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Contrast sensitivity and low power oblique axis astigmatism

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Abstract

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CONTRAST SENSITIVITY
AND
LOW POWER OBLIQUE AXIS ASTIGMATISM

BY

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K.E.C. & S.K.L.

ABSTRACT

Currently, Snellen acuity testing is the primary clinical method of assessing a patient's visual potential. Often, however, low power oblique astigmats report a subjective visual perceptual improvement when corrected, with little or no improvement in Snellen acuities. Contrast sensitivity testing was carried out on four subjects, each with low power oblique axis astigmatism. Testing was performed monocularly and binocularly through: 1) the appropriate sphere power; and 2) with the cylindrical component added. The contrast sensitivity function was significantly enhanced through the cylinder correction for middle spatial frequencies. This suggests that contrast sensitivity testing provides a more sensitive method of determining overall visual performance. Also, patients with low amounts of oblique astigmatism will benefit more from the astigmatic correction than Snellen acuities would indicate.

CONTRAST SENSITIVITY
AND
LOW POWER OBLIQUE AXIS ASTIGMATISM

Retinal contrast mechanisms and the visual information processing system have been studied for years by researchers dealing with the question of how the brain extracts information from its sensory organ, the eye (7). However, it is only in the last fifteen years that the combination of research knowledge and technological development have made available to the clinician the tests and equipment needed to begin using a new technique to better analyze a patient's level of visual functioning. Presently, the most widely accepted tool for assessing visual function is the Snellen acuity chart. For example, many U.S. laws utilize Snellen acuity standards when determining legal blindness and when deciding whether or not a person should have a driver's license (32). Recently, the technique known as contrast sensitivity testing has gained popularity in the vision care community because it is thought to be a much more broad and sensitive test of a patient's visual functioning than the Snellen test (2,3,10,22). Not only does it determine a patient's best acuity in continuously quantifiable terms, but it can be used to refine refractive error corrections and evaluate a contact lens fit more accurately, as well as help differentially diagnose certain pathologies.

Diagnostic gratings, as contrast sensitivity gratings are often called, have been used mostly in research labs. Typically, the gratings have been generated on very expensive electronic equipment, which was one of the reasons that contrast sensitivity testing has not been regularly done in the local clinician's office. Researchers used the diagnostic gratings in such forms as optokinetic drums, photographic plates, and electronic prototypes to behaviorally test animal and human visual resolution thresholds (2,3,5,12,15,24, 25,29,30). As testing procedures were refined, the data revealed more information than was expected. It had been generally known that high spatial frequency losses correlated with visual acuity loss, but less was known about animal and human losses in the low and mid frequency range. Further research revealed that certain patterns of spatial frequency loss were consistently found in certain pathologies and could be used as predictive indicators of a patient's level of visual function (10,13,23,28,31). Comerford and others write that disease entities such as multiple sclerosis, glaucoma, tumors of the central visual system, macular disease, and cataracts are examples of pathologies which have been diagnosed and evaluated earlier in their progression with the use of contrast sensitivity testing than with the use of other standard diagnostic routines(10). As a result, some patients have benefited from early treatment regimes, not generally available in the later stages of pathological progression.

Another use of contrast sensitivity testing now being explored is for the assessment of a contact lens fit. Edema caused by a poorly fitting lens causes decreases in the higher spatial frequency range not always detectable by Snellen acuity criteria (4). As Comerford relates though, a deviant contrast sensitivity function is not always caused by a pathology. For the contact lens wearer, it may mean that there is some residual uncorrected refractive error. Thus, contrast sensitivity testing can also be used to refine refractive corrections more accurately (10).

When studying the contrast sensitivity function (CSF) of patients with reduced visual acuity (refractive or amblyopic), it is interesting to note the different patterns of loss. Hess and Howell report that in amblyopes two different CSF loss patterns may exist. One type of amblyope may show a "level" loss, which is a consistent loss across all spatial frequencies, or another type may show a "notch" loss, which is a spatial frequency loss only in a small specific range (6,18). Another type of amblyope known as a meridional amblyope also shows deviant CSF results in the orientation that parallels his/her acuity deficit (13). Comerford sums it up by writing that:

> "Finally the study of CSF as a function of refractive state suggests a reason for the finding that patients prefer more minus than indicated by the standard 'maximum plus for maximum visual acuity'. The patient reports that the letters get darker and more defined because contrast sensitivity is improved by additional refractive correction." (10)

Pratt, a successful clinician, was aware of the principle of contrast and used it years ago to develop his test for astigmia, the Pratt Near Cylinder Test. Now, astigmats can also benefit from CSF testing, in that more accurate refinements of the cylindrical correction are possible. Formal contrast sensitivity testing has thus scientifically proven that visual contrast mechanisms can be efficiently utilized for the quality assessment of a patient's level of visual functioning.

