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ABSTRACT

Numerous age-related changes in the structure and function of the visual system have been noted in the research literature. However, little is known about the extent to which these visual changes contribute to the problems experienced by older persons in the natural environment. In an attempt to estimate the nature and magnitude of the real-world visual problems which accompany normal adult aging, a large number of male and female participants in the Baltimore Longitudinal Study on Aging (N=397) were examined. They ranged from 22 to 92 years of age with oversampling in the 65+ subgroups. Participants completed a survey designed to assess the magnitude of visual problems experienced with everyday tasks and while driving an automobile. Approximately half of the participants also received a comprehensive examination of their visual status in the form of a psychophysically rigorous assessment of their contrast sensitivity function (CSF). Factor analysis of the survey responses revealed that visual problems experienced while driving increased with age. The emergence of these age-related difficulties occurred along five major dimensions: unexpected vehicles in the peripheral field, judgments of vehicle speed, dim instrument panel displays, windshield problems, and the inability to read street signs. These age-related increases in self-reported visual problems were significantly related to concomitant losses in contrast sensitivity at both intermediate and high spatial frequencies. These data point to areas of research which could yield promising benefits for improving real-world visual functioning among older adult populations.

INTRODUCTION

Approximately 12% of the U.S. population is currently aged 65 or older. These persons represent the fastest growing demographic group in the country. It has been estimated that by the year 2020 this age group will increase to 17% of the population - resulting in 50 million eligible drivers over the age of 65. As many as half of these older persons will be over the age of 75 (Transportation Research Board, 1988). Similar "graying" trends have been noted in populations throughout the world (Organization for Economic Cooperation and Develoment, 1985). Because advancing adult age is often accompanied by declines in motor, sensory and cognitive function, human factors engineers and scientists have begun to develop guidelines to help design products and environments which are "optimized" to meet the emerging needs of an increasingly older society (e.g., Schieber, Fozard, Gordon-Salant and Weiffenbach, 1991).

Among all of the senses, vision is the principal source of information for safely and effectively operating a motor vehicle (see Shinar and Schieber, 1991). Unfortunately, adult aging is accompanied by numerous deleterious changes in visual capacity and function. The resting size of the pupil decreases, the eye's crystalline lens becomes cloudy and loses its ability to focus near objects and the incidence of retinal degeneration and pathology climbs to alarming levels. These changes combine to yield age-related decrements in visual acuity and contrast sensitivity - especially under poor illumination conditions - and also contribute to increased problems with discomfort and disability glare (Schieber, 1988; 1992). In addition to these ocular changes, advanced adult aging has also been found to be associated with declines in higher-order visual functions such as motion/velocity perception and visual search (Schieber, 1992).

Despite the recent advances in describing and understanding age-related change in visual capacity, little is known about the extent to which these visual decrements contribute to real-world functional abilities such as driving a motor vehicle. Recent research suggests that survey instruments - such as well-defined questionnaires - may provide a reliable means for identifying both the nature and extent to which visual declines impact common daily activities (see Kosnik et al., 1988; Kline et al., *in press*). This study attempted to extend these techniques to the domain of automobile driving and provide an initial attempt at validating the survey approach through the concomitant collection of contrast sensitivity functions - the comprehensive assessment of the visual system's optical and neural response to spatial form information.

METHOD

Vision Survey

Subjects. Participants in the survey portion of the study were unpaid adult volunteers from the Baltimore Longitudinal Study on Aging (BLSA), a normative study conducted by the National Institute on Aging. The participants ranged in age from 22 to 92 years and, for the purposes of analysis, were divided into 4 age subgroups as follows: $N_{20\text{-}39} = 40$, $N_{40\text{-}59} = 114$, $N_{60\text{-}79} = 184$ and $N_{80+} = 59$. This sample (N=397) was typical of the BLSA in that they were highly educated and healthy. More than half of the subjects in each group had received post-graduate education and 90% reported that their health was good to excellent (see Kline, et al. *in press* for additional details regarding the nature of the sample and the survey instrument).

