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Visual risk factors for driving difficulty among older drivers

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Abstract

This study sought to evaluate associations between visual function and self-reported difficulty with driving tasks. Drivers ($N = 384$) between the ages of 55 and 85 were selected from ophthalmology practices and optometry clinics; three out of four of the sample had cataracts and the remaining were cataract-free. Information on driving exposure and difficulty was obtained via self-report. Visual functional status of all participants was measured with respect to acuity, contrast sensitivity, disability glare and useful field of view. Cognitive impairment was evaluated using the Mattis Organic Mental Syndrome Screening Examination. The results show a pattern of difficulty in high-risk driving situations among those with decreased visual acuity and contrast sensitivity, even after adjustments for age, gender, weekly mileage, and cognitive impairment.

Keywords: Vision impairment; Eye disease; Driving; Motor vehicle; Visual acuity; Visual field; Contrast sensitivity; Useful field of view; Elderly

1. Introduction

As some people age many of their visual, physical, and cognitive functions decline (Retchin et al., 1988; Shinar and Schieber, 1991; Marottoli et al., 1993). Many tasks are affected by these declines in function, including the ability to safely operate an automobile. This may in part explain the fact that older drivers have the highest fatality rate per mile driven; their overall crash rates are also high (Williams and Carsten, 1989). Given the increase in the elderly population, the detrimental consequences to this segment of the population will continue, if not increase. Many studies have attempted to identify the contributing causes of automobile crashes among older drivers; the majority have focused on medical conditions and visual and cognitive impairments (Retchin et al., 1988; Koepsell et al., 1994; Marottoli et al., 1996; Owsley et al., 1998, 1999).

There has also been a recent interest in changes in driving habits among older drivers (Retchin et al., 1988; Marottoli et al., 1993; Forrest et al., 1997; Stutts, 1998; Burns, 1999). Research has demonstrated that many older drivers restrict not only the time spent driving but also their driving circumstances (e.g. driving at night or in the rain) (Marottoli et al., 1996; Forrest et al., 1997; Ball et al., 1998; Stutts, 1998). Reasons as to why this group reduces their driving may vary from reduced driving need, functional impairments and increased awareness of their own impaired ability. The question of interest for many studies is what characteristics are associated with modification of driving circumstances. Visual and cognitive functioning impairments have been shown to be associated with driving cessation and self-regulation (Marottoli et al., 1996; Forrest et al., 1997; Ball et al., 1998; Stutts, 1998; Owsley et al., 1999). Marottoli et al. (1993) investigated factors associated with driving cessation, number of miles driven and changes in mileage in a community-living elderly population. Driving cessation was associated with neurologic disease (i.e. Parkinson's disease or stroke) or presence of cataracts, higher age, not working, lower income,

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participation in fewer activities and Rosow–Breslau disability (Marottoli et al., 1993). High mileage drivers ($\geq$ 5000 miles/year) were more likely to be young, male, still working, more active, less disabled and to have a higher income (Marottoli et al., 1993). The predictors of reduced mileage were increasing age and the performance of fewer Rosow–Breslau items (Marottoli et al., 1993). Stutts (1998) reported that older drivers with poorer cognitive and/or visual function drive fewer miles or avoid driving in particular situations (e.g. driving during rush hour). Ball et al. (1998) examined the association between visual and cognitive impairment in older drivers and their avoidance of potentially challenging driving situations. Results showed that older drivers with visual impairments are more apt to avoid difficult driving circumstances than those free of visual impairments (Ball et al., 1998; Owsley et al., 1999).

To date, few studies have provided information on factors associated with difficulty in specific driving circumstances (e.g. driving at night) (Stutts, 1998; Gallo et al., 1999). Much of the prior research has focused on driving cessation and/or avoidance as the outcome of interest. However, this research has targeted a population that has already modified their driving exposure (Marottoli et al., 1993; Ball et al., 1998; Stutts, 1998). If older adults find certain driving situations to be difficult, they may eventually modify their driving exposure. The ability to retain a driver's license and, in doing so, maintain independence in the face of advancing age can affect the overall quality of life. Elderly adults rely heavily on the automobile to maintain an active and independent lifestyle. Kosnik et al. (1988) found that those aged 65 and older use their cars for 80% of their errands and trips. Thus the loss of a driver's license can be traumatic because it is likely to be the first compromise in an older adult's independence. By assessing the effects of visual, physical, and cognitive impairments on the driving habits of the elderly population, interventions can then be focused on enhancing the safety of these and other road users.

