DRIVER FITNESS IN PATIENTS WITH COGNITIVE IMPAIRMENT AND GLAUCOMA

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Summary: Recent evidence suggests a relationship between cognitive impairment and glaucoma. Whether impaired visual perception in glaucoma contributes to reduced cognitive function in patients with dementia, or cognitive impairment further limits visual perception due to optic nerve damage in glaucoma is unclear. One objective of this study was to see if there were significant differences on measures of perceptual, cognitive and driving performance between older drivers with cognitive impairment and/or glaucoma who still had good visual acuity. A second goal was to measure the strength of association between measures of visual, cognitive, and driving performance. 302 older drivers were classified as having glaucoma alone (n=69), cognitive impairment alone (n=41), both (n=21) or neither (n=171). All participants had good visual acuity, a valid drivers license and were still driving. Demographic, health status, driving accidents and clinical tests of vision and driving performance variables were analyzed using one-way ANOVAS and Pearson correlations. Across demographic, clinical and driving measures there were significant differences between those with cognitive impairment, with or without glaucoma, and controls. Subjects with glaucoma showed significant differences with controls on accidents, driving simulation tests of divided attention and car following delay. Driving simulator and UFOV measures were significantly correlated with self reported accidents. Driving simulation is a valid way to evaluate task performance and may be a more sensitive and salient method of detecting the additive and/or interactive effects of glaucoma and cognitive impairment in older drivers than vision and neuropsychological tests alone.

INTRODUCTION

The older driver population is projected to double by the year 2030, and the prevalence of glaucoma estimated to double by 2020 (Quigley), placing an increasing burden on physicians and other care providers to assess and counsel older drivers about driver safety. As the population ages the demand to assess driver fitness will dramatically increase. In the U.S. and globally, driving has become essential to maintaining mobility and independence in older drivers. Loss of driving privileges can lead to poor economic, health and quality of life outcomes (Fonda). Further, glaucoma and cognitive impairment are two of the most prevalent conditions in older drivers and significantly increase the risk of injurious crashes and death (Owsley, Johnson, Haymes, Szlyk and Dawson, Rizzo, 2009). The primary risk factor for glaucoma and AD is age.

There is increasing evidence of a relationship between Glaucoma and AD, but it is unclear how they might interact. They can share similar mechanisms for neuronal degeneration: Abeta protein plaques and fibrillary tangles found centrally in the brain in AD are also found in the optic nerve and retina in glaucoma, suggesting that a similar biological mechanism may underlie both diseases (Kirby). Additionally, it has been suggested that visual impairment seen in AD may be due to some AD patients having undiagnosed glaucoma. Recent research has found that damage from glaucoma can extend to the lateral geniculate nucleus and visual cortex (Yucel, Kirby). Visual impairments in Alzheimer's disease can also occur at the level of the brain in sub-cortical visual association areas involving contrast sensitivity, visual motion, memory and depth perception (Rizzo). Combined, these findings suggest that glaucoma could account for some of the visual deficits seen in AD patients. Alternatively, Alzheimer's disease may explain unexpected visual impairment in some glaucoma patients, (progressing visual field loss without corresponding optic nerve changes) with low intra-ocular pressures and good visual acuity (Valenti). Whether impaired vision leads to reduced cognitive abilities or reduced cognition results in impaired visual perception, will need further investigation.

Although vision is essential for driving (Rizzo), it is not clear which vision skills and tests are actually more closely related to the ability of driving safely (Medeiros). Despite visual acuity being the most commonly tested visual parameter for licensure by motor vehicle departments, most studies have found no or only a weak association between visual acuity and automobile crash rates (Medeiros). This clearly indicates the need for a more comprehensive evaluation of visual performance as it relates to driving ability. Further, the interaction of co-morbidities on task performance is infrequently studied. Therefore, the first objective of this study was to see if there were significant differences on measures of perceptual, cognitive and driving performance between older drivers who still have good visual acuity, with cognitive impairment and/or glaucoma, and controls. The second objective was to measure the strength of association between measures of vision, cognition, driving performance and behind the wheel accidents.