Materials. The *Your Vision Survey* (Sekuler, Kline and Kosnik, 1988) is composed of three parts. The first is concerned with demographic information such as age, gender, education level, general and visual health. The second section (Part A) consists of 18 items regarding the level of difficulty experienced during the performance of everyday visual tasks (e.g., seeing in dimly lighted environments, reading, seeing detail in moving displays, etc.). The third section (Part B) consists of a number of questions regarding the respondent's motor-vehicle driving experience followed by 18 items designed to assess the level of visual difficulty experienced with various visually based driving tasks (e.g., problems with oncoming headlights, seeing the instrument panel at night, judging speed, etc.). Respondents use a 4-point scale to rate either the degree of difficulty (1 = none at all, 2 = a little, 3 = quite a bit and 4 = a lot) or the frequency of difficulty (1 = never, 2 = rarely, 3 = occasionally and 4 = frequently) experienced with the task or problem described.

Procedure. BLSA participants completed the vision survey during their biennial visit to the Gerontology Research Center in Baltimore, MD between the dates of September 1988 and August 1989. Completion of the survey took between 15 and 20 minutes.

Contrast Sensitivity Testing

Subjects. Contrast sensitivity assessments were collected from more than half of the participants in the survey portion of the study. The number of subjects in each of the 4 age subgroups was: $N_{20\text{-}39} = 42$, $N_{40\text{-}59} = 89$, $N_{60\text{-}79} = 86$ and $N_{80+} = 8$ ($N_{Total} = 225$). All subjects wore their regular eyeglasses (or contact lenses) according to their individual needs.

Apparatus. The stimuli (sinusoidal luminance gratings) used to assess contrast sensitivity were presented upon a large monochrome (white phosphor) CRT display which was viewed from a distance of 6 meters to reduce the need for visual accommodation. Stimulus generation/calibration, response collection and administration of the psychophysical protocol were all under the control of a dedicated laboratory computer.

Procedure. Participants viewed a bipartite display on a computer-driven CRT screen. This display was divided into two rectangular regions, one above the other, each of which was 3 degrees (of visual angle) high and 6 degrees wide. Each of these rectangular display regions was held at a constant space-average luminance of 22 cd/m^2. During each assessment trial the computer would randomly present a sinusoidal grating in either the top or bottom stimulus region. The contrast and spatial frequency of the target was determined according to an adaptive up-down staircase procedure. The participant's task was to indicate, via a set of switches, whether the target appeared in the top or bottom position on the CRT display (i.e., a two-alternative, forced-choice procedure). Contrast thresholds were collected for each of 6 stimulus spatial frequencies: 0.5, 1, 2, 4, 8 and 16 cycles per degree (c/deg) of visual angle. This data was used to generate a contrast sensitivity function for each of the participants. The entire contrast sensitivity assessment procedure lasted approximately 50 minutes.

RESULTS

Vision Survey

Only data from the driving tasks portion of the survey (Part B) are discussed here. Readers interested in the visual difficulties encountered during non-driving tasks should refer to Kline et al. *(in press)* and Kosnik et al. (1988; 1990). A summary of general driving behavior and background as reported on the survey is presented in Table 1. Of the 397 participants, 383 were currently driving, 10 used to drive but had discontinued the practice and 4 had never driven a motor vehicle. All 10 of those who had quit driving were over the age of 64. The most frequently reported reasons for having stopped driving were health-related problems (n = 5) and problems with traffic congestion and/or involvement in a traffic accident (n = 4). Several of the older participants reported that they limited their driving to daytime conditions only. Data from these respondents as well as those reporting serious eye diseases were eliminated from subsequent analyses, yielding an effective N of 333.

Correlational analyses performed upon the driving background data revealed several interesting trends associated with increasing adult age. For example, older drivers reported driving fewer miles on an annual basis ($r_{331} = -0.37$, $p < 0.001$), less during rush hour conditions ($r_{331} = -0.25$, $p < 0.002$) and less at nighttime ($r_{331} = -0.42$, $p < 0.001$).