The purpose of this study is to examine the association between driving difficulty and specific aspects of visual function (acuity, contrast sensitivity, disability glare, useful field of view). It was hypothesized that older drivers reporting difficulty with certain driving tasks (e.g. left-hand turns) would be more likely to have visual functional impairments. This will be one of the first studies to investigate the independent association between specific visual impairments and driving difficulty among older adults while controlling for other visual impairments and age, gender, weekly mileage, and cognitive impairment.

2. Methods

2.1. Study subjects

The subjects in this study were participants in the Impact of Cataracts on Mobility (ICOM) Project. A detailed description of the study methods is provided elsewhere (Owsley et al., 1999). Briefly, two groups of subjects were assembled, older drivers with cataract and those without cataract. Cataract, an increased opacification of the crystalline lens, is a leading cause of vision impairment in adults over 60 years and compromises many aspects of vision including acuity, contrast sensitivity, and visual field sensitivity (Heuer et al. 1988; Klein et al., 1992; Rubin et al., 1993). Cataract hampers health-related quality of life, and is associated with increased difficulty with visual activities of daily living (Mangione et al. 1992; Steinberg et al. 1994), impaired physical performance (Applegate et al., 1987), and reduced mental status (Applegate et al., 1987). Vision impairment from cataract is now largely reversible due to technological advances in surgical techniques and intraocular lens design, with over 85% of cases reaching 20/40 acuity or better post-surgery (Stark et al., 1983). Cataract surgery is the most common surgical procedure performed on Medicare beneficiaries representing 12% of the overall Medicare budget (Stark et al., 1989).

Study subjects were required to be between the ages of 55 and 85, to be living independently in the community and legally licensed to drive. The exclusion criteria for the subjects were amblyopia, use of a wheelchair for mobility, and the presence of dementia, Parkinson's disease, psychosis or any illness that would prohibit annual clinic visits. To identify subjects, medical record reviews were conducted in ten ophthalmology practices and two optometry clinics in Birmingham, AL. All persons meeting the inclusion criteria were contacted by a letter describing the study which was followed by a phone call. Those who agreed to participate were scheduled for a visit to the Clinical Research Unit in the Department of Ophthalmology, University of Alabama at Birmingham (UAB). Approximately 50% of eligible persons declined participation in the study. This was not surprising given the long study protocol (three patient visits over 3 years each lasting 2–3 h) and the fact that many patients were scheduled for cataract surgery the following week and preferred not the make an additional visit to the clinic. Fortunately, the vast majority of those who refused to participate consented to telephone interviews regarding their health and functioning. Those who refused were slightly older and reported more visual difficulty and reductions in driving exposure than those who agreed to participate.

2.2. Data collection

In addition to demographic information (e.g. age, race, and gender) information on driving habits, visual function, and cognitive status was collected.

2.3. Driving habits

The driving habits questionnaire (DHQ) was used to collect driving information for the past year; the details of the DHQ are provided elsewhere (Owsley et al., 1999). The DHQ was interviewer-administered and all information was self-report and not validated against actual driving performance. The DHQ addresses six domains; the domain of interest in this paper is driving difficulty. This domain asks the respondents to rate the degree of difficulty experienced in eight specific driving situations: driving in the rain, on the interstate, on high traffic roads, during rush hour, alone, making left-hand turns and parallel parking. Ratings are made on a five-point scale (5, no difficulty; 4, a little difficulty; 3, moderate difficulty; 2, extreme difficulty; 1, so difficult I no longer drive in that situation). Information was also collected on driving exposure (miles/week). This was divided into two categories; driving less than 150 miles per week and driving 150 miles per week or more.

