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## *Role of the Crystalline Lens in the Spatial Vision Loss of the Elderly*

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This study examined the contribution of the crystalline lens to the spatial contrast sensitivity loss experienced by many healthy older adults. Spatial contrast sensitivity was measured in three groups of adults: older adults who had undergone cataract extraction and intraocular lens (IOL) insertion; older adults who were in good ocular health (age-matched to the first group); and young adults also in good ocular health. Older adults had decreased contrast sensitivity at higher spatial frequencies compared to young adults, agreeing with earlier reports. In addition, both groups of older adults had similar contrast sensitivity at higher frequencies, contrary to what would be expected if the aged, noncataractous crystalline lens significantly hampered contrast transfer in the healthy older eye. Results imply that the crystalline lens is not primarily responsible for the spatial sensitivity loss of healthy older adults. Furthermore, these data indicate that for at least some IOL patients, spatial vision can be restored to a level similar to their age-mates who have no history of lens opacity or ocular disease. *Invest Ophthalmol Vis Sci* 26:1165-1170, 1985

Many older adults in good ocular health have decreased contrast sensitivity for intermediate and high spatial frequencies.<sup>1,2</sup> Earlier research<sup>1</sup> has suggested that a large portion of this spatial vision loss can be accounted for by the reduced retinal illuminance of the aged eye.<sup>3</sup> When the retinal illuminance in a group of 20-year-olds was reduced to the estimated level of a group of 60-year-olds, the contrast sensitivity of the 20-year-olds decreased to a level similar to that of the 60-year-olds. These results imply that the retinal illuminance reduction in the older eye underlies much of the elderly's threshold elevation for spatial targets.

There are two primary sources of reduced retinal illuminance in the aged eye<sup>3</sup>: "senile miosis," the

decrease in pupil area in later adulthood; and the increased optical density of the crystalline lens. The major purpose of the present study was to examine whether the lens contributes significantly to older adults' loss in spatial contrast sensitivity. If the increased light absorption and scatter of the aged lens appreciably reduces the contrast of the retinal image in the older eye, older adults would require more contrast to detect spatial targets than would younger adults.

To evaluate the role of the crystalline lens in the elderly's spatial vision loss, we measured spatial contrast sensitivity in a group of older adults who had previously undergone cataract extraction and intraocular lens (IOL) insertion. Since the crystalline lens had been removed in these individuals, we were presented with the opportunity to bypass the effects of the crystalline lens in examining how aging affects spatial vision. Contrast sensitivity data from these pseudophakic patients were then compared to data from older adults of the same age range who were in good ocular health and who had intact crystalline lenses. The rationale behind the comparison is as follows: If changes in the crystalline lens contribute to the contrast sensitivity loss in older adults, one would expect that the IOL group would have better contrast sensitivity than the "old-normals." If lens changes play little or no role in producing older adults' loss in contrast sensitivity, then contrast sensitivity should be similar in the two groups.

**Materials and Methods.** *Subjects:* Spatial contrast sensitivity was measured in three groups of adults: older adults with IOLs, older adults with intact crystalline lenses, and young adults with intact crystalline lenses. Each group will now be discussed in detail.

**Table 1.** Details on surgery and IOLs

<i>Subject</i>	<i>Surgical method*</i>	<i>Lens manufacturer</i>	<i>Lens position</i>	<i>Lens power</i>	<i>Months since surgery†</i>
1	Phaco (cap)	Precision-Cosmet	Posterior	+17.50	5
2	PECO (cap)	Precision-Cosmet	Posterior	+21.00	6
3	Phaco (cap)	IOLab	Posterior	+21.00	9
4	Phaco	IOLab	Posterior	+20.50	13
5	PECO (cap)	IOLab	Posterior	+23.00	18
6	PECO (cap)	IOLab	Posterior	+19.00	12
7	PECO (cap)	IOLab	Posterior	+17.00	25
8	PECO (cap)	IOLab	Posterior	+17.50	12
9	Phaco	Precision-Cosmet	Posterior	+18.50	1
10	Intracapsular cryo extraction	Medallion	Iris-plane	+20.00	56

\* Phaco: phacomulsification; PECO: planned extracapsular extraction; cap: capsulotomy.