Data from the 18 driving-related items on the survey as well as the demographic variables of age, gender, education and overall health were analyzed using a principal components factor analysis with simple orthogonal rotation. The 5 factors with eigenvalues greater than 1.0 together with the item loadings upon these factors which exceeded 0.30 are reported in Table 2. As discussed thoroughly by Kline et al. (*in press*), the first 3 factors (General problems; Illumination problems;

Table 1.
Driving Background of Survey Respondents

Characteristic	Total (N=397)	Age Group 20-39 (n=40)	40-59 (n=114)	60-79 (n=184)	80+ (n=59)
Driving Status:					
presently drive	383	40	114	177	52
used to drive	10	0	0	4	6
never drove	4	0	0	3	1
no nighttime driving	6	0	0	2	4
Annual Miles Driven:					
<5000	74	4	9	37	24
5000 - 9999	100	9	22	49	20
10000 - 14999	118	15	39	59	5
15000 - 19999	40	3	13	23	1
>20000	49	9	30	9	1
(missing data)	(2)		(1)		(1)
Percent Rush Hour Driving:					
00 - 10	201	19	45	99	38
11 - 20	73	4	21	42	6
21 - 30	42	7	13	19	3
31 - 40	17	3	9	3	2
41 - 50	16	2	6	8	0
>50	33	5	20	6	2
(missing data)	(1)				(1)
Percent Nighttime Driving:					
00 - 10	189	7	30	108	44
11 - 20	125	18	54	49	4
21 - 30	37	5	15	15	2
31 - 40	20	6	10	4	0
41 - 50	9	3	4	1	1
>50	2	1	1	0	0
(missing data)	(1)				(1)

Table 2.
Results of Factors Analysis of Visual Problems related to Driving

SURVEY ITEM	FACTORS[a] 1	2	3	4	5
age			.68		
difficulty judging vehicular speed	.39		.56		
self-rated overall visual quality		-.34	-.53	.30	
surprised by other vehicles when merging	.40		.47		
unexpected vehicles in periphery	.34	.35	.41		
other vehicles move too quickly	.49		.39		
glare from windshield when sun low in sky	.49		.39		
failure to read street sign in time	.54		.30		
instrument panel too dim		.65	.31		
glare from oncoming headlights	.81				
headlight glare in rearview mirror	.80				
glare from dimmed headlights	.77				
street lights on sooner	.55	.46			
ignore dirt/rain on windshield	.52		.31		
surprised by vehicles at dusk	.50	.38			
distant objects out of focus at night	.50	.42			
instrument panel out of focus at night		.79			
taillights of other vehicles too dim .		.72			
steering wheel/dashboard obstructs vision		.59			
gender				-.61	
difficulty staying in own lane				.61	
education					.81
self-rated overall health					.55

[a] Factors 1-5 cluster into the following functional groups: 1 = General Vision/Driving Problems; 2 = Illumination Difficulties; 3 = Age-related Visual Driving Problems; 4 = Gender; and 5 = Health/Education

and Age-related problems) were interrelated. That is, many of the survey items which loaded on the first factor also loaded upon the other two factors. The fourth (Gender-related problems) and fifth (Health/education) factors shared only a single item with the other factors emerging from this analysis.

The age variable loaded only on the third factor (0.68). This factor was associated with age-related declines in overall self-assessment of the quality of vision (-0.53) as well as increased levels of difficulty across age for 8 of the 18 driving-related items on the survey instrument (viz., difficulty judging speed, being surprised by vehicles while merging, unexpected appearance of vehicles in the peripheral field of vision, other vehicles moving too quickly, problems with glare from the sun, problems seeing past haze on the windshield, difficulty reading street signs, and instrument panels which are too dim - see Table 2). The age-related trends associated with each of these survey items are presented in Figure 1. Subject responses for each of these items were partitioned into age groups by decade and analyzed with a series of one-way ANOVAs. The linear trends for the effects of increasing adult age were significant for all seven analyses ($p < 0.001$).