2.4. Visual function

Visual functional status of all participants was measured with respect to acuity, contrast sensitivity, disability glare and useful field of view. All measurements were made while subjects wore their habitual optical correction (i.e. whatever correction they typically wore during the performance of everyday distance activities such as driving). Distance acuity was measured using the ETDRS letter chart and expressed as log minimum angle of resolution (logMAR) (Ferris et al., 1982). Contrast sensitivity was assessed using the Pelli–Robson contrast sensitivity chart and expressed as log contrast sensitivity (contrast sensitivity Log) (Pelli et al., 1988). Both visual acuity and contrast sensitivity were divided into quartiles based on the characteristics of the study sample. Disability glare was measured with the MCT-8000 (VisTech Consultants, Dayton, OH, USA) and defined as visual acuity (logMAR) under conditions of glare versus no glare. Impairment was defined as the difference in acuity under glare and acuity under no glare when this value was greater than 0. The size of the useful field of view (UFOV®) was assessed with the Visual Attention Analyzer, Model 2000 (Visual Resources, Inc., Chicago, IL, USA). The UFOV® task was comprised of three subtests designed to assess processing speed, divided attention and selective attention (Ball et al., 1998). In order to summarize UFOV® performance, scores from each of these subtests are summed to yield a composite reduction score. Subtest scores range from 0, indicating no problem, to 30, indicating great difficulty. Thus overall UFOV® scores can range from 0 (no difficult in any subtest) to 90 (great difficulty in all subtests). Although driving is a behavior where people normally use two eyes, all vision tests except UFOV assessed each eye separately and therefore binocular measures of visual function were not available. The rationale for assessing each eye separately was the study's focus on cataract, which can vary in presence and severity in the two eyes. However, research suggests that visual function in the better eye is a very good approximation of the visual function used to perform most behaviors (Rubin et al., 1995). Therefore, only better eye measures of visual function were utilized in the analysis.

2.5. Cognitive function

Mental status was evaluated using the Mattis Organic Mental Syndrome Screening Examination (MOMSSE), which is designed to assess the cognitive function in the elderly. This 20-min test provides a composite score of cognitive function that reflects performance in areas such as general information, abstraction, attention, orientation, verbal memory, visual memory, speech, naming, comprehension, sentence repetition, writing, reading, drawing, and block design. Composite scores range from 0 to 28, with lower scores representing higher functioning. Using a previously established convention, a score of greater then 9 indicated cognitive impairment (Owsley et al., 1991). All cognitive and visual tests were performed in the same 3-h visit.

2.6. Statistical analysis

Although measures of difficulty were on a five-point scale, generally subjects responded that they had no difficulty or moderate difficulty leaving very few subjects in the remaining categories. Therefore, for each driving situation on the DHQ a dependent variable was created; for each situation subjects were classified as having no difficulty versus having any degree of difficulty. An additional dependent variable classified subjects as having any difficulty with three or more of the driving situations on the DHQ.

Frequency distributions for demographic, driving and cognitive characteristics of the study population by driving situations were generated and chi-square tests were used to assess the association between the specified characteristics and driving difficulty. Logistic regression was used to calculate odds ratios (ORs) and 95% confidence intervals (CIs) to assess the strength of the association between visual characteristics and driving difficulty. Separate models for better and worse eye were developed and, in order to focus on the independent associations between vision and driving difficulty, all associations were adjusted for age, gender, driving exposure, and cognitive status. Only results for better eye visual function are presented here; any differences in the pattern of results between better and worse eye models were noted. Adjustment of P-values for multiple comparisons was not conducted as there were a priori hypotheses regarding the association between visual characteristics and driving difficulty.

3. Results

Table 1 presents the demographic, driving and cognitive characteristics of the study population by each driving situation. Subjects who reported difficulty driving alone were older than those who did not report such difficulty. African–Americans were more likely to report difficulty driving on the interstate, driving alone, and making left turns. Difficulty driving in the rain, at night and parallel parking was more common among females. Those with cognitive impairments were more likely to report difficulty driving in all situations except driving at night, in the rain, and on high traffic roads. Driving 150 miles or more per week was associated with difficulty in all driving situations except for driving during rush hour and driving alone.

Table 2 presents the better eye visual characteristics of the study population by driving difficulty. All areas of driving difficulty were found to be associated with decreased visual acuity and contrast sensitivity. Disability glare was not associated with difficulty with any driving task. Difficulty driving in the rain, on the interstate, during rush hour, making left-hand turns and parallel parking were the only driving situations found to be associated with impaired UFOV.

Table 3 presents the associations between difficulty with driving tasks and visual characteristics. Following adjustment for age, gender, weekly mileage, and cognitive impairment the associations between visual acuity and contrast sensitivity and driving difficulty persisted. Following adjustment for age, gender, weekly mileage, and cognitive impairment impaired disability glare demonstrated associations with difficulty driving on high traffic roads, during rush hour, alone and making left hand turns. Difficulty driving in the rain was the only driving situation associated with impaired UFOV following similar adjustment.