† Months elapsing between surgery and psychophysical testing.

The first group consisted of 10 older adults, mean age 70 yr (SD = 7), who had previously undergone cataract extraction and IOL insertion. Table 1 lists the details on surgery and lens type for each subject. One of us (H.L.) performed all surgeries. Selection criteria for inclusion of patients in this study were strict. Only patients who were free from postoperative complications (eg, glaucoma, hyphema, macular edema) and who had clear media were included in the study. Nine out of the 10 subjects had undergone extracapsular cataract extraction and IOL insertion into the posterior chamber. Seven of these subjects had capsulotomies, which resulted in a hole of approximately 3 mm in diameter in the posterior capsule along the visual axis. Although the other two subjects did not have capsulotomies, they did have clear posterior capsules. An intracapsular procedure was used on the tenth subject, with placement of an iris-plane lens. Psychophysical measurements were made within 1½ years of surgery on 80% of the patients. The time between the date of surgery and the date of psychophysical testing averaged 16 mo.

We chose to study aphakic patients with IOLs rather than aphakic patients with spectacle or contact lens corrections, for the following reason. Spectacle correction of aphakia, and to a smaller extent contact lens correction, substantially magnifies the retinal image. Ogle<sup>4</sup> has estimated that retinal image size is increased by 32% with spectacles and by 8% with contact lenses. This magnification thereby decreases the imaged spatial frequency of a pattern. As Enoch and colleagues<sup>5,6</sup> have pointed out, this image magnification is a crucial consideration in interpreting the spatial contrast sensitivity function of aphakic patients, especially when comparing this group's contrast sensitivity to that of other patients with intact crystalline lenses. This potential problem in interpretation was avoided in the present study by studying patients with IOLs which had been inserted into the posterior chamber (or for one patient, iris-plane). It

was determined, by taking into account lens power and position along the optic axis, that IOLs in these positions produce no or only a very small amount of change in retinal image size from that produced by the intact crystalline lens. For example, we calculated the retinal image size produced by a 20D lens positioned at 3 mm from the corneal apex (ie, approximate position of the crystalline lens in the schematic eye discussed by Ogle<sup>4</sup>). We then calculated the retinal image size produced by this lens when it was moved forward 1 mm toward the iris-plane. There was only a miniscule change in retinal image size (less than 0.0001 percent difference in magnification). This makes it highly unlikely that imaged spatial frequency would be significantly different in the IOL and old-normal groups, permitting us to make direct comparisons in their spatial contrast sensitivity.

The second group consisted of 11 older adults, mean age 71 yr (SD = 7), in the same age range as the IOL group. These subjects were recruited from the same general population as subjects tested in our earlier work on aging and contrast sensitivity,<sup>1</sup> and like subjects in the earlier study, they were in good ocular health. Their crystalline lenses exhibited the increased density characteristic of old age, but they were not cataractous.

The third group consisted of 12 young adults, mean age 21 yr (SD = 4), also in good ocular health and with intact crystalline lenses. These young adults were tested in order to assess the degree of contrast sensitivity loss in the older adults.

To assess ocular health in subjects in all three groups, detailed ophthalmologic exams were carried out on each subject. These exams included ophthalmoscopy, biomicroscopy, applanation tonometry, refraction, and best-corrected acuity measurement. Special attention was given to the assessment of the retina, particularly in the older age groups. Only patients whose ophthalmoscopic exams indicated that they were free from retinal disease were included in

the sample; no patients exhibited drusen or defects of the macular pigment epithelium. Furthermore, we used a functional criterion requiring that all study participants have 20/30 acuity or better. Mean letter-acuity (best-corrected) for distance for the three groups was as follows (minimum angle resolvable): IOL = 1.25 (SD = 0.20); old-normal = 0.98 (SD = 0.24); young = 0.83 (SD = 0.12). All eyes tested, including those of the IOL group, were free from diseases of the anterior segment and optic nerve, and had normal intraocular pressure ( $\leq 20$  mmHg).

Pupils were dilated with 0.5% tropicamide in an attempt to bring pupil diameters to similar levels in young and old adults. The effect of senile miosis was reduced in older subjects, but older subjects still had slightly smaller pupils during psychophysical testing, as compared to the young group. Pupil diameter in both older groups averaged 5 mm, while pupils in young adults averaged 6 mm.

