CAN DRIVING AT THE SIMULATOR "DIAGNOSE" COGNITIVE IMPAIRMENTS?

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ABSTRACT

There is increasing concern and interest about the association of cognitive impairments and driving performance among the elderly, and several recent studies have identified significant driving performance deficits in cognitively impaired older people, measured by means of changes in driving simulator metrics. In this paper, it is attempted to reverse the question: can driving at the simulator reveal the presence of cognitive impairments? This question has a two-fold interest: first, driving at the simulator may allow for the detection of subtle changes in driving due to cognitive impairments imperceptible in one's daily routine; and second, driving simulators may have potential of becoming in the future useful tools for the screening of older individuals and assist clinicians both in the medical examination and the advice on whether to continue driving. Data from a large interdisciplinary driving simulator study were analyzed by means of discriminant analysis techniques, in order to classify individuals as healthy or cognitively impaired on the basis of their simulated driving performance. The analysis sample included 86 individuals, out of which 38 patients with Mild Cognitive Impairment (MCI) and 21 patients with Alzheimer's disease (AD). The results suggest that variables discriminating between healthy and impaired individuals are average speed and headway, lateral position variability, throttle position, reaction time and accident occurrence at incidents. The functions developed correctly classified more than 65% of the individuals, a share that dropped to around 60% when cross-validation analysis was implemented. Overall, although MCI and AD patients had significant shares of misclassified cases, these misclassifications were mostly between the one pathology and the other; very few pathological cases were classified as healthy, and all of these concerned MCI patients. It is indicated that driving at the simulator may under certain conditions assist in the screening for cognitive impairments.

Key-words: driving simulator; cognitive impairments; MCI; Alzheimer's disease; discriminant analysis.

BACKGROUND AND OBJECTIVES

Numerous studies have associated cognitive impairments among the elderly with driving performance. Particular focus has been placed on Alzheimer's disease (AD), and Mild Cognitive Impairment (MCI), i.e. the prodromal stage of many neurodegenerative diseases, with prevalence estimated at least 10% among the elderly (*1*). The main purpose of these studies was to assess fitness-to-drive and identify specific driving performance deficits and risks due to the disease and the related cognitive impairments, following a formal diagnosis on the basis of clinical, neurological and neuropsychological assessments.

Existing results have been largely consistent, with cognitively impaired people driving at lower speeds, with increased variability in vehicle lateral position and / or wheel steering angle, difficulties in operating the gearbox, increased driving errors and violations, and slower reaction time at incidents and / or brake response (*2, 3, 4*).

In this paper, the question is reversed: can driving at the simulator assist in the screening for cognitive impairments, towards their diagnosis? In order to address with question, the simulated driving performance of 86 drivers aged older than 55 years (out of which 27 healthy controls, 38 MCI patients and 21 AD patients) was associated with their clinical diagnosis, in order to attempt to classify the drivers into healthy or cognitively impaired groups on the basis of their driving performance.

LITERATURE REVIEW

Cognitive and driving impairments are strongly interrelated, with critical impact on the mobility and quality of life of older individuals. A considerable amount of research is devoted to the degree to which cognitive impairments affect driving, ranging from mild impairments (MCI) and pre-dementia conditions, to dementing diseases, stroke, cerebrovascular disease, Parkinson's disease etc.

Mild Cognitive Impairment (MCI), which is the prodromal stage of several dementing diseases, has prevalence in persons older than 65 years of age ranging from 10% to 20% (depending on the population studied and on the diagnostic criteria utilized) (*1*); however, its effect on driving ability has received less attention compared to other clinical groups, and is a critical issue for further research (*2, 4*). Existing studies also indicate driving difficulties in several driving performance measures and more errors between AD patients and cognitively intact individuals (*5, 6, 7, 8, 9, 10*).