In the final logistic regression models, all associations were adjusted for demographic factors, miles driven per week, cognitive status as well as other visual characteristics (i.e. visual acuity, contrast sensitivity, disability glare, UFOV) (Table 4). The results indicated that decreasing visual acuity was associated with difficulty driving at night (for trend $P = 0.0003$). Although the trend tests were not statistically significant for several driving tasks (on high traffic roads, during rush hour, alone, making left hand turns), these tasks were significantly associated with visual acuity impairment greater than 0.20 logMAR. Those with decreased contrast sensitivity had difficulty making left turns after additional adjustment for visual characteristics. No areas of driving difficulty were found to be associated with impaired disability glare. After adjustment for demographic factors, miles driven per week, cognitive status, and visual characteristics, subjects with impaired UFOV were more likely to reported difficulty driving in the rain. Tables 3 and 4 also assess overall driving difficulty (see Section 2 for definition) by visual function characteristics. Both impaired visual acuity and contrast sensitivity were associated with overall driving difficulty (Table 3); however, in the multivariable analysis, only visual acuity demonstrated independent associations (Table 4).

4. Discussion

The results of this study support the hypothesis that older drivers with visual impairments have more difficulty with driving in specific situations. We found that decreased visual acuity was independently associated with difficulty driving in a variety of driving situations including driving at night and on high traffic roads, both of which are highly demanding visual tasks. Drivers reporting difficulty making left turns were more likely to have decreased contrast sensitivity. Difficulty driving in the rain was independently associated with impaired useful field of view.

To date few studies have evaluated the relationship between specific driving tasks and specific aspects of visual impairment. Most research in this area has focused on the association between driving cessation and visual impairment (Marottoli et al., 1993; Kingston et al., 1994; Forrest et al., 1997; Stutts, 1998; Gallo et al., 1999). Marottoli et al. (1993) reported that older drivers who had stopped driving were over twice as likely to have cataracts. Forrest et al. (1997) also reported that older females drivers with poor vision were more likely to stop driving, a finding also consistent with that of Gallo et al. (1999). However, Gallo et al. (1999) also reported that older drivers who adapted their driving were more likely to report visual impairment. Kingston et al. (1994) reported similar findings for both male and female older drivers. Finally, Stutts (1998) found that older drivers with impaired contrast sensitivity drove less while those with impaired acuity tended to avoid risky driving situations. At least one study has evaluated the association between visual function and difficulty with specific driving situations; the results were consistent with those reported here (Ball et al., 1998).

Table 1
Demographic, driving, cognitive characteristics of the study population by driving difficulty

	In the rain		On the interstate		At night		On high traffic roads		During rush hour		Alone		Making left-turn		Parallel parking		Total
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	
N	226	149	79	285	246	120	115	251	132	210	72	310	59	312	83	205	384
Age																	
50–59	7.1	2.7	10.1	3.5	6.9	2.5	9.6	3.2	6.8	3.8	15.3	2.9	15.3	2.9	9.6	3.4	5.2
60–69	35.8	36.2	31.7	38.3	35.8	35.8	31.3	38.3	31.1	40.5	38.9	35.2	25.4	38.1	25.3	42.0	35.9
70–79	50.9	57.7	46.8	55.1	50.8	60.0	52.2	54.2	56.1	52.4	37.5	57.4	50.9	54.5	59.0	50.7	53.6
80–89	6.2	3.4	11.4	3.2	6.5	1.7	7.0	4.4	6.1	3.3	8.3	4.5	8.5	4.5	6.0	3.9	5.2
P	0.434		0.850		0.600		0.668		0.402		0.005		0.395		0.464		
Race																	
White	83.6	88.6	73.4	90.9	82.5	87.8	82.6	88.8	83.3	88.1	75.0	88.1	74.6	88.8	78.3	85.9	51.8
Black	16.4	11.4	26.6	9.1	12.2	17.5	17.4	11.2	16.7	11.9	25.0	11.9	25.4	11.2	21.7	14.2	48.2
P	0.181		0.001		0.169		0.101		0.214		0.004		0.003		0.117		
Gender																	
Male	47.4	61.1	43.9	55.7	51.6	35.0	53.0	44.6	47.0	43.3	51.4	47.4	55.9	45.8	50.6	36.1	85.7
Female	52.7	38.9	56.1	44.3	48.4	65.0	46.96	55.4	53.0	56.7	48.6	52.6	44.1	54.2	49.4	63.9	14.3
P	0.009		0.062		0.003		0.135		0.511		0.544		0.155		0.023		
MOMMSE[a]																	
≤9	81.9	87.9	73.4	88.1	82.9	87.5	83.5	86.9	79.6	88.6	70.8	88.1	74.6	88.1	79.5	87.8	84.6
>9	18.1	12.1	26.6	11.9	17.1	12.5	16.5	13.2	20.5	11.4	29.2	11.9	28.4	11.9	20.5	12.2	15.4
P	0.115		0.001		0.258		0.391		0.023		0.001		0.006		0.072		
Miles per week																	
0–149	37.6	48.3	29.1	46.3	37.4	52.5	33.0	47.4	37.1	47.6	36.1	42.3	27.1	43.9	33.7	52.2	41.1
150+	62.4	51.7	70.9	53.7	62.6	47.5	67.0	52.6	62.9	52.4	63.9	57.7	72.9	56.1	66.3	47.8	58.9
P	0.040		0.006		0.006		0.010		0.057		0.340		0.016		0.005		