*Contrast sensitivity testing:* Contrast thresholds for detection were measured for a series of sinusoidal gratings of the following spatial frequencies: 0.8, 2.4, 4.8, 9.1, 18.2 cycles/degree (c/d). Gratings were vertical and stationary. They were generated by a Nicolet Optronics Vision Tester (CS2000, Nicolet; Madison, WI), a microprocessor programmed to display gratings on a television monitor. The display subtended a visual angle of  $5.1 \times 6.9$  deg. Mean luminance of the display remained constant during testing at 103 cd/m<sup>2</sup>; surround luminance was 5 cd/m<sup>2</sup>.

A threshold tracking procedure, based on von Bekésy's audiometric method, was used to determine contrast threshold for each spatial frequency.<sup>7</sup> The details of this procedure are identical to those of an earlier study.<sup>1</sup> To review, a test grating was initially presented at a randomly selected subthreshold contrast; the computer then gradually increased the contrast of the grating. The observer was instructed to press a button when the pattern first became visible, which then signalled the computer to decrease contrast. The observer kept the button pressed as long as the grating was visible, and released the button when the grating became invisible. The button's release signalled the computer to increase contrast, and the entire cycle began again. This process terminated after eight reversals of contrast. Contrast threshold was defined as the geometric mean of eight contrast reversals. Before beginning the threshold measurement task, subjects received practice sessions for two gratings, 0.8 and 4.8 c/d.

Contrast sensitivity testing was carried out under monocular viewing. Subjects were refracted (both spherical and cylindrical components) at the test distance of 2.4 m and wore this correction during psychophysical testing. Prior to testing, the nature of

the procedure was explained to all subjects and written informed consent was obtained.

**Results.** Figure 1 displays for each group, mean contrast sensitivity as a function of spatial frequency. Contrast sensitivity is defined as the reciprocal of contrast threshold. Table 2 lists by group mean log contrast threshold and its variability for each spatial frequency. For illustration purposes, Figure 2 shows sample contrast sensitivity data from two subjects in each group. This study has three basic findings.

First, data from the young group and old-normal group agree with the previously reported finding<sup>1</sup>: older adults have decreased contrast sensitivity at higher spatial frequencies (at 9.1 c/d  $t(21) = 2.97$ ,  $P < 0.005$ ; at 18.2 c/d  $t(15) = 1.89$ ,  $P < 0.05$ ). The magnitude of older adults' sensitivity loss is smaller in the present study than in the previous work. For example, in the present study the young/old difference at 16 c/d is approximately 0.3 log units. In the earlier report,<sup>1</sup> the young/old difference at this spatial frequency for subjects of comparable ages was approximately 0.5 log units. The smaller young/old difference in the present study stems from the fact that older adults in the present work have better contrast sensitivity than older adults in the earlier work, most likely due to the fact that the former have larger pupils (5 mm) than do the latter (3 mm). An increase in pupil size of this magnitude increases retinal illuminance, thereby increasing subjects' contrast sensitivity to higher spatial frequencies.<sup>8</sup>

A second result is that at intermediate and high spatial frequencies contrast sensitivity in the IOL group is very similar to that of the old-normal group ( $P > 0.10$  for frequencies  $\geq 2.4$  c/d). Finally, the IOL group had significantly greater sensitivity at the lowest frequency tested (0.8 c/d) than did the old-normal group ( $t(18) = 2.5$ ,  $P < 0.025$ ) and the young group ( $t(19) = 3.32$ ,  $P < 0.005$ ).

**Discussion.** If the crystalline lens of the older eye is a major contributor to the elderly's loss in spatial vision at higher spatial frequencies, one would expect that the IOL group, who have undergone lens removal, would have better high frequency sensitivity than the old-normal group. However, contrast sensitivity at higher spatial frequencies is very similar in the two groups, suggesting that the crystalline lens is not a major contributor to the contrast sensitivity loss of healthy older adults. The elimination of optical factors associated with increased lenticular density did not improve older adults' sensitivity to higher spatial frequencies. These results are consistent with the Zuckerman et al analysis<sup>9</sup> indicating that lens opacity must be fairly substantial (40% cataract) before image contrast is significantly reduced.