What factors have encouraged the transition of CSF testing from research laboratories to the clinical practitioner's office? Contrast sensitivity testing has become easier to conduct and less costly for the clinician in terms of time and money due to the refinement of commercially produced equal luminance photographic gratings. Infant visual acuity testing is conducted with these types of photographic gratings in a procedure known as the preferential looking technique (12). The first public mass screening of some 66 infants, ages 2 weeks to 36 months, was conducted last March 10th, 1984, through the joint efforts of the University of Washington and Pacific University's College of Optometry, utilizing this technique. More conventional testing may take place in-office as the patient views near and far CSF charts comprised of the photographic gratings. However, the electronic prototypes are still used where precise luminance levels and exact threshold values are desired. Contrast sensitivity charts found their way into outer space in the fall of 1983 (14). Ginsburg, developed the plates to assess the astronauts' vision as they were affected by weightlessness and other space flight stresses. The photographic charts which are now available for clinical use, are patterned after the CSF plates used by NASA and the U.S. Air Force. They are called the Vistech Contrast Test System (VCTS 6500) and are reported to have excellent correlation with the automated electronic CSF testing equipment (Ginsburg;14,33). Norms have been established and are being continually updated for various age groups, with and without pathology, and with various refractive anomolies (3,11,23,25,26,28). With a sound data base supporting standardized equipment and procedures, the interpretation of a patient's contrast sensitivity function, stands to be a valid and reliable tool for the clinician in the diagnosis, evaluation and treatment of visual system disorders.

A number of studies have been done relating contrast sensitivity and refractive error, in general terms, or specifically isolating astigmatic errors as the main point of focus (9,21,26). Researchers agree that uncorrected astigmatic errors do decrease the CSF. Also sensitivity in orientations of the gratings other than horizontal or vertical. This factor could have made the Beazley, et al., mean age estimate somewhat younger if there were a number of undetected low power astigmats amongst their subjects. Thus the "oblique" effect must be considered in any study of contrast sensitivity, combined with astigmia, where the orientations of the test gratings are to be manipulated.

Kinney also did contrast sensitivity testing at different orientations of gratings, but she was interested in learning if astigmia caused a difference in sensitivity to the two commonly used types of grating wave forms, namely, the square wave form or the sinusoidal wave form (21). She found that astigmia did affect high spatial frequency ranges with the sine wave form in the power meridian perpendicular to the orientation of the stripes and that square wave forms produced similar decrements except that there was also a reduction at 0.2 cpd. This apparent low frequency loss was due to a loss of the higher order harmonics in the wave form and for most practical testing purposes would not affect CSF testing results. The two aforementioned studies have done what Bodis-Wollner and Camisa recommended in 1980 (6). They suggested that more studies be done relating astigmia, contrast sensitivity, and orientation such that a better understanding of such visual problems as meridional ambiyopia might be gained. It is with similar intentions and motivations that this study on contrast sensitivity and low power oblique axis astigmatism was undertaken.

Of patients presenting with oblique axis cylinder refractive errors, a small subset, comprised of those with low power astigmatic error (1.00 D or less) will often show no change or only slight change in Snellen acuities with and without the astigmatic correction in place (for example, a change from 20/20 -2 without correction to 20/20 +1 with correction). However, many of these same patients will also report a major subjective improvement in the visual perceptual clarity and overall quality of perceptual processing when the astigmatic correction is worn. These patients will demand the cylinder correction even though, by Snellen acuity criteria, they do not "need" it. Are these patients simply hallucinating? Or is there some improvement in their visual information processing abilities which goes undetected by standard Snellen acuity measurements?

Kinney's study has shown that the introduction of an astigmatic lens into the optics of an otherwise emmetropic visual system can cause losses in contrast sensitivity in the mid and upper spatial frequency ranges (21). The possibility exists, then, that perhaps this same sort of contrast sensitivity effect might be responsible for the "qualitative" improvement (with no Snellen acuity change) seen when these low power, oblique axis astigmats are fully corrected.