[a] Score on the Mattis Organic Mental Syndrome Screening Examination.

Table 2
Better eye descriptive characteristics of the study population by driving difficulty

	In the rain		On the interstate		At night		On high traffic roads		During rush hour		Alone		Making left-turn		Parallel parking		Total
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	N
N	226	149	79	285	246	120	115	251	132	210	72	310	59	312	83	205	384
Visual acuity[a]																	
<0.06	32.7	43.0	20.3	41.1	27.6	54.2	23.5	42.2	28.0	44.8	23.6	39.0	13.6	41.0	32.5	41.5	35.9
0.06–0.20	26.6	36.9	29.1	31.6	28.9	35.0	27.8	32.7	26.5	31.0	22.2	33.2	22.0	32.1	25.3	33.2	31.0
0.21–0.40	26.6	12.8	30.4	17.9	27.2	8.3	28.7	15.9	27.3	16.7	30.6	18.4	33.9	18.0	21.7	17.6	20.8
>0.40	14.2	7.4	20.3	9.5	16.3	2.5	20.0	9.2	18.2	7.5	23.6	9.4	30.5	9.0	20.5	7.8	12.2
P	0.001		0.001		0.001		0.001		0.001		0.001		0.001		0.004		
Contrast sensitivity[b]																	
>1.50	18.1	18.1	27.9	10.5	18.3	7.5	23.5	9.2	23.5	8.6	26.4	11.9	39.0	10.3	27.7	10.2	14.6
1.35–1.50	31.4	31.4	32.9	30.2	34.2	23.3	32.2	30.1	29.6	30.5	31.9	30.0	30.5	30.5	32.5	30.7	30.7
1.25–1.34	27.4	27.4	16.5	30.5	24.0	35.0	24.4	29.5	25.6	28.6	23.6	28.4	22.0	28.5	18.1	28.3	27.3
<1.25	23.0	34.9	22.8	28.8	23.6	34.2	20.0	30.7	21.2	23.4	18.1	29.7	8.5	30.8	21.7	30.7	27.3
P	0.003		0.001		0.001		0.001		0.001		0.002		0.001		0.001		
Disability glare																	
≤0.25	83.6	85.9	77.2	85.6	82.5	87.5	84.4	84.5	84.1	84.3	80.6	85.8	83.1	84.6	86.8	85.4	84.6
<0.25	16.4	14.1	22.8	14.4	17.5	12.5	15.7	15.5	15.9	15.2	19.4	14.2	17.0	15.4	13.3	14.6	15.4
P	0.551		0.073		0.221		0.978		0.962		0.264		0.762		0.762		
Useful field of view[c]																	
≥40	62.0	73.2	58.2	70.2	66.3	69.2	65.2	68.9	59.9	72.9	66.7	67.1	55.9	70.8	59.0	72.2	67.1
<40	38.1	26.9	41.8	29.8	33.7	30.8	34.8	31.1	40.1	27.1	33.3	32.9	44.1	29.2	41.0	27.8	32.9
P	0.025		0.045		0.579		0.482		0.012		0.944		0.024		0.030		

[a] Log MAR (minimum angle of resolution).
[b] Contrast sensitivity Log.
[c] Percent reduction.