If older adults' threshold deficit in spatial vision

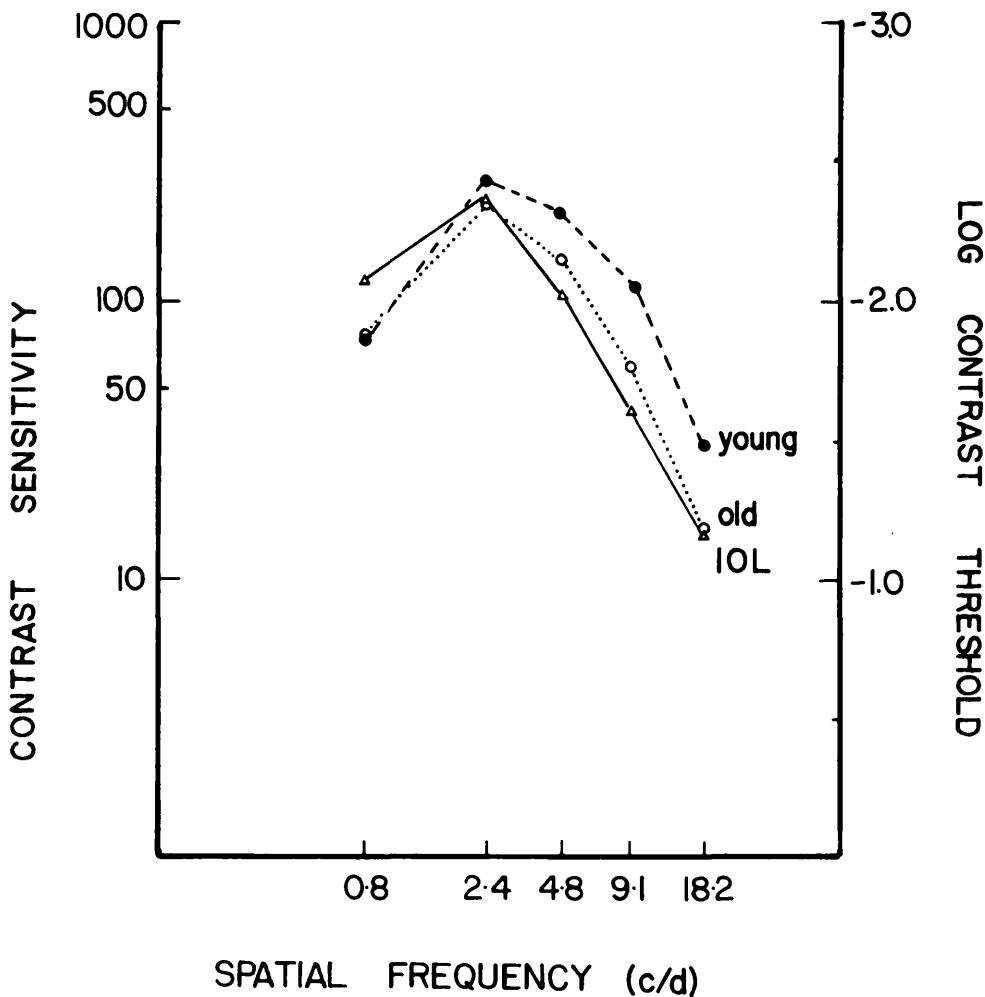


Fig. 1. Mean contrast sensitivity as a function of spatial frequency, displayed for each group. See Table 2 for within-group variability.

should not be properly attributed to aging-related changes in the crystalline lens, what factors do underlie the deficit? We suspect that the retinal illuminance reduction associated with senile miosis plays a major role, which is consistent with other reports.<sup>10</sup> When older adults' pupils were dilated to an average of 5 mm, a significant portion (40%) of their high spatial

frequency loss disappeared, supporting the idea that senile miosis is a significant contributor to the threshold deficit. A 0.3 log unit difference in contrast threshold remained between the young and old-normal groups. By applying the DeVries-Rose law,<sup>8</sup> one can calculate that about one-third of this threshold difference is attributable to the 1-mm pupil diameter difference between young and old adults in this study. The young/old difference that still remains even when pupil diameter is taken into account may be due to neural changes in the senescent visual system, that are as yet empirically undiscovered. Alternatively, the remaining young/old difference may be attributable to noise in the data, since we are basing these estimates on group averages.