The purpose of this study, then, was to test that hypothesis by measuring the contrast sensitivity functions of low power, oblique axis astigmats, with and without cylinder correction in place, at various orientations of the grating pattern.

METHODS

Four males, three optometry students and one faculty member at Pacific University College of Optometry, served as subjects for this study. They ranged in age from 25 to 44 and were in general good health with no ocular pathologies. Their refractive Rx's are shown in Table 1. One subject (#3) showed a one line improvement in Snellen acuity (20/20 to 20/15) OD, OS, OU when the astigmatic error was corrected. The others showed no more than a two letter improvement (for example 20/20 -2 to 20/20).

Contrast sensitivity measurements were carried out using the Nicolet "Nic-Optronics CS2000 Contrast Sensitivity Testing System"(32). The instrument is located in the Ocular Diagnostics and Special Testing Clinic at Pacific University College of Optometry. It is calibrated and programmed to match standards developed at the State College of Optometry, State University of New York (SUNY); and for ease of cooperative use of the instrument, the same values were adopted for this study. Specifically, the instrument is calibrated at an average screen luminance of 75 candelas per meter squared; the screen is masked with a piece of white plexiglas with a 20 cm. diameter circular hole cut in the center, giving a surround luminance of 25 candelas per meter squared; spatial frequencies of 0.7, 1.2, 2.0, 4.0, 6.0, 11.4, 16.0, and 22.8 cycles per degree were tested, with four measurements made at each frequency. The method of increasing contrast, going from "unseen" to "seen" was used. The entire screen unit was mounted in a cradle frame which allowed it to be rotated through a complete 360 degree range.

Subject #1:	-1.00 -0.50 X 120 OD,	-1.00 -0.50 X 57 OS
Subject #2:	plano -1.00 X 118 OD,	+0.25 -1.00 X 52 OS
Subject #3:	+0.25 -0.75 X 147 OD,	+0.25 -0.75 X 42 OS
Subject #4:	-1.75 -0.50 X 145 OD,	-0.75 -0.50 X 57 OS

TABLE 1. Refractive errors of the experimental subjects.

Testing was accomplished in a fully darkened room, at a distance of 3 meters from the screen. Each subject was fitted with a trial frame containing his appropriate spherical correction, to which the cylinder component could be added. Contrast sensitivity measurements at all eight spatial frequencies were tested monocularly and binocularly, with and without the astigmatic error corrected. The measurements were made, for each subject, with the sine wave gratings oriented at the horizontal, vertical, obliques, and at the exact axis of the tested eye's astigmatic error as well as 90 degrees away from the axis(90°, 180°, 45°, 135°, OD axis, OS axis, OD axis +90°, and OS axis +90°). Since it took approximately 1.5 hours to test monocularly and binocularly, with and without the cylinder correction at one orientation, only two grating orientations were tested in any one session. The complete series of measurements was taken over four sessions of three hours each, extending through a one week period of time.

RESULTS

The contrast sensitivity functions of the four subjects were essentially the same in overall shape and detail, varying , primarily, only in vertical placement along the contrast axis. All the subjects showed the same differences between conditions of testing, with and without cylinder correction in place. The first four figures illustrate the findings of Subject #1, who showed the smallest improvement with the cylinder correction in place. In these figures, the circles represent contrast sensitivity functions for the spherical correction only and the triangles indicate the contrast sensitivity function for the sphere plus cylinder correction condition. Figure 1, which illustrates results for gratings oriented at 90 degrees, shows a moderate increase in contrast sensitivity at spatial frequencies from 6.0 cpd to 22.8 cpd, when the cylinder correction is worn. Figure 2 is for gratings oriented at 180 degrees, and also shows a moderate increase in contrast sensitivity from 6.0 to 22.8 cpd when the astigmatism is corrected. Figures 3 and 4 represent data for Subject #1 when the gratings were oriented at the two principal oblique axes, 45 and 135 degrees. When the gratings are oriented parallel (or close to parallel) to the astigmatic axis (perpendicular to the meridian of cylinder power), the largest effect of the astigmatic correction is seen. On the other hand, there is virtually no effect on either the binocular contrast sensitivity or on the contrast sensitivity of the eye whose axis is approximately 90 degrees away from the grating orientation. Thus, for gratings oriented at 135 degrees (within + or - 15 degrees of the OD axis for all four subjects) only the right eye contrast sensitivity function is enhanced by the addition of the