Table 3
Associations between better eye visual characteristics and driving difficulty adjusted for age, gender, mileage, and cognitive impairment

	In the rain	On the interstate	At night	On high traffic roads	During rush hour	Alone	Making left-turn	Parallel parking	Driving difficulty
	OR[a] (95%CI)[b]	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)
Visual acuity[c]									
≤0.06	REF[d]	REF	REF	REF	REF	REF	REF	REF	REF
0.06–0.20	1.0 (0.6, 1.6)	1.8 (0.9, 3.8)	1.8 (1.0, 3.0)[e]	1.6 (0.9, 3.0)	1.3 (0.8, 2.4)	1.3 (0.6, 2.8)	2.3 (0.9, 5.8)	0.9 (0.4, 1.7)	1.5 (0.9, 2.5)
0.21–0.40	2.9 (1.5, 5.7)[e]	3.3 (1.5, 7.1)[e]	7.8 (3.5, 17.4)[e]	3.8 (1.9, 7.4)[e]	2.5 (1.3, 4.7)[e]	3.9 (1.8, 8.5)[e]	6.7 (2.6, 17.1)[e]	1.4 (0.6, 2.9)	3.2 (1.8, 6.0)[e]
>0.40	2.2 (1.0, 4.9)[e]	3.3 (1.4, 7.8)[e]	13.1 (3.7, 46.8)[e]	3.9 (1.8, 8.3)[e]	3.3 (1.5, 7.0)[e]	4.4 (1.9, 10.4)[e]	9.5 (3.6, 25.5)[e]	2.4 (1.0, 5.6)[e]	3.5 (1.7, 7.2)[e]
P trend	0.002	0.001	0.0001	0.0001	0.0004	0.0001	0.0001	0.045	0.0001
Contrast sensitivity[f]									
>1.50	REF	REF	REF	REF	REF	REF	REF	REF	REF
1.35–1.50	1.6 (0.9, 2.9)	0.7 (0.3, 1.5)	1.0 (0.6, 1.9)	1.4 (0.7, 2.6)	1.3 (0.7, 2.5)	1.7 (0.8, 3.9)	3.3 (1.1, 9.7)[e]	0.9 (0.4, 2.0)	1.4 (0.8, 2.5)
1.25–1.34	1.8 (1.0, 3.3)[e]	1.3 (0.6, 2.6)	2.3 (1.2, 4.2)[e]	1.7 (0.9, 3.3)	1.4 (0.7, 2.5)	2.5 (1.1, 5.7)[e]	4.3 (1.5, 12.5)[e]	1.3 (0.6, 2.8)	1.5 (0.9, 2.7)
≤1.25	1.6 (0.9, 2.9)	2.4 (1.0, 5.4)[e]	3.2 (1.3, 7.6)[e]	3.8 (1.8, 8.3)[e]	3.4 (1.6, 7.4)[e]	3.9 (1.6, 9.4)[e]	13.3 (4.4, 40.1)[e]	2.8 (1.2, 6.6)[e]	3.1 (1.5, 6.3)[e]
P trend	0.008	0.02	0.001	0.001	0.007	0.002	0.0001	0.02	0.004
Disability glare[f]									
≤0.25	REF	REF	REF	REF	REF	REF	REF	REF	REF
>0.25	1.2 (0.8, 1.9)	1.4 (0.8, 2.4)	1.3 (0.8, 2.1)	1.7 (1.1, 2.7)[e]	1.5 (1.0, 2.4)[e]	2.1 (1.2, 3.8)[e]	2.3 (1.2, 4.2)[e]	0.8 (0.4, 1.7)	1.4 (0.8, 2.4)
Useful field of view[g]									
≤40	REF	REF	REF	REF	REF	REF	REF	REF	REF
>40	1.6 (1.0, 2.7)[e]	1.3 (0.7, 2.3)	1.0 (0.6, 1.7)	1.1 (0.7, 1.9)	1.5 (0.9, 2.6)	0.9 (0.5, 1.7)	1.8 (0.9, 3.4)	1.5 (0.8, 2.7)	1.2 (0.8, 1.9)

[a] Adjusted for age, gender, weekly mileage, and cognitive impairment.
[b] Odds ratio; confidence interval.
[c] Log MAR (minimum angle of resolution).
[d] Reference category.
[e] $P \leq 0.05$.
[f] Contrast sensitivity Log.
[g] Percent reduction.

