers may not avoid situations where their driving performance is inadequate; while self-regulation has also been related to motivational factors, preferences and lifestyle (Molnar et al., 2013). In our study we examined patterns of current exposure for study participants; we found that both groups have similar patterns of exposure regarding the frequency of driving in certain conditions: they rarely drive long distances (more than 2 hours) and often in the proximity of their homes. Although both groups drive frequently in urban areas, it is notable that MCI drivers do not drive so often in heavy traffic and in a lesser extent than controls. The exposure pattern of drivers with MCI represents urban – close distance – driving, probably in the proximity of the home, i.e. they are exposed to an urban environment but less so to the high demands of a heavy traffic environment; this exposure pattern is consistent with their concerns.
Neither group drives so often on freeways, but drivers with MCI do so to a lesser extent than controls. Elderly controls seem more exposed to high-speed driving than MCI patients, a finding which is consistent with their primary concern.

In translating the results, we should recognize that the specific problems in driving (as they are described in the relevant questions) cannot be attributed to isolated/distinct functions. Similarly, in forming the questions we did not attempt to decompose the complex driving task into specific cognitive or motor skills; the questions were formed to help drivers to identify specific problems in their performance that are associated to interrelated difficulties.

This work does not directly translate into design values or specific infrastructure countermeasures that adapt to different groups of drivers; however it may provide us with indications about the situations (in an infrastructural context) involving driving tasks with performance requirements associated with perceived concerns.

Public involvement in road safety, particularly in RSAs, has been advocated for almost two decades (e.g. Kanellaidis, 1999). The RSA process provides increased opportunities for road user participation that could be beneficial to road safety; the view point of affected groups of road users in various projects (urban/rural) has the potential to enhance the safety of a road infrastructure project (either new road or changes to existing layout or features) and its overall acceptance. The findings of the present study revealed the demands of road environments as perceived by vulnerable road users (either cognitively normal older drivers or drivers with MCI, who may experience subtle changes in driving skills). As affected groups they might be involved in road safety audits particularly at an operation stage, helping auditors acquire a better understanding of their perceptions, needs and expectations in respect of specific roads or road features. Their contribution can be utilized both in the task analysis and the positive guidance processes. Their input may include their difficulties (perceptions) and proposals for improvements. Their difficulties regarding particular elements and subtasks of the driving tasks that correspond to the particular road or road features (for example intersection driving, wayfinding, or entering and exiting maneuvers at an interchange) can be indicative of their needs (associated with cognitive abilities) and violations of their expectancies regarding certain operational and geometric design features (e.g. identification of conflicting or missing information, inadequate sight distances); they can also provide input to help improve the design of the road or road feature being audited.

The study results provide no evidence of self-awareness since we have not yet analyzed the extent to which perceived driving difficulties may be related to actual impairments in functional ability. Our future research will attempt to relate perceptions and performance in visual, perceptual, cognitive and motor functions.

In conclusion, the study identified certain patterns of difficulties perceived by the MCI group and discussed examples of situations where the associated combined demands may be imposed and thus may merit special attention; perceptions of driving difficulties and problems may be important when auditing or designing improvements of particular benefit to the most vulnerable subgroup of elderly drivers who might still be able to drive.

References

American Association of State Highway and Transportation Officials (AASHTO) (2011). *A Policy on Geometric Design of Highways and Streets.* Washington D.C.

AASHTO (2010). Highway Safety Manual, First Edition, American Association of State and Highway Transportation Officials

Alexander, G.,& Lunenfeld, H. (1986). *Driver expectancy in Highway Design and Traffic Operations*. Technical Report FHWA-TO-86-1. FHWA, U.S. Department of Transportation.
AUSTROADS (2009). *Guide to Road Safety Part 6: Road Safety Audit*, Austroads Publication No. AGRS06/09, Sydney.
Ball, K., Owsley, C., Stalvey, B., Roenker, D., Sloane, M. ,& Graves, M. (1998). Driving avoidance and functional impairment in older drivers, *Accident Analysis and Prevention*, 30(3), 313-322, doi: 10.1016/S0001-4575(97)00102-4.
Broberg, T.,& Willstrand, T. D. (2014). Safe mobility for elderly drivers—Considerations basedon expert and self-assessment. *Accident Analysis and Prevention 66*, 104-113.
Campbell, J. L., Lichty, M. G., Brown, J. L., Richard, C. M., Graving, J. S., Graham, …,& Harwood, D. (2012). *Human factors guidelines for road systems* (NCHRP Report 600). Presented at the NCHRP Report 600 (Second Edition): Human Factors Guidelines for Road Systems, Transportation Research Board of the National Academies, Washington, DC.
Carr, D. B., & Ott, B. R. (2010). The older adult driver with cognitive impairment: "It's a very frustrating life". *Journal of the American Medical Association, 303*(16), 1632-1641.
De Raedt, R. *Cognitive / Neuropsychological Functioning and Compensation Related to Car Driving Performance in Older Adult*s, Vrije Universiteit, Brussel, Belgium, 2000.
De Raedt, R. ,& Ponjaert-Kristoffersen, I. Can Strategic and tactical compensation reduce crash risk in older drivers? *Age & Ageing*, 29, 2000, pp. 517-521.
Devlin, A., McGillivray, J., Charlton, J., Lowndes, G., & Etienne, V. (2012). Investigating driving behaviour of older drivers with mild cognitive impairment using a portable driving simulator. *Accident Analysis & Prevention*, *49*, 300-307.
Eby, D.W., Molnar, L.J., Shope, J.T., Vivoda, J.M. ,& Fordyce, T.A. (2003). Improving older driver knowledge and self-awareness through self-assessment: The driving decisions workbook. *Journal of Safety Research*, 34, pp. 371-381.
FHWA (2006). *Road Safety Audit Guidelines*, US Department of Transportation, Federal Highway Administration (FHWA), Publication No. FHWA-SA-06-06.
Frittelli, C., Borghetti, D., Iudice, G., Bonanni, E., Maestri, M., Tognoni, G., ... & Iudice, A. (2009). 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), 232-238.
Fuller, R.,& Santos, J.A. (2002). *Human Factors for Highway Engineers*, Chapt.3, Ergonomics of the driver's interface with the road environment: the contribution of psychological research, 1st Ed., Pergamon, Oxford,
Hakamies-Blomqvist L., Sirén A.,& Davidse R. (2004). *Older drivers - a review*, VTI Rapport 497A, Swedish National Road and Transport Research Institute, Linköping, Sweden.
Hakamies-Blomqvist, L. (2004). *Safety of older persons in traffic*. Paper presented at Transportation in an Aging Society: A Decade of Experience, Transportation Research Board, Washington, DC, (pp. 22-35).
Holland, C.A. *Older drivers: a review*, Road Safety Research Report No. 25, Department for Transport, Local Government and the Regions, London, UK, 2001.