METHODS

Participants

All subjects for this study were recruited consecutively from community dwelling patients coming for a routine ophthalmology office visit with binocular LOGMAR visual acuity better than 20/40 or better, who were 65 years of age or older, still driving with a valid drivers license and were willing to participate in the study. Participants were recruited until we had a sample size of 30 driving subjects still driving over the age of 85. 302 older drivers were eligible for inclusion and this sample size was estimated to be large enough to provide sufficient numbers of patients with glaucoma and cognitive impairment. Exclusions excluded patients with severe receptive aphasia that would prevent them from understanding test instructions. Patients with an attack of epilepsy in the last six months or a stroke in the last six months with a complete homonymous hemianopia or severe neglect were also excluded.

Measures

Psychophysical measures. LogMAR visual acuity, Pelli-Robson contrast sensitivity, Randot Stereo Acuity, and Useful Field of View.

Cognitive/neuropsychological measures. Mini-Mental State Exam, Benton Visual Retention Test – working memory (BVRT), Trails Making A&B – visual search, executive functioning, and the Stroop Color Word Test – divided attention, working memory, executive functioning, and tests for neglect such as line cancellation and line bisection. These tests were chosen because they have been frequently correlated with driving performance.

Self-Report measures. Visual Analogue Scales for general health perception, visual health perception and difficulty driving, and number of accidents, falls and hospitalizations in past 12 months.

Driving simulation and behind the wheel measures. Sim Score and BTW (pass or fail).

Table 1. Measures and cut-points for tests of impairment

Measures	Impairment Cut-points
Psychophysical tests	
Visual acuity (logMar)	logMAR 0.4 or better
Contrast sensitivity (log_{10} units)	Log10 =/<1.34
Stereo acuity (degrees)	<100 degrees
Visual processing speed (milliseconds)	>100ms
Divided attention (milliseconds)	>350ms
Vision-dependent NP tests*	
Benton Visual Retention Test (score, 1-10)	>6 errors
Stroop Color Word Test (seconds)	<20 correct
Trails A Test (seconds)	>60 seconds
Cognitive test	
Mini-Mental State Exam (score, 1-30)	Score <25
Falls (number)	>2/yr
Driving** (self report)	
Accidents (average per group)	>1 in 12 months
Difficulty with driving (score, 1-10)	Score >7
Driving simulator- Sim Score	pass/fail, component simulator tasks
Road test	pass/fail

Driving Simulator Apparatus. A fixed-base simulator powered by a STISIM Drive System (version 1.03; Systems Technology Inc., Hawthorne, CA) and ECCI Track Star 6000 wheels and pedals (Extreme Competition Controls, Inc. Minneapolis, MN) was used. The high fidelity system contained a “Scenario Definition Language” which rendered and updated (60 Hz) an interactive 10-mile driving scenario that took about 10-12 minutes to complete. Computer generated images were projected on to a screen (approximately 52" x 39”) with a visual angle of 65° and a viewing distance of approximately 44". We simulated a two-lane road in a rural-like setting in which car following, divided attention, reaction time and lane departure events were captured.

On-road Assessment. All subjects completed an on-road driving test utilizing the standardized road test used by the California Department of Motor Vehicles (DMV) administered by a Certified Driving Rehabilitation Specialist (CDRS). Traffic maneuvers include turning, crossing intersections, changing lanes, and driving on freeways. The examiner rated whether maneuvers were completed unsatisfactorily, and if so the way in which the performance was unsatisfactory (e.g., inadequate traffic check) and degree of risk (safe or unsafe). Examiner evaluations provided a "global" "pass/fail" rating score based on whether driving maneuvers were completed satisfactorily and in a risky or unsafe manner.

Data analysis. Descriptive statistics, one way-ANOVA and Pearson correlations were used to analyze the data.