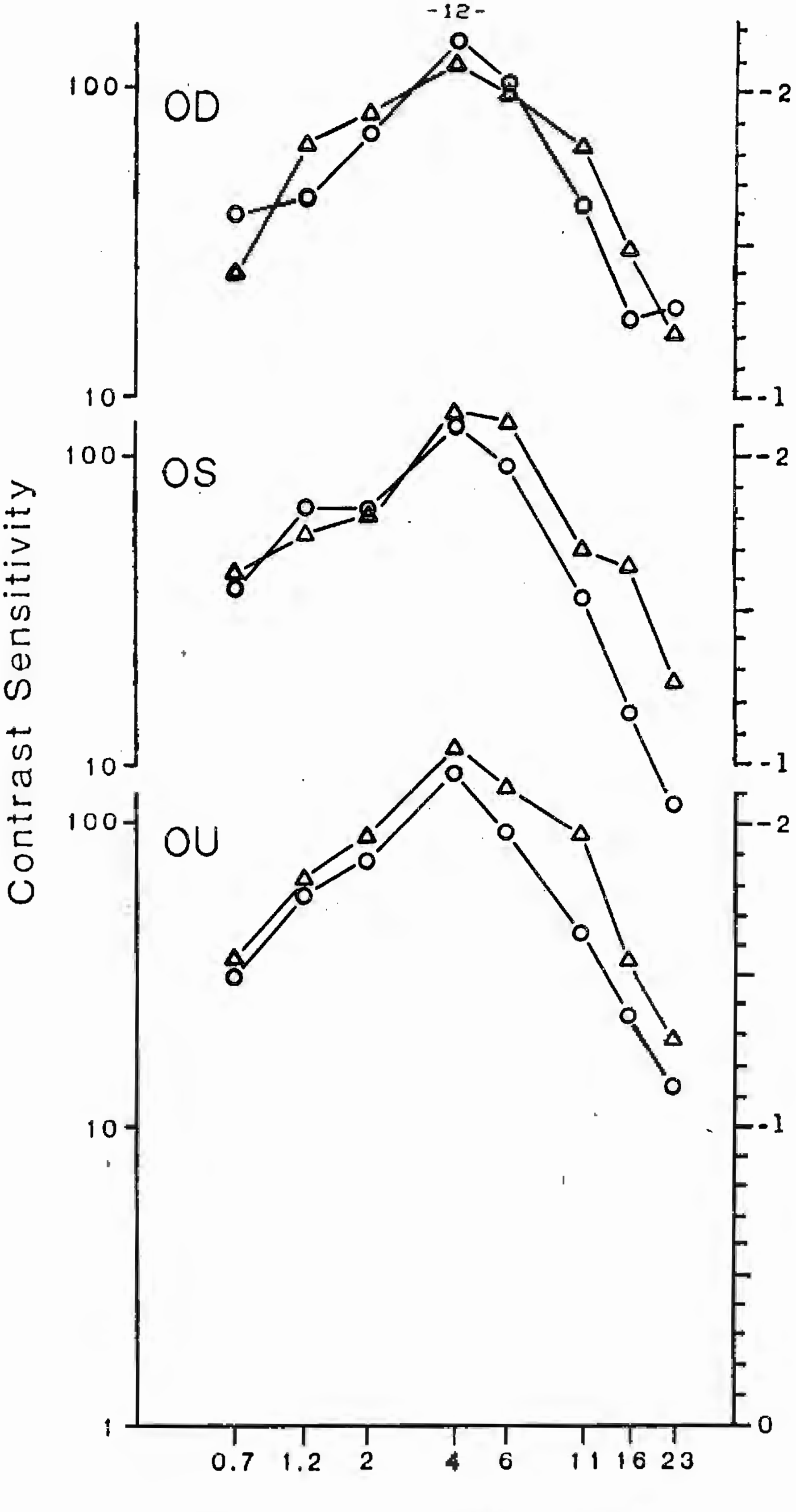

FIGURE 1. Contrast sensitivity functions for subject #1 under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 90 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