Table 2. Mean and variability for log contrast threshold by group

c/d		IOL	Old-normal	Young-normal
0.8	M	-2.073	-1.897	-1.844
	SEM	0.064	0.037	0.054
2.4	M	-2.361	-2.323	-2.428
	SEM	0.141	0.076	0.058
4.8	M	-2.024	-2.148	-2.325
	SEM	0.125	0.098	0.059
9.1	M	-1.612	-1.760	-2.057
	SEM	0.102	0.079	0.064
18.2	M	-1.156	-1.192	-1.493
	SEM	0.129	0.042	0.124

The IOL group's heightened sensitivity at the lowest spatial frequency tested (0.8 c/d) is puzzling. One might suspect that there may be some image minification in the IOL patients, which would increase a grating's imaged spatial frequency. If this were true, one would expect the IOL group to have higher sensitivity for a low spatial frequency grating than would normal older adults. But, this explanation is

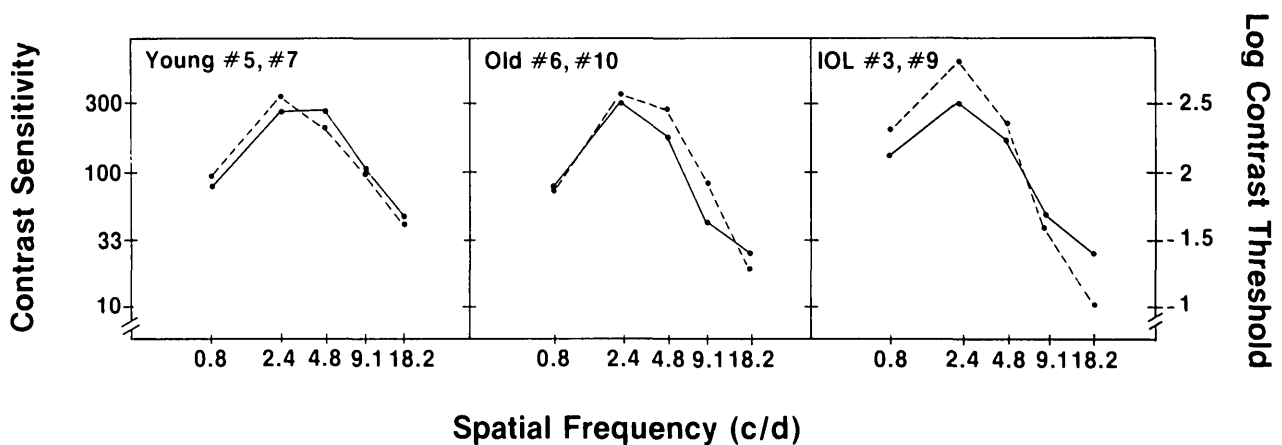


Fig. 2. Sample contrast sensitivity data for two patients in each group. Contrast sensitivity is plotted as a function of spatial frequency.

unsuitable for the present circumstances. IOLs for all subjects were positioned in the same or near same position that was once occupied by the crystalline lens. This implies that there should be no or only a minimal change in retinal image size, as compared to when the crystalline lens was intact.

It could be that the seemingly anomalous elevation in sensitivity in the IOL group at 0.8 c/d may be related to the optical characteristics of the IOL as compared to the human crystalline lens. The contrast transfer characteristics of the IOL may be different from those of the crystalline lens, but measurements of this type for IOLs have never been reported. Optical standardization procedures for IOLs involve the determination of lens power and resolution, but do not involve the measurement of modulation (contrast) transfer functions.<sup>11</sup> Knowledge of the contrast transfer characteristics of IOLs, and how they compare to the human lens, would be useful to researchers and clinicians who are interested in predicting, monitoring and describing contrast sensitivity capacities in patients after IOL insertion.