RESULTS

Demographic data

Study participants consisted of 302 older drivers with 20/40 or better visual acuity currently driving with a valid driver's license. 38.4% of drivers were 80 years of age or older and 9.9% was 85 or older. Of the 302 drivers, 52.7 were males. Caucasians comprised 65.2% of drivers, Hispanics 20.2%, African-Americans 5.0%, Asian-Pacific Islanders 8.3% and others 1.3%. 47.7% of drivers had some college education or more. 18.5% of drivers had 1 or more accidents. Age, ethnic diversity and education levels closely matched census data for the zip code in which the study was conducted. There were 69 subjects (22.8%) with glaucoma, but without cognitive impairment; 41 (13.6%) had some degree of cognitive impairment and no glaucoma; 21 (7.0%) had both cognitive impairment and glaucoma and 171 (56.6%) had neither condition.

One-way ANOVAs

One-way ANOVAs were used to see if there was a significant difference in performance between groups with glaucoma, cognitive impairment, both conditions and controls on various measures of health status, self-reported accidents, vision, neuropsychological and driver safety (see Table 2). Generally there were significant differences across most measures between groups with either cognitive impairment alone, or cognitive impairment and glaucoma, and controls. A marginally significant difference in self-reported General Health Status (GHP) was observed between those with both cognitive impairment and glaucoma, and controls ($F = 2.72$ 3,4 $p = .045$), whereas, self-reported visual heath perception (VHP) showed significant differences between those with glaucoma alone and those with cognitive impairment, with or without glaucoma ($F = 5.81$ (1,3 2,3 3,4 p.000) and controls. Performance on measures of vision, cognition and driver safety (driving simulation measures) showed significant differences between groups with conditions and controls when cognitive impairment or cognitive impairment combined with glaucoma was present (see Table 2). As expected, glaucoma subjects demonstrated significant differences on tasks of divided attention (UFOV $F = 43.76$ 1,4 p.000), (DAMRT $F = 50.17$ 1,4 p.000), (DACORR $F = 114.25$ 1,4 p.000). Results on the driving simulator measures for global pass/fail driving simscores ($F = 86.22$ 1,4 p.000) and Car Following delay (cfdelay $F = 48.26$ 1,4 p.000) also showed significant differences between glaucoma subjects and controls. Impaired performance on the Benton Visual Retention test for working memory, was the only test to

demonstrate an additive effect of glaucoma over cognitive impairment alone (F=60.18 2,3 p.000) Failure to demonstrate a significant difference between subjects with cognitive impairment alone and those with both cognitive impairment and glaucoma, was likely due to the small sample size of the group with both conditions. Differences in performance between groups on most measures of vision, cognition and some measures of driving simulator performance were both statistically significant, as well as, clinically relevant. Significant differences between glaucoma subjects and controls were only marginally significant for self reported accidents (F=24.24 1,4 p.08), which may be due to the small sample size of glaucoma patients with moderate to severe glaucoma.

Table 2. One-way ANOVAS between groups with Glaucoma, Cognitive Impairment, both conditions and neither condition (control group)