Table 4
Association between better eye visual characteristics and driving difficulty adjusted for visual acuity, contrast sensitivity, disability glare, useful field of view, age, gender, weekly mileage, and cognitive impairment

	In the rain	On the interstate	At night	On high traffic roads	During rush hour	Alone	Making left-turn	Parallel parking	Driving difficulty
	OR[a] (95%CI)[b]	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)	OR[a] (95%CI)
Visual acuity[c]									
≤0.06	REF	REF	REF	REF	REF	REF	REF	REF	REF
0.06–0.20	0.9 (0.5, 1.5)	1.7 (0.8, 3.5)	1.6 (0.9, 2.8)	1.5 (0.8, 2.8)	1.2 (0.7, 2.2)	1.2 (0.5, 2.5)	1.8 (0.7, 4.7)	0.7 (0.4, 1.5)	1.4 (0.8, 2.4)
0.21–0.40	2.7 (1.3, 5.3)[d]	2.8 (1.2, 6.3)[d]	6.9 (3.0, 15.8)[d]	3.5 (1.7, 7.2)[d]	2.4 (1.2, 4.8)[d]	3.1 (1.3, 7.1)[d]	5.0 (1.9, 13.6)[d]	1.2 (0.5, 2.8)	3.1 (1.6, 5.8)[d]
>0.40	1.5 (0.6, 3.89)	2.1 (0.8, 5.7)	10.6 (2.8, 41.2)[d]	3.0 (1.2, 7.2)[d]	2.6 (1.1, 6.4)[d]	3.0 (1.1, 8.1)[d]	5.1 (1.7, 15.7)[d]	1.7 (0.6, 4.6)	2.8 (1.2, 6.4) ¶
P trend	0.3270	0.1883	0.0003	0.0717	0.1904	0.4414	0.1093	0.0730	0.1441
Contrast sensitivity[e]									
>1.50	REF	REF	REF	REF	REF	REF	REF	REF	REF
1.35–1.50	1.6 (0.9, 2.9)	0.6 (0.3, 1.5)	1.0 (0.5, 1.8)	1.3 (0.7, 2.5)	1.3 (0.7, 2.4)	1.6 (0.7, 3.7)	2.7 (0.9, 8.3)	0.9 (0.4, 1.9)	1.3 (0.7, 2.4)
1.25–1.34	1.5 (0.8, 2.9)	0.9 (0.4, 2.0)	1.4 (0.7, 2.7)	1.2 (0.6, 2.4)	1.0 (0.5, 2.0)	1.7 (0.7, 4.0)	2.4 (0.8, 7.4)	1.2 (0.5, 2.8)	1.1 (0.6, 2.0)
≤1.25	1.9 (0.8, 4.5)	1.6 (0.6, 4.1)	1.5 (0.6, 4.0)	2.6 (1.1, 6.1)[d]	2.2 (0.9, 5.2)	2.3 (0.8, 6.4)	6.1 (1.8, 20.7)[d]	2.3 (0.9, 6.0)	1.9 (0.9, 4.3)
P trend	0.9631	0.3896	0.4524	0.2192	0.5621	0.7484	0.0231	0.1581	0.6940
Disability glare[e]									
≤0.25	REF	REF	REF	REF	REF	REF	REF	REF	REF
>0.25	1.1 (0.6, 2.1)	1.5 (0.8, 3.0)	1.0 (0.5, 2.0)	0.8 (0.4, 1.5)	0.8 (0.4, 1.6)	1.5 (0.7, 3.2)	0.8 (0.3, 1.9)	0.6 (0.3, 1.5)	1.1 (0.6, 2.0)
Useful field of fiew[f]									
≤40	REF	REF	REF	REF	REF	REF	REF	REF	REF
>40	1.6 (1.0, 2.8)[d]	1.2 (0.6, 2.2)	0.9 (0.5, 1.6)	0.9 (0.5, 1.6)	1.3 (0.7, 2.2)	0.8 (0.4, 1.5)	1.3 (0.6, 2.6)	1.2 (0.6, 2.4)	1.1 (0.7, 1.8)

[a] Adjusted for visual acuity, contrast sensitivity, disability glare, useful field of view, age, gender, weekly mileage, and cognitive impairment.
[b] Odds ratio; confidence interval.
[c] Log MAR (minimum angle of resolution).
[d] $P \leq 0.05$.
[e] Contrast sensitivity Log.
[f] Percent reduction.