More specifically, the relationship between cognitive impairments and driving risks so far has mainly been investigated in on-road tests or driving simulators (*11*). Results clearly establish that drivers with cognitive impairments may drive at – often dangerously – lower speeds, have difficulty in positioning the vehicle on the lane and maintaining that position, may have slower reaction time at unexpected events, may be more vulnerable to complex driving environments and more affected by in-vehicle or external distraction (*12*), may conduct more driving errors and unintentional traffic violations etc. (*13*). However, older drivers with cognitive impairments are often capable of self-regulating to some extent, and their driving impairments are partly balanced by their reduced exposure (driving), especially in demanding conditions (e.g. avoidance of motorways, night-time driving etc.) and the lower speeds (*14*).

It is suggested that preclinical dementia may have subtle cognitive and functional effects, which could combine to impair complex behaviors such as driving. Several researches underline that emphasis should be placed on the early – and often preclinical – stages of the diseases, where cognitive impairments may be imperceptible in one's daily routine, and undetectable with routine medical screening tools, yet already affecting driving ability (*15*). In a recent study (*16*), for instance, a composite score reflecting psychometric functioning was

unassociated with the number of on-road driving errors, but AD biomarker patterns were identified and associated with these driving errors, suggesting the presence of AD pathology which would not be identified through standard tools. Consistent with this idea, postmortem studies of the brains of asymptomatic older drivers who were killed in car accidents found that many had underlying AD neuropathological changes (*17*).

Another recent study (*18*) presented an exploratory analysis of the extent to which differences between drivers with mild cognitive impairment and controls on a sign recall task in a fixed-base driving simulator could better predict whether a driver will be diagnosed with MCI, compared to self-reports of a decrease in driving proficiency or of avoidance of driving, or age alone. However, neither recall scores, nor self-reported frequency of avoiding driving, nor driver age predicted a clinical diagnosis of MCI, and only self-reported decline in global driving ability was significant.

Nevertheless, recent medical and neuropsychological research, underlines that there is strong need for identifying sensitive tools to measure cognitive and functional changes in the early stages, and although some have cautioned that it may not be feasible to assess functional impairment at the earliest stages of the disease, the results suggest that driving tests on the road or through simulation, may eventually provide such a measure. A driving simulation test in particular, although often criticized for lacking the fidelity required for generalizing the results with respect to driving performance (*19*), might provide more detailed information on the types and importance of driving errors and could be repeated in other settings and with other samples (*16*).

DATA COLLECTION

This research was implemented by an interdisciplinary team including transportation engineers of the Department of Transportation Planning and Engineering, of the National Technical University of Athens (NTUA), as well as neurologists and neuropsychologists of the University of Athens Medical School, at ATTIKON University General Hospital. The study was approved by the Ethics Committee of the "ATTIKON" University General Hospital. Informed consent was obtained from all individuals studied.

This large scale study had multiple objectives, namely testing the driving behavior of different age groups, including young, middle-aged and older people, with emphasis and over-sampling of older people, both cognitively impaired and healthy. The total sample consists of 317 participants, out of which 105 were cognitively impaired older individuals. The diseases diagnosed included mostly (75%) MCI, AD and Parkinson's disease, as well as a small share on frontotemporal dementia (FTD), stroke, sleep disorders (RBD), multiple sclerosis (MS), depression etc.). All participants were recruited among patients of the 2nd Department of Neurology of the University of Athens Medical School at ATTIKON University General Hospital.

Sampling frame

For the purposes of the present analysis, a sample of 86 individuals aged >55 years old was selected from the total sample, including the respective healthy controls (27 individuals), the MCI (38 individuals) patients and the AD patients (21 individuals) explicitly diagnosed by the neurology / neuropsychology research teams. PD patients were excluded as in most cases they did not present significant cognitive impairments; similarly, the remaining patients formed a rather heterogeneous group of pathologies and were excluded to allow for a more focused analysis.

In total, 59 of the participants were males and 25 were females. The gender distribution of the control group was balanced, but males were over-represented in the MCI group and there were no females in the AD group. Moreover, the mean age of the control group was 65 years, while for the MCI and the AD groups the mean age was 70 and 75 years respectively. Females had slightly lower mean age in all groups, with the same general trend of increasing age with the presence of pathology (see Figure 1). It is noted that the distributions of gender and age groups in this sample are representative of the prevalence of these pathologies in the general population (*1*).