Risk Factor	1-Glaucoma	2-Cog imp	3-Both	4-Neither	F	Sig.
Age and Self-reported Health Status, Falls and Accidents						
	n=69	n=41	n=21	n=171		
age	76.37 (6.16)	80.28 (6.10)	80.25 (6.79)	76.60 (5.94)	5.70 (1,2 1,3 2,4)	.001
ghp	7.71 (1.57)	7.25 (1.88)	6.62 (2.26)	7.69 (1.56)	2.72 (3,4*)	.045
vhp	7.19 (1.92)	7.02 (1.88)	5.28 (3.08)	7.31 (1.70)	5.81 (1,3 2,3 3,4)	.001
fallslev	0.63 (.90)	1.51 (.94)	1.37 (1.14)	0.53 (.96)	13.71(1,2 1,3 2,4, 3,4)	.000
accidents	0.29 (.63)	0.71 (.88)	1.06 (1.06)	.09 (.34)	24.24 (1,2 1,3 1,4** 2,4 3,4)	.000
Performance on Vision and Neuropsychological Abilities						
	n=69	n=41	n=21	n=171		
Va	0.18 (.10)	0.23 (10)	.27 (.09)	0.17 (.10)	8.72 (1,3 2,4 3,4)	.000
pelli	1.49 (.16)	1.40 (.16)	1.33 (.23)	1.53 (.14)	12.04 (1,2 1,3 3,4 4,2)	.000
vps	43.00 (70.54)	102.72(76.81)	124.51 (110.61)	26.41 (22.47)	34.12 (1,2 1,3 2,4 3,4)	.000
divattn	153.42 (120.47)	290.02 (141.91)	345.81 (117.81)	102.17 (108.08)	43.76 (1,2 1,3 1,4 2,4 3,4)	.000
mmse	27.43 (1.75)	22.46 (2.17)	22.00 (1.50)	27.52 (1.72)	125.92 (1,2 1,3 2,4 3,4)	.000
benton	5.40 (1.65)	2.58 (.93)	2.25 (.85)	5.73 (1.70)	60.18 (1,2 1,3 2,3 2,4 3,4)	.000
stroop	24.5$ (9.62)	15.53 (7.86)	15.25 7.97)	24.96 (11.87)	11.46 (1,2 1,3 2,4 3,4)	.000
trails	48.29 (19.24)	87.05 (42.42)	98.81 (67.40)	46.94 (33.19)	34.41 (1,2 1,3 2,4 3,4)	.000
Driving Performance – Behind the Wheel						
	n=13	n=6	n=7	n=12		
BTW	1.15 (.37)	1.50 (.54)	1.57 (.53)	1.25 (.45)	1.66	.192
Driving Performance – Driving Simulator						
	n=30	n=38	n=15	n=38		
simscore	1.20 (.40)	1.89 (.31)	1.93 (.25)	1.00 (.00)	86.22 (1,2 1,3 1,4 2,4)	.000
DAMRT	5.77 (1.39)	7.773 (1.05)	7.88 (1.08)	4.74 (1.20)	50.17 (1,2 1,3 1,4 2,4 3,4)	.000
DACORR	8.96 (2.39)	2.76 (2.23)	3.12 (2.96)	10.57 (1.03)	114.25 (1,2 1,3 1,4 2,4 3,4)	.000
SDLP	0.79 (.25)	1.26 (.28)	1.29 (.27)	0.84 (.26)	27.83 (1,2 1,3 2,4 3,4)	.000
CLXNUM	0.73 (.94)	2.05 (.86)	2.00 (1.25)	0.55 (.76)	23.84 (1,2 1,3 2,4 3,4)	.000
REENUM	0.48 (.91)	1.71 (1.11)	1.73 (1.22)	0.67 (.91)	12.091,2 1,3 2,4 3,4)	.000
rtmean	5.07 1.12)	6.27 (.66)	6.30 (.75)	4.64 (.65)	32.15 (1,2 1,3 2,4 3,4)	.000
cfmod	0.59 (.16)	0.21 (.08)	0.20 (.13)	.63 (.75)	100.94 (1,2 1,3 2,4 3,4)	.000
cfdelay	4.98 (.89)	6.24 (.94)	6.29 (.89)	3.94 (.89)	48.26 (1,2 1,3 1,4 2,4 3,4)	.000
cfcoher	0.52 (.14)	0.25 (.09)	0.24 (.15)	0.77 (.84)	8.55 (2,4 3,4)	.000

* .08; ** .07

Correlations

Correlations were done to measure the strength of association between different measures of driver fitness (see Figure 1) in older drivers. MMSE, falls, UFOV, simscore and individual driving simulator tasks were all significantly correlated with self-reported accidents. Consistent with previous studies by Owsley and others, visual acuity is only weakly correlated with accidents. In descending order, accidents are significantly correlated with visual processing speed, divided attention (driving simulator), divided attention (UFOV), MMSE, contrast sensitivity and visual acuity. In addition to divided attention, other component measures of driving simulation significantly correlated with accidents are tasks of lane position (center line crossing and standard deviation of lane position), divided attention and car following.