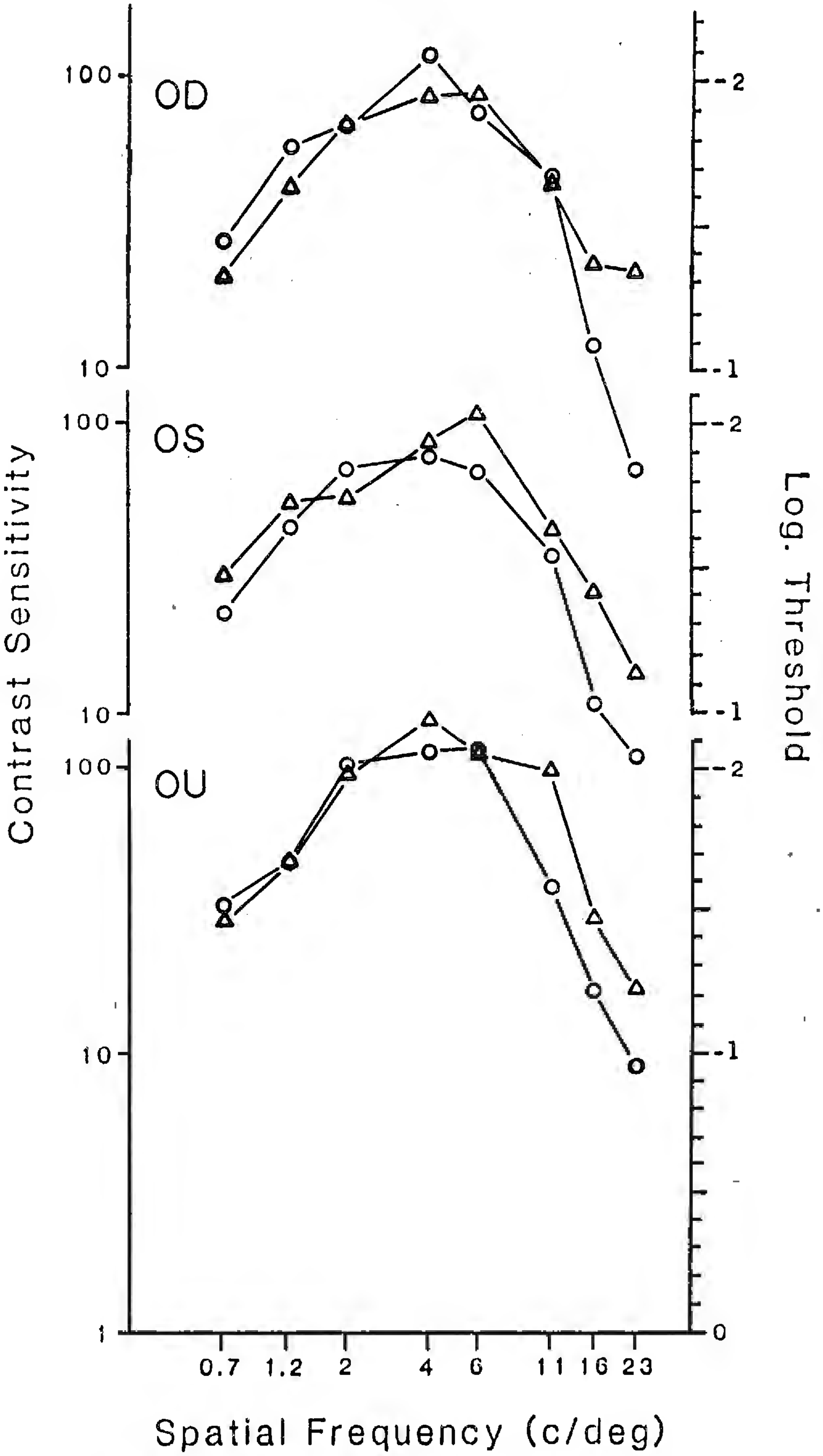

FIGURE 2. Contrast sensitivity functions for subject #1 under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 180 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