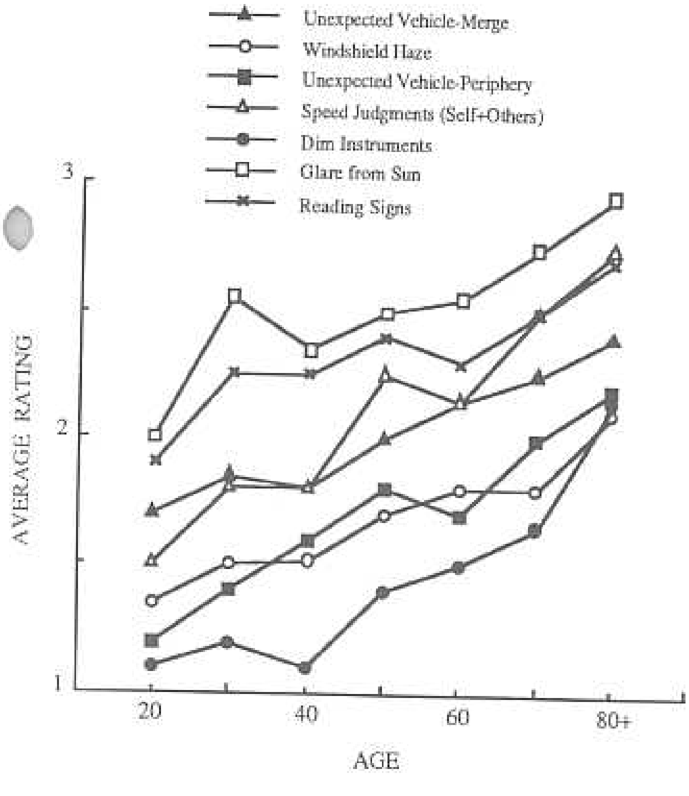

Figure 1.
Magnitude of self-reported visual problems as a function of age

Contrast sensitivity

The contrast sensitivity function (CSF) collected from each participant was parameterized in the form of three statistics for the purpose of simplifying data analyses and comparisons. These 3 CSF parameters were: peak (or maximum) contrast sensitivity, the half-amplitude low cutoff spatial frequency and the half-amplitude high cutoff spatial frequency, respectively. Figures 2 and 3 depict the age-related trends observed for these CSF parameters. Regression analyses revealed that all three parameters used to represent the CSF changed as a function of increasing adult age. The following regressions on the age variable were observed: peak contrast sensitivity ($r_{223} = -0.24$, $p < 0.01$), low cutoff frequency ($r_{223} = -0.26$, $p < 0.001$) and high cutoff frequency ($r_{223} = -0.31$, $p < 0.05$).