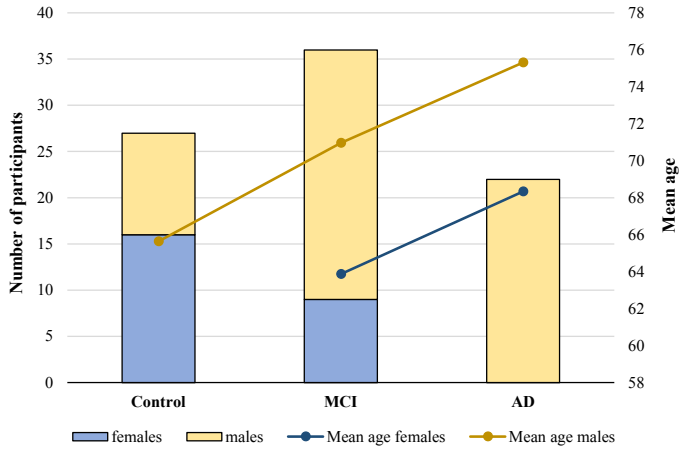

FIGURE 1 Sample size, gender and age of MCI, AD and healthy controls

Medical and neuropsychological assessment and diagnosis

A first assessment of the participants concerned the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of their disorders as well as other related parameters of potential impact on driving (e.g. use of medication affecting the Central Nervous System).

A second assessment concerned the administration of a series of neuropsychological tests and psychological-behavioral questionnaires to the participants. The battery used covers a large spectrum of Cognitive Functions: visuospatial and verbal episodic and working memory, general selective and divided attention, reaction time, processing speed, psychomotor speed, mental flexibility and task shifting etc. and included in total 13 tests (e.g. Mini Mental State Examination, Clock Drawing Test, Semantic and Phonemic Fluency, Symbol Digit Modalities Test - Written & Oral, Hopkins Verbal Learning Test-Revised, Trail Making Test etc.) - for a detailed description the reader is referred to (*20*).

The driving assessment was carried out once the sample was classified into the 3 groups by the neurological and neuropsychological teams (AD, MCI or control group), on the basis of their diagnosis. All MCI patients had Clinical Dementia Rating (CDR) = 0.5 and all AD patients had CDR=1.0.

Driving Simulator assessment

The NTUA driving simulator is a dynamic quarter-cab and consists of 3 wide screens 40’’, driving position and support motion base. The dimensions at a full development are

230x180cm, while the base width is 78cm and the total field of view is 170 degrees. The simulator is validated against a real world environment, with satisfactory relative validity as regards gender, age groups and area type i.e. urban or rural (*21*).

Patients were to carry out the simulator experiment while under their usual medication. The driving simulator experiment started with a practice drive on the basis of several quantitative and qualitative criteria of familiarization with the simulator (usually 10-15 minutes). Afterwards, all participants drove two sessions (approximately 20 minutes each). Each session corresponded to a different road environment: a rural route (single carriageway, lane width 3m, zero gradient and mild horizontal curves) and an urban route (dual carriageway, separated by guardrails, lane width 3.5m, narrow sidewalks, commercial uses and roadside parking).

In each road environment, there were 6 trials, under different traffic and cognitive workload conditions. More specifically, traffic conditions tested included low traffic (ambient vehicles' arrivals corresponding to an average traffic volume Q=300 vehicles/hour, i.e. drawn from a Gamma distribution with mean m=12sec, and variance σ^2=6 sec,) and high traffic (ambient vehicles' arrivals corresponding to an average traffic volume of Q=600 vehicles/hour, i.e. drawn from a Gamma distribution with mean m=6sec, and variance σ^2=3 sec), whereas cognitive workload conditions tested included undistracted driving, conversation with passenger and mobile phone conversation. It is noted, however, that most of the participants aged >55 years old reported that they never used their mobile phone while driving and preferred not to use it during the simulator experiment.