It is also important to point out that the elevation in sensitivity in the IOL group at 0.8 c/d does not appear to be a spurious result, which is supported by the following. A separate measurement of subjects' contrast thresholds at 0.8 c/d was made during the practice session. Contrast threshold in the practice trials was defined as the geometric mean of eight contrast reversals. As in the actual experiment, the IOL group exhibited heightened sensitivity at 0.8 c/d during the practice session (mean log contrast threshold = -1.836), as compared to thresholds from the old-normal group (-1.694) and young-normal group (-1.662). Furthermore, as in the actual experiment, sensitivity at 0.8 c/d for the old-normal and young-normal group was similar.

In addition to de-emphasizing the role of the

crystalline lens in the spatial vision loss of the elderly, the data in Figure 1 also document that for some IOL patients, spatial vision can be restored to a level similar to their age-mates who have no history of lenticular opacity or ocular disease. Although previous reports have shown that IOL insertion can result in good acuity,<sup>12</sup> these studies have often omitted age-matched control groups crucial for data interpretation. Additionally, assessment of spatial vision in IOL patients has for the most part been limited to acuity, omitting an evaluation of their ability to see a broad range of target sizes. Research is now needed where vision before and after IOL insertion is compared using contrast sensitivity measurements, which provide a more comprehensive quantification of spatial vision. Furthermore, the present study points toward the potential usefulness of contrast sensitivity techniques in evaluating and comparing vision with different types of IOLs and after different types of surgical procedures.

**Note added in proof.** In a forthcoming paper (Sloane and Owsley), it will be argued that senile miosis may have less of a role in producing older adults' high frequency loss than is currently believed. It appears that neural factors may figure more prominently in producing this deficit than previous analyses have indicated.

**Key words:** contrast sensitivity, spatial vision, aging, intra-ocular lens, crystalline lens

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## *Gender-Related Differences in the Morphology of the Lacrimal Gland*

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Previous research has demonstrated that distinct, gender-related differences exist in the morphology of the rat lacrimal gland. The purpose of the present study was to determine whether this sexual dimorphism is unique to the rat, or extends as well to other species. Lacrimal glands were collected from adult male and female rats, mice, guinea pigs, rabbits and humans (biopsies). Tissues were processed for light microscopy and examined with a Zeiss Videoplan II image analysis system. For morphometric determinations, we measured the area of approximately 50 glandular acini per animal for a total count of greater than 244 acini per gender per species. Our results demonstrated that significant gender-related differences exist in lacrimal glands of rats, mice, guinea pigs, rabbits, and humans. In all species analyzed, acinar area in lacrimal glands of males was larger than that of females. These findings suggest that gender differences in lacrimal gland morphology may be a general phenomenon in a variety of species. *Invest Ophthalmol Vis Sci* 26:1170-1175, 1985

Recent studies from our laboratory have demonstrated that significant, gender-related differences exist in the ocular secretory immune system of the rat.<sup>1-3</sup> Concentrations of both immunoglobulin A (IgA) and secretory component (SC) were much higher in tears of male rats than those of female rats. Similarly, lacrimal (exorbital) glands from males produced sig-

nificantly more IgA and SC in vitro than did glands from females. Because lacrimal tissue is the primary source of tear IgA and SC,<sup>3,4</sup> our results suggest that the lacrimal gland is responsible for the gender-associated differences in mucosal immunity in the eye.

This sexual dimorphism of the exorbital gland, though, does not appear to be limited to involvement with the secretory immune system. Over the past 40 yr, researchers have shown that distinct differences exist between lacrimal glands of male and female rats and these include variations in the following parameters: acinar size, membrane appearance, nuclear volume and morphology, DNA and RNA content, the quantity of nucleoli and vesicles, enzyme activity, glycoprotein and total protein levels, and connective tissue area<sup>5-8</sup> (also see Sullivan et al,<sup>3</sup> Cavallero,<sup>6</sup> and Paulini et al<sup>7</sup>). Thus, gender has a significant impact on the morphology, histochemistry, biochemistry, immunology, and genetics of the rat lacrimal gland.

The purpose of the present study was to determine whether the sexual dimorphism in the lacrimal gland is unique to the rat, or extends as well to other species. As a means for experimental comparison, we have focused upon the size of acinar structures. Lacrimal acini in the rat are qualitatively much larger