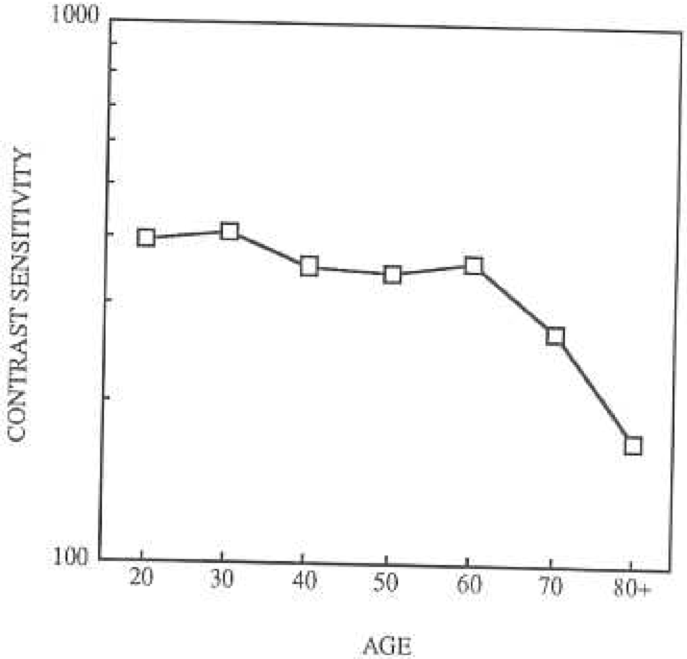

Figure 2
Peak contrast sensitivity as a function of age

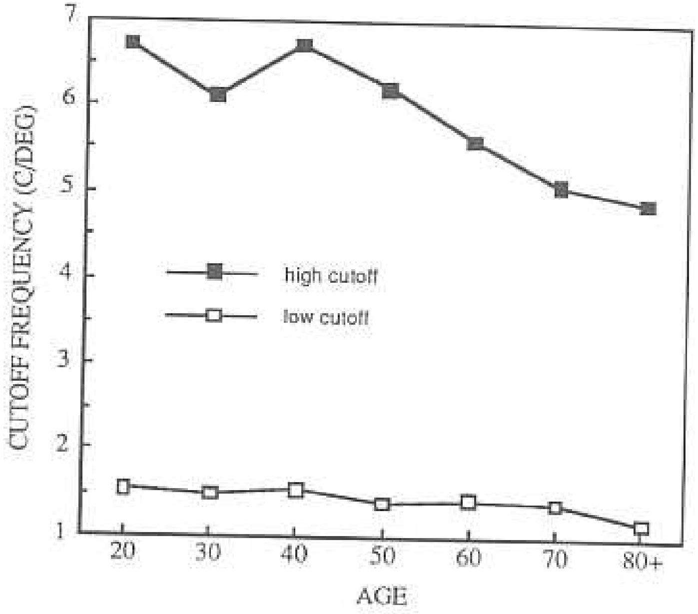

Figure 3
CSF half-amplitude cutoff parameters as a function of age

A canonical correlation analysis was conducted in order to determine if the contrast sensitivity function, as represented by the 3 derived parameters, was related to the magnitude of problems reported on the age-related survey items. The predictor set of variables for this analysis included all 3 CSF parameters while the criterion variables consisted of those items from the driving part of the survey which had previously been shown to be related to increasing adult age (i.e., loaded on the "age" factor). The results of this analysis revealed that the first canonical correlation was significant ($p < 0.0001$) indicating that the predictor and criterion sets of variables were statistically related. Neither of the remaining canonical correlations yielded statistical significance. All 3 contrast sensitivity parameters loaded highly on the first canonical factor. That is, factor loadings of 0.642, 0.649 and 0.590 were observed for the low cutoff frequency, peak contrast sensitivity and high cutoff frequency, respectively. These loadings indicate that the contrast sensitivity parameters, as a unit, were able to predict the degree of difficulty reported within the set of "age sensitive" items on the survey instrument. The first canonical factor loadings for the criterion set are summarized in Table 3. These loadings indicate that all of the survey items which were found to be significantly related to advancing age were also associated with the contrast sensitivity function as parameterized herein.

Table 3.
Item Loadings on First Canonical Factor

instrument panel too dim	-0.924
unexpected vehicle in peripheral field	-0.667
surprised by other vehicles while merging	-0.523
seeing past haze on windshield	-0.507
other vehicles move too quickly	-0.382
failure to read street signs in time	-0.374
difficulty judging vehicular speed	-0.334
glare from sun on windshield	-0.302

A stepwise multiple regression analysis was conducted to evaluate the relative power of the 3 contrast sensitivity parameters in regards to predicting the level of difficulty reported on the age-related survey items. Both peak contrast sensitivity ($R = 0.35$, $F = 17.66$, $p < 0.001$) and the high cutoff frequency ($R = 0.23$, $F = 12.45$, $p < 0.001$) were significantly related to the magnitude of difficulties reported on this subset of the visual problems while driving survey. As can be seen, the peak contrast sensitivity measure was somewhat more powerful in predicting aggregate visual difficulty than was the high cutoff frequency parameter.