During each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive. More specifically, incidents in rural area concerned the sudden appearance of an animal (deer or donkey) on the roadway, and incidents in urban areas concerned the sudden appearance of an adult pedestrian, or of a child chasing a ball on the roadway. The hazard appeared at the same location for the same trial (i.e. rural area, high traffic) but not at the same location between the trials, in order to minimize learning effects. The moment that the hazard appeared was defined on the basis of both the simulator vehicle speed and the time to collision in order to have identical conditions for each participant as regards available reaction time (i.e. no possibility for the incident to appear more closely or more suddenly to one participant than to another).

In this research, the driving data of the rural area drive low traffic and undistracted condition are used for the analysis, being the least demanding condition in terms of road environment and participants' mental workload.

ANALYSIS METHODOLOGY

Research hypotheses

Previous analyses of the experiment data revealed several driving deficits of cognitively impaired older people. MCI and AD patients in particular were found to drive at lower speeds and with increased headways from the leading vehicle, have longer reaction time and accident risk at unexpected incidents, drive at lower gearbox position and with increased engine rounds per meter (rpm), make more errors (e.g. unintentional lane departures, sudden braking, engine stops etc.) (*13*). These results are exploited in the present research in order to investigate whether driving simulator measures can predict the presence of cognitive impairments.

Two research hypotheses are tested, as follows:

- A "conservative" hypothesis is first examined, aiming to test whether the simulator may be a screening tool for the presence of cognitive impairments in general, so that further

medical and neuropsychological tests may diagnose a specific pathology (MCI, AD or other).

- A more ambitious hypothesis, aims to test whether driving at the simulator may identify different pathologies; although from a medical viewpoint, it is hardly pertinent or meaningful to attempt to identify specific pathologies from the driving simulator data, previous analysis results suggest that there are different driving deficits associated with different pathologies, and consequently it may be easier to identify specific conditions.

Discriminant Analysis

A discriminant analysis technique was used for the purposes of this research, which uses a linear combination of predictors that characterizes or separates two or more classes of objects or individuals, and explicitly attempts to model the difference between the classes. Discriminant analysis is broken into a 2-step process: first, testing significance of a set of discriminant functions, and second, classification of individuals. The first step is computationally identical to MANOVA. One first performs the multivariate test, and, if statistically significant, proceeds to see which of the variables have significantly different means across the groups.

The discriminant function coefficients denote the unique contribution of each variable to the discriminant function, while the structure coefficients denote the simple correlations between the variables and the functions. The discriminant function score for the i^{th} function is:

$$D_i = \sum_{i=1}^{p} d_i Z_i \qquad (1)$$

Where Z is the score on each predictor, and d_i is the discriminant function coefficient. Once the discriminant functions are determined and groups are differentiated, the utility of these functions can be examined via their ability to correctly classify each data point to their a priori groups. Classification functions are derived from the linear discriminant functions to achieve this purpose. For unequal sample sizes n_j in each group the classification function has the following form:

$$C_j = c_{j0} + \sum_{i=1}^{p} c_{ij} x_i + ln\left(\frac{n_j}{N}\right) \qquad (2)$$

for the j^{th} group, $j = 1...k$, x are raw scores of each predictor, c_{jo} is a constant and N the total sample size.