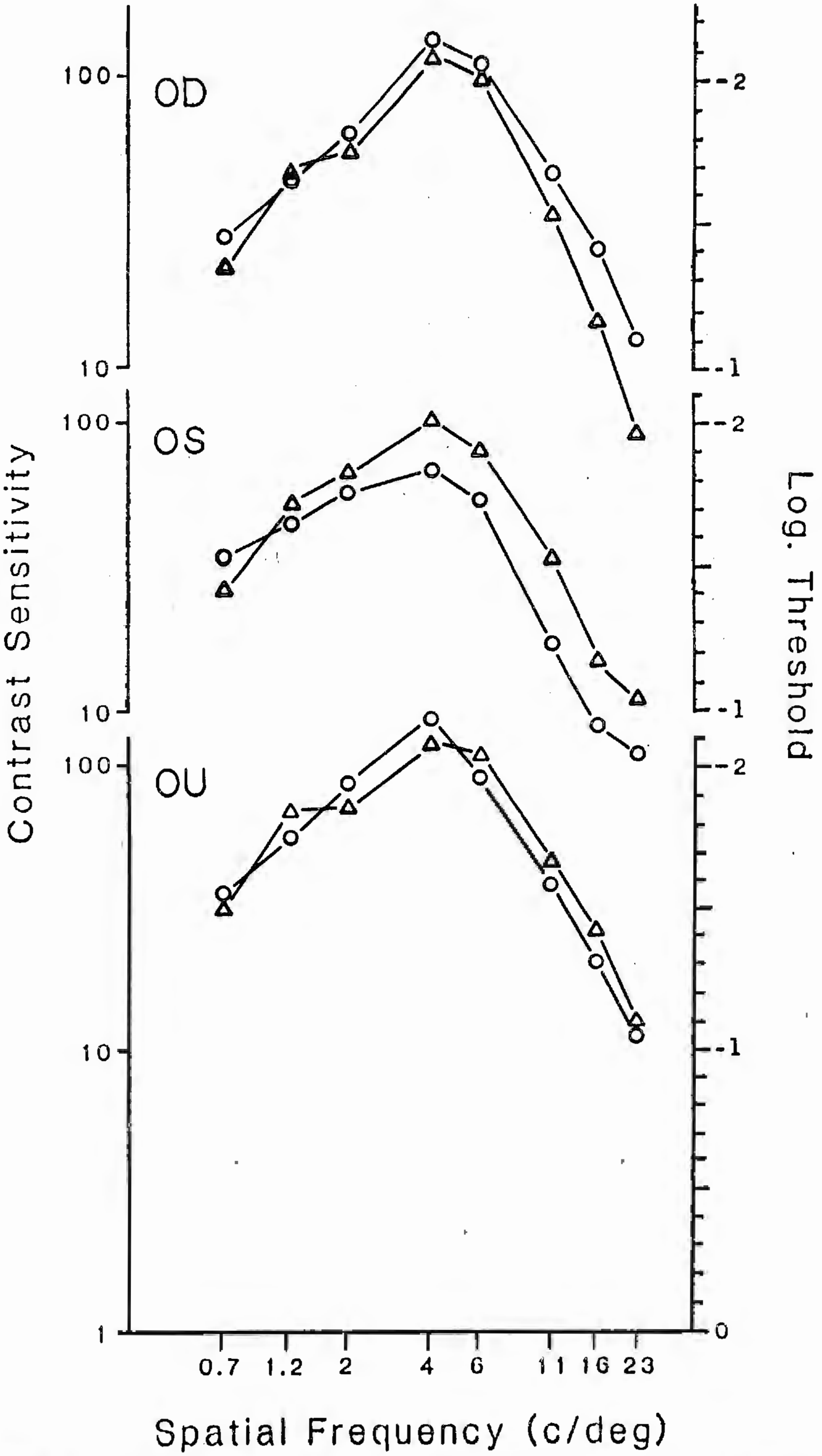

FIGURE 3. Contrast sensitivity functions for subject #1 under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 45 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