IHT (2008). *Road Safety Audit*, The Institution of Highways & Transportation, London.
Kanellaidis, G.,&Vardaki, S. (2011). Highway geometric design from the perspective of recent safety developments. *ASCE Journal of Transportation Engineering, Forum piece*,. 137(12), pp. 841-844.
Kanellaidis G. (1999). Aspects of Road Safety Audits, ASCE Journal of Transportation Engineering, Vol. 125, No. 6, November/December, pp.481-486.
Knoblauch, R., Nitzburg,& M., Seifert, R. (1997). *An Investigation of Older Driver Freeway Needs and Capabilities*, Federal Highway Administration, McLean VA.
Lundberg, C., Johansson, K., Ball, K., Bjerre, B., Blomqvist, C., Braekhus, A., ... & Winblad, B. (1997). Dementia and driving: An attempt at consensus. *Alzheimer Disease & Associated Disorders*, *11*(1), 28-37.
Lunenfeld, H., & Alexander, A.(1990). *User's Guide to Positive Guidance* (3rd Edition). Report No. FHWA-SA-90-017. FHWA, U.S. Department of Transportation, Washington, DC.
Meng, A., ,& Siren A. (2012). Cognitive problems, self-rated changes in driving skills, driving-related discomfort and self-regulation of driving in old drivers. *Accident Analysis and Prevention 49,* 322– 329.
O'Connor, M. L., Edwards, J. D., Wadley, V. G., & Crowe, M. (2010). Changes in mobility among older adults with psychometrically defined mild cognitive impairment. *Journal of Gerontology: Psychological Sciences, 65(B)*(3), 306-316.
O'Connor, M., Edwards, J. D., & Bannon, Y. (2013). Self-rated driving habits among older adults with clinically-defined mild cognitive impairment, clinically-defined dementia, and normal cognition. *Accident Analysis and Prevention, 61*, 197-202.
OECD/ITF, (2008). *Towards Zero: Ambitious Road Safety Targets and the Safe System Approach*.
Okonkwo, O. C., Griffith, H. R., Vance, D. E., Marson, D. C., Ball, K. K., & Wadley, V. G. (2009). Awareness of functional difficulties in mild cognitive impairment: a multi-domain assessment approach. *Journal of the American Geriatric Society, 57*(6), 978-984.
Petersen, R. C., & Morris, J. C. (2005). Mild cognitive impairment as a clinical entity and treatment target. *Archives of Neurology*, *62*(7), 1160-1163.
Sims, R. V., McGwin Jr, G., Allman, R. M., Ball, K., & Owsley, C. (2000). Exploratory study of incident vehicle crashes among older drivers. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *55*(1), M22.
Staplin, L. (2012) Choosing Among Measures of Driver Cognitive Status that Predict Crash Risk. Maryland Older Driver Symposium, May 2012.
Staplin, L., Lococo, K. H., Gish, K. W., & Decina, L. E. (2003). *Model driver screening and evaluation program, final technical report. Volume II: Maryland Pilot Older Driver Study* (No. HS-809 583,). Washington, DC: National Highway and Traffic Safety Administration.
Staplin, L., Lococo, K., & Byington, S. (2001). "Older driver highway design handbook". Federal Highway Administration, Mc Lean ,VA.
Vardaki, S.,& Karlaftis, M. G. (2011). An investigation of older driver road safety perceptions and driving performance on freeways. *Advances in Transportation Studies (Special Issue 2011)*, 7-18.
Vardaki, S., Yannis, G., Antoniou C., Pavlou, D., Beratis, I., Papageorgiou S., (2015*). Do simulator measures improve identification of older drivers with*

MCI?. Paper presented at the 94th Annual meeting of the Transportation Research Board, Washington.

Wadley, V. G., Okonkwo, O., Crowe, M., Vance, D., Elgin, J., Ball, 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. doi: 10.1177/0891988708328215

Yannis, G., Golias, J., Antoniou, C., Papadimitriou, E., Vardaki, S., Papantoniou, & P., Economou, A. (2013) *Design of a large driving simulator experiment on performance of drivers with cerebral diseases*. Paper presented at Road Safety and Simulation RSS013 International Conference, Rome.