In this paper, the medical diagnosis was used as the dependent variable and the simulator driving performance measures with proved association with cognitive impairments were used as independent variables. Previous research with this dataset, as well as existing results from other related studies, were used to select the independent variables among the numerous simulator variables. The independent variables tested included:

- Average speed
- Speed variability (StdSpeed)
- Mean Lateral position (LateralPositionAverage)
- Lateral position variability (StdLateralPosition)
- Gearbox position (GearAverage)
- Gearbox Position Variability (StdGearAverage)
- Engine rounds per meter (RpmAverage)
- Engine rounds per meter variability (StdRpmAverage)
- Mean headway from lead vehicle (HWayAverage)

- Steering angle (WheelAverage)
- Steering angle variability (StdWheelAverage)
- Number of engine stops (EngineStops)
- Number of hits of roadside bars (HitOfSideBars)
- Number of lane departures (OutsideRoadLines)
- Number of sudden brakes (SuddenBrakes)
- Number of speed limit violations (SpeedLimitViolation)
- High engine rounds per meter (HighRoundsPerMinute)
- Reaction time at first unexpected event (ReactionTime1)
- Accident occurrence at first unexpected event (Acc.Prob.1)

In addition to these simulator metrics, the participant's age was included in the independent variables, to control for the positive relationship between age and pathology, which was also identifiable through the sampling process.

RESULTS

Identification of cognitive impairments

As a first step of the analysis, the conservative hypothesis was tested. For that purpose, cognitively impaired individuals were grouped together and were tested against healthy controls. The Wilks' lambda test of equality of group means suggested that the only variables that significantly distinguished impaired from healthy individuals were age and reaction time at incidents, which were consequently the only variables retained in the discriminant function. This result suggested that the simulator metrics did not add to the identification of cognitive impairments in general, since reaction time may be directly measured by several neuropsychological tests.

Identification of MCI or AD patients

Next it was examined whether simulator metrics may identify cognitive impairments specifically due to MCI or AD pathologies. In this case, the dependent variable had three groups (controls, MCI and AD) and therefore two discriminant functions are estimated (the number of discriminant functions examined is equal to the number of groups minus 1; however, some discriminant dimensions may not be statistically significant.). The Wilks' Lambda and F-tests for equality of group means presented in Table 1 suggest that the variables most likely to discriminate groups are average speed, gearbox position, mean headway, reaction time at incident, accident occurrence at incident, and age. Lateral position variability and the number of sudden brakes are also marginally significant at 90% confidence level.

TABLE 1 Tests of equality of group means (MANOVA) for the simulator metrics

	Wilks' Lambda	F	df1	Sig.
Age	,761	13,042	2	,000*
AverageSpeed	,870	6,184	2	,003*
StdevAverageSpeed	,961	1,666	2	,195
LateralPositionAverage	,968	1,378	2	,258
StdLateralPosition	,948	2,286	2	,108
GearAverage	,840	7,909	2	,001*
StdGearAverage	,974	1,089	2	,341
RpmAverage	,999	,059	2	,942
StdRpmAverage	,998	,069	2	,934
HWayAverage	,910	4,093	2	,020*
WheelAverage	,987	,555	2	,576
StdWheelAverage	,990	,399	2	,672
EngineStops	,973	1,158	2	,319
HitOfSideBars	,997	,114	2	,892
OutsideRoadLines	,974	1,095	2	,339
SuddenBrakes	,957	1,874	2	,160
SpeedLimitViolation	,972	1,214	2	,302
HighRoundsPerMinute	,994	,255	2	,775
ReactionTime 1	,781	11,634	2	,000*
Acc.Prob.1	,906	4,314	2	,017*

* Statistically significant at 95% confidence level

On the basis of these significant and marginally significant variables, the discriminant functions were estimated. The best performing model was selected on the basis of both the discriminant function performance and the classification results. In that model, lateral position variability was retained being significant at 90%, while the number of sudden brakes was removed. Table 2 shows the quality of the discriminant functions; function 1 explains 88% of the total variance and significantly differentiates the groups, as suggested by the Wilks' Lambda test. Function 2 does not appear to significantly further discriminate between groups, as suggested by the Wilks' Lambda test and is therefore redundant.

TABLE 2 Eigenvalues and Wilks' Lambda tests of canonical discriminant functions.