Comparison of the results of this study to the existing literature is, however, difficult. This is due to the fact that, to our knowledge, this is the first study to evaluate the independent association between visual impairment and difficulty with specific driving tasks. This study is also novel in that the results were similarly adjusted for demographic characteristics, driving exposure, and cognitive status. This is an important advancement in our understanding of this issue as the interrelationship between measures of visual function is likely to cloud their relationship with driving. Therefore, the determination of the independent role of these measures is likely to provide a more valid estimate of the relationship between vision and driving difficulty. In fact, the results of this study support this assertion in that nearly all measures of visual function demonstrated associations with driving tasks prior to adjustment for each other. In the final multivariable models, the nature of these relationships became much more clear. Specifically, we found that visual acuity was independently associated with nearly every driving task. It is important to note that those more visually demanding tasks (e.g. at night, making left hand turns) were more strongly associated with visual acuity than were other tasks (e.g. in the rain). We believe that these findings support the conclusion that visual acuity is an important component of driving in general and that declines in acuity are likely to affect more complex driving tasks. Contrast sensitivity was significantly associated with making left-hand turns; positive associations were also observed for driving on high-traffic roads, during rush hour, alone, and parallel parking. Many of these tasks, including making left-hand turns, driving on high traffic roads, and during rush hours, can also be classified as visually complex and require the ability to discriminate objects within the field of view.

The results of this study have important implications for future research and intervention endeavors. It is likely that many older drivers who are aware of the problems they are experiencing with their vision decrease the amount of driving or refrain from driving in certain situations. The possibility that older drivers recognize their own driving difficulty and modify their driving to accommodate this fact is encouraging. Older drivers, faced with declining visual function, may feel that certain driving tasks (e.g. driving alone or at night) may put them at an increased risk of being in a crash or simply make them uncomfortable and thus, alter their driving tasks to avoid such situations. Thus, the promotion of self-regulation as a method for improving safety among older drivers with visual impairments needs to be assessed as an intervention. However, such regulation is likely to come at the expense of mobility and independence. Further, it remains to be seen whether such self-regulation is, in fact, associated with safer driving (i.e. lower crash rates). If this is true, then interventions to promote self-regulation would be attractive and could be targeted towards those with greatest difficulty (i.e. visually impaired). However, for certain groups of older drivers, it may also be possible to actually improve mobility and safety and reduce driving difficulty. Therefore, interventions to improve visual function (e.g. cataract surgery) represent an opportunity to modify those factors that motivate the older driver to stop or reduce their driving, particularly in certain situations. In terms of driving cessation, there are inconsistent findings with regard to cataracts. Marottoli et al. found that cataracts was associated with driving cessation, while Campbell et al. (1993) found cataracts to be unrelated to the decision to stop driving. It may be hypothesized that some older adults reduce their driving with the progression of cataracts and, having adapted their driving, maintain these new driving patterns after surgery. Future studies should attempt to evaluate changes in driving habits following cataract surgery as this treatment option has the possibility of improving the quality of life for the older driver with respect to vision and mobility.

The results of this study should be interpreted in light of several limitations and strengths. First, the evaluation was limited to a certain subset of the population; subjects were originally selected on the basis of the presence versus absence of cataracts. However, this provided us a wide range of visual function that may not have been available had a population-based sample been assembled. Further, because over half of those with cataract would be undergoing surgery during the follow-up period of the study, we will be able to evaluate whether improvements in vision are associated with a reduction in driving difficulty. Second, our study used self-reported driving difficulty. However, this is only problematic if inaccurate responses to questions on driving difficulty occurred differentially by measures of visual function; we believe this is unlikely. The cross-sectional nature of this study does not necessarily imply a causal relationship between visual impairment and driving difficulty. Finally, given the large number of comparisons in the study it is possible that some significant associations arose due to chance.

This study also has several strengths. Visual and attentional impairments were not determined by self-report as in most other studies, but by objective and reliable methods. Further, to date, few studies have evaluated the independent association between driving habits (e.g. cessation, avoidance, difficulty) and specific types of visual function. Another strength of this study was the use of a comprehensive driving questionnaire that has been shown to have construct validity (Owsley et al., 1999).

In summary, this study supports the hypothesis that vision impairment is associated with driving difficulty, particularly visual acuity and contrast sensitivity. These findings have a number of implications for clinicians and researchers. For the clinician faced with assessing the older driver, these results indicate that measures of visual function can be used to identify older drivers experiencing driving difficulty. Such patients might then be targeted for more intensive discussions regarding driving safety. Finally, interventions that improve visual function, such as cataract surgery, should be evaluated for their impact on driving behavior and safety.

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