DISCUSSION

The analysis of the data collected in this series of studies indicates that survey techniques hold much potential for identifying and evaluating real-world visual problems encountered among the aged - the most rapidly growing segment of our population. The age-related increase in the magnitude and frequency of self-reported visual problems was found to be related to more objective measures of visual function and status - namely, the contrast sensitivity function. This result, together with other recent findings, offers strong support for both the reliability and validity of survey techniques toward the characterization of the effectiveness of visual function in non-laboratory environments (see Kline et al., *in press*; Kosnik et al., 1988;1990). As such, survey techniques represent promising opportunities for applied research initiatives aimed at optimizing product design to the sensory and perceptual limitations of older populations (Schieber et al., 1991).

Perhaps the most salient feature of the data collected in these studies was the high degree of correspondence between the magnitude and types of visual problems reported by older observers while driving and previous laboratory-based research on vision and aging. For example, older drivers who rated their visual quality as lower also tended to report problems with reading street signs and automobile instrument panels which were too dimly illuminated. These self-reported problems were entirely consistent with previous reports of age-related declines in visual acuity, contrast sensitivity and diminished ocular transmissivity due to decreased pupillary diameter and lens opacification (see Schieber, 1992). The increase in reported problems with speed estimation and the rapid flow of vehicular traffic also was anticipated by laboratory and field studies on vehicular speed judgment reported by Scialfa et al., (1987a). The finding of age-related increases in problems with glare from the sun while driving was consistent with previous laboratory studies of the deleterious effects of glare (e.g., Wolf, 1960). Yet, failure to observe an age-related increase in the magnitude of problems due to glare from headlights was somewhat surprising. It is likely, however, that this anomaly resulted from a simple "ceiling" effect. That is, most respondents, regardless of age, reported significant levels of problems with headlight glare at night. The rating scale employed may not have been sufficiently sensitive to reflect an age trend superimposed upon this population-wide complaint.

Two of the age-sensitive survey items involved driving problems which could be described as reflecting the development of "peripheral vision" difficulties with advancing adult age; namely, problems with the unexpected appearance of vehicles in the peripheral field of vision and the tendency to be surprised by other vehicles while merging. These results are especially interesting since they suggest that older drivers may be at least partially aware of the emergence of a sort of "functional tunnel vision" which may accompany advancing age. That is, recent research strongly suggests that many older adults develop perceptual deficits which interfere with their ability to detect and/or recognize objects outside of their central field of view (e.g., Ball et al., 1988; Scialfa et al., 1987b) and that such declines in the "Useful Field of View" are significantly related to the incidence of highway accidents among older drivers (Ball and Owsley, 1991).

This study did not examine directly either the accident history or the compensatory strategies that older drivers use to help them deal with their increased visual problems. However, our data regarding age differences in the type and amount of driving (see Table 1) suggest that older drivers may change their driving habits in response to age-related visual declines. That is, all of the respondents under 65 years of age currently drove and did so both in day and nighttime conditions; while all of the drivers who no longer drove at all or who no longer drove at night were 65 or older. Also, as reported in a survey study conducted by Yee (1985), our older respondents reported driving significantly fewer miles annually and were less likely to drive in adverse conditions such as at night or during rush hour traffic. Further research is needed to determine the extent to which such age differences in driving behavior patterns reflect actual compensations for visual impairment as opposed to changes stemming from lifestyle or health factors. Nonetheless, it is interesting to note that a recent large-scale epidemiological study of why older persons stop driving revealed that "visual complaints" represented the single most frequent explanation offered by such individuals (Shinar, 1992).

In addition to illustrating the promising potential of survey instruments for functional investigations of older populations, these data suggest that when people are asked to respond to well defined tasks that they have considerable insight into their own age-related visual difficulties. Such information appears to be a useful supplement to that garnered using more traditional procedures. The survey approach has been partially validated insofar as age-sensitive items on the survey instrument were found to be statistically related to deficiencies on the contrast sensitivity function. Future research will be needed to determine the extent to which the self-reported problems of older observers correspond to functional vision losses other than contrast sensitivity.

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