Function	Eigenvalue	% of Variance	Wilks' Lambda	Chi-square	df	Sig.
1	,687a	87,9	,541	49,091	14	,000
2	,095a	12,1	,914	7,233	6	,300

Table 3 presents the discriminant functions coefficients and the respective structure matrix (i.e. the pooled within-groups correlations between the variables and the discriminant function). The latter is to be interpreted in the same way that factor loadings are interpreted in a factor analysis, and therefore it is observed that age, average speed, gearbox position, reaction time

and accident occurrence at incidents are strongly correlated with discriminant function 1, while mean headway and lateral position variability are strongly correlated with discriminant function 2.

TABLE 3 Canonical discriminant function coefficients (left panel) and structure matrix (right panel)

	Coefficients		Correlations (structure matrix)	
Variables	Function 1	Function 2	Function 1	Function 2
Age	,492	-,844	,645*	-,546
AverageSpeed	-,497	-,348	,636*	,156
GearAverage	-,293	-,035	-,525*	-,116
ReactionTime 1	,396	,008	-,465*	-,025
Acc.Prob.1	,103	,544	,379*	,023
HWayAverage	-,138	,048	,353	,442*
StdLateralPosition	,268	,644	,231	,440*

*Largest absolute correlation between variable and any discriminant function

The classification function was estimated, with prior classification probabilities derived on the basis of the initial group sizes. Classification results are presented in Table 4. In total, the model correctly "diagnosed" 65.1% of all drivers, i.e. 67% of healthy controls, 68% of MCI patients and 57% of AD patients - it is noted however that another 38% of AD patients were misclassified as MCI, indicating that the pathology is highly identifiable also for this group, although not to its full extent. These results seem promising and suggest that driving simulator metrics may reveal cognitive impairments with driver age controlled for.

It is well known, however, that these classification results are an overestimation of the actual potential of the model, as the classification is made on the same cases that were used to develop the model. A cross-validation analysis is presented in the next section to assess this effect.

TABLE 4 Original vs. predicted group membership classification results

			Predicted			
		Diagnosis	Control group	MCI	AD	Total
Original	Count	Control group	18	8	1	27
		MCI	10	26	2	38
		AD	1	8	12	21
	%	Control group	66,7	29,6	3,7	100,0
		MCI	26,3	68,4	5,3	100,0
		AD	4,8	38,1	57,1	100,0

Cross-validation

Cross-validation was done in two steps; results are presented in Table 5. First, a leave-one-out classification was carried out, in which cases are classified with the discriminant function estimated on the basis of all other cases except this one. This provides a "correction" of the classification results. It is indicated (see top panel of Table 5) in this case that 59% of healthy controls are correctly classified (another 37% is falsely classified as MCI), 63% of MCI are correctly classified (another 10.5% is falsely classified as AD) and 47.6% of AD are correctly classified (another 47.6% is falsely classified as MCI).

As a second step, the sample was split in two parts, on the basis of a random (Bernoulli) case selection process: a part of the sample (70% of cases) was selected for developing the model, while the remaining 30% of the sample (i.e. 5 controls, 14 MCI and 6 AD) was kept for prediction on the basis of the model developed. The results (see bottom panel of Table 5) show that the share of correct classification dropped for all groups, which was expected both because of the smaller sample used to develop the discriminant function, and the removal of the bias in the classification. In this case, 60% of controls, 43% of MCI and 33% of AD patients are correctly classified. Nevertheless, even in this case 71.5% in total of MCI patients are classified as cognitively impaired (either as MCI or as AD) and all AD patients are classified as cognitively impaired. Moreover, none of the control group are classified as AD.

TABLE 5 Model cross-validation - Original vs. predicted group membership classification results - leave-one-out classification (top panel), unselected cases (top panel).

Observed		**Diagnosis**	**Predicted**			Total
			Control group	MCI	AD	
Leave-one-out cross-validation*	Count	Control group	16	10	1	27
		MCI	10	24	4	38
		AD	1	10	10	21
	%	Control group	59,3	37,0	3,7	100,0
		MCI	26,3	63,2	10,5	100,0
		AD	4,8	47,6	47,6	100,0
Unselected cases**	Count	Control group	3	2	0	5
		MCI	4	6	4	14
		AD	0	4	2	6
	%	Control group	60,0	40,0	,0	100,0
		MCI	28,6	42,9	28,6	100,0
		AD	,0	66,7	33,3	100,0
*.Each case is classified by the functions derived from all cases other than that case.						
**. 30% of the initial sample not used to derive the functions.						