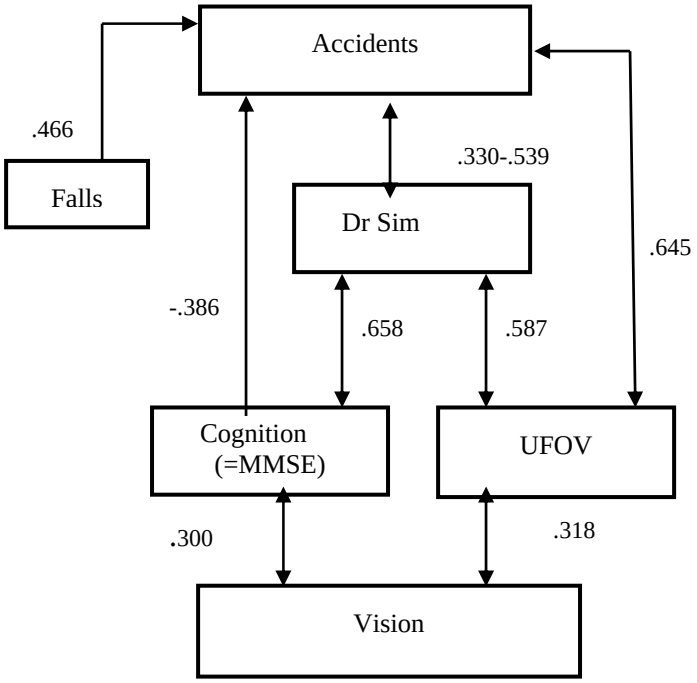

Figure 1. Predictive Model
(Pearson 2-tailed Correlations, p>.01 for all variables)

DISCUSSION

Cognitive impairment and glaucoma have a number of shared attributes, but impaired vision due to pathology in the central nervous system is one of the most important and underappreciated. The most likely mechanism in glaucoma is due damage to the optic nerve resulting in neural under sampling to the lateral geniculate nucleus and a diminished visual signal strength to the striate (V1) cortex and visually important sub-cortical areas (MT-V5). Patients with mild cognitive impairment (MCI), various stages of Alzheimer's disease (AD), Parkinson's disease and stroke have impaired vision mostly related to an impairment in "iconic" memory" and visual attention needed for rapid higher order visual processing (object identification and categorization). Other sub-cortical visual areas related to motion, contrast sensitivity and attentional switching are also involved in MCI and AD. Vision is a highly complex integrated brain function and patients with MCI, AD and glaucoma share specific driving-related visual

impairments including a loss of contrast sensitivity, diminished visual processing speed, impaired divided attention and visual search, a "contracted spotlight" of attention, delayed reaction times, impaired structure from motion and others. Although our data generally did not demonstrate a clear additive effect of impairments due to glaucoma on most non-driving simulator measures, simulator measures related to divided attention and delayed car following were sensitive enough to detect an effect due to glaucoma beyond cognitive impairment alone. Whether factors causing visual impairments in older drivers with MCI, dementia and glaucoma are interactive or are simply concurrent age-related changes each contributing to neuronal entropy is not clear. Either way, our results demonstrate that relating visual performance to task performance in may be a more sensitive and salient method of evaluating driver fitness. There were a number of limitations to this study, which might explain our results. The most important was the method of subject selection resulting in a relatively small sample size in the group with glaucoma only. Further, ninety-three % of the subjects with glaucoma had mild or moderate glaucoma. Severe glaucoma with better characterization of the size, depth, shape and location of visual field defects and information on optic nerve head anatomy and nerve fiber layer loss will be needed in future research. Better definitions and standards of driver impairment will also improve research methods and study design.

CONCLUSION

Driving simulation is a valid way to evaluate task performance and may be a more sensitive and salient method of detecting the additive and/or interactive effects of glaucoma and cognitive impairment in older drivers than vision and neuropsychological tests alone. Further research is needed to clarify the relationship between the depth and location of visual field defects in glaucoma and driving errors on the simulator and behind the wheel. Additional research is also needed to more extensively explore the relationship between patients with moderate or severe glaucoma and cognitive impairment.

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