DISCUSSION

The results of the discriminant analysis model development and validation did not support the conservative research hypothesis that it would be easier (and more appropriate for a medical

viewpoint) to attempt to identify the presence of cognitive impairment in general rather than distinguish different pathologies. A model simply distinguishing healthy from impaired individuals did not achieve satisfactory performance, and the only variables that were found to discriminate were age and reaction time, not providing added value to what would be already known from basic medical screening of those individuals.

The more ambitious analysis attempting to discriminate between MCI and AD pathologies rather surprisingly resulted in more robust models and satisfactory classification of individuals. This may be attributed to the fact that these different pathologies present different driving deficits: lower speed, slower reaction times and lower gearbox position are common trends, but the effects are more pronounced on MCI patients than on AD patients, while longer headways and increased lateral position variability are more specific to AD patients. Consequently, the explicit separation of pathologies allowed for the contributions of different simulator variables to the classification be more easily identified.

In this case, the classification results are encouraging, even when correcting for case selection bias. On the other hand, the classification results leads to returning to the conservative hypothesis: it is not possible and meaningful to use the classification results for "diagnosis", as only 50-60% of all cases are accurately classified. However, the misclassification occurs almost exclusively between "neighboring" groups, e.g. MCI classified as AD or vice-versa, healthy classified as MCI. Consequently, the model may be most useful for a general classification in cognitively impaired or not, with only an indication of specific pathology.

Therefore, the potential of identifying ("diagnosing") cognitive impairments through a driving test alone appears to be significant. It is noted that no cognition measurements while driving (e.g. memory, recall, recognition, attention) were included in this analysis; a recent research on the potential of using such cognitive tasks in a driving simulator study to predict cognitive impairments did not find significant effects (*18*). On the contrary, the "diagnoses" obtained in this research were based on driving performance measures and errors alone. It is underlined however that the experiment used in this research was not designed to help identify cognitive impairments, but to assess the driving performance of individuals with a known diagnosis. This analysis attempted to reverse the question and the results are encouraging that a more focused driving test with an even larger sample might provide more insights.

CONCLUSION

This paper aimed to address the need for early detection of cognitive and driving impairments, by further exploring their correlation and their potential identification towards a medical screening diagnosis. There is increasing interest in such early detection tools, especially as it has been found that cognitively impaired individuals are often asymptomatic but their driving performance is very sensitive to this early onset of the diseases.

The results from using driving simulator metrics and individual age to discriminate between healthy and cognitively impaired individuals under moderate traffic conditions suggest that driving performance measures that successfully classify drivers are average speed, headways, lateral position variability, incident reaction time, accident occurrence at incidents, and gearbox position. The discriminant functions correctly "diagnosed" nearly 65% of all drivers, with better rates for healthy or MCI drivers - it is noted however that the presence of pathology was highly identifiable, as most misclassifications were between the one pathology group and the other.

This paper of course does not suggest that driving at the simulator may substitute the formal medical and neuropsychological examination that is required for diagnosis. It is suggested that driving at the simulator may provide useful insight as per the driving

performance of older people, and as per their cognitive state through the observable driving performance deficits (which are due to their cognitive decline).

There is promising indication that the simulator may under certain conditions be used as a "neuropsychological tool" revealing the presence of cognitive impairments and guiding to further formal testing towards a diagnosis. Given that driving requires several cognitive skills, the development of dedicated simulator tests allowing to examine specific cognitive domains critical for safe driving but also associated with highly prevalent pathologies - often undetectable in their early stages - might have a two-fold added value to assist clinicians, both in the screening and examination process and in the provision of more targeted and substantiated advice as regards driving.

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