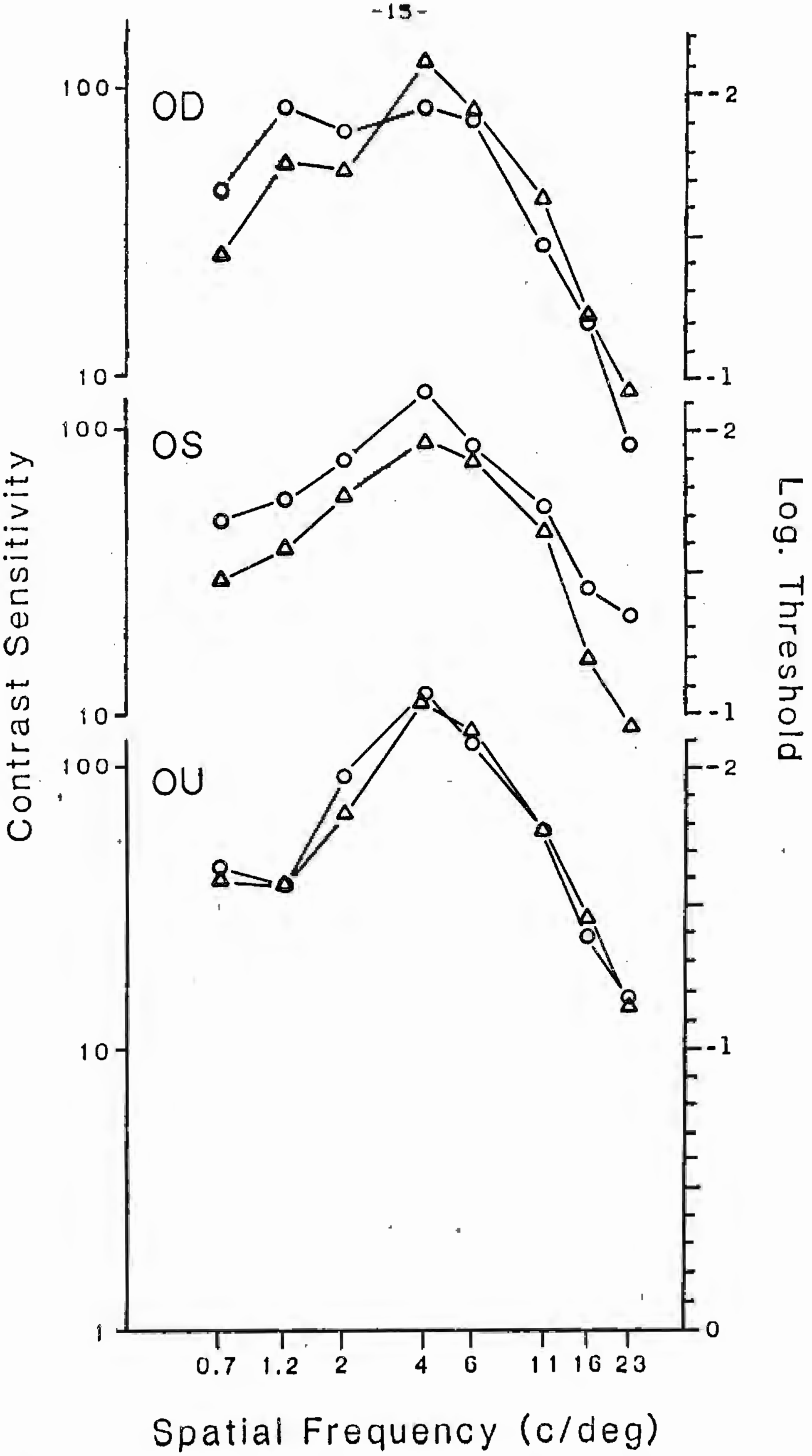

FIGURE 4. Contrast sensitivity functions for subject #1 under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 135 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

cylinder correction; and for gratings oriented at 45 degrees (within + or - 12 degrees of the OS axis for all four subjects) only the left eye contrast sensitivity function is influenced. These same changes occur in virtually identical amplitudes whether the gratings are oriented at 45 and 135 degrees, at the OD and OS axes, or 90 degrees away from the right and left eye axes. The individual curves for the remaining three subjects are similar to those curves of Subject #1 and grating orientations at oblique axes from 115 to 150 degrees and from 40 to 60 degrees all yield similar results. Therefore, only the pooled group mean data from the four principal orientations, 90, 180, 45, and 135 degrees are considered here. Figure 5, for gratings at 90 degrees, shows the same group trends as seen in Subject #1's data, only the differences between conditions are more clear cut. There are large differences seen between the curves depicting contrast sensitivity functions for the sphere only condition and the sphere plus cylinder condition for spatial frequencies of 6.0, 11.4., and 16.0 cpd. The differences are slightly larger, as seen in Figure 6, when the gratings are oriented at 180 degrees. Here, as at 90 degrees, under all conditions of viewing, monocularly and binocularly, the contrast sensitivity at 6.0, 11.4, and 16.0 cpd is enhanced by the astigmatic correction. The grouped data for gratings oriented at 45 and 135 degrees reveal the same results as seen in the individual data for Subject #1. In Figure 7, with gratings oriented at 45 degrees, there is a pronounced improvement in contrast sensitivity for spatial frequencies of 2.0, 4.0, 6.0, 11.4, and 16.0 cpd when the left eye views the gratings with the cylinder correction in place (in all subjects, the OS axis was within + or - 12 degrees from 45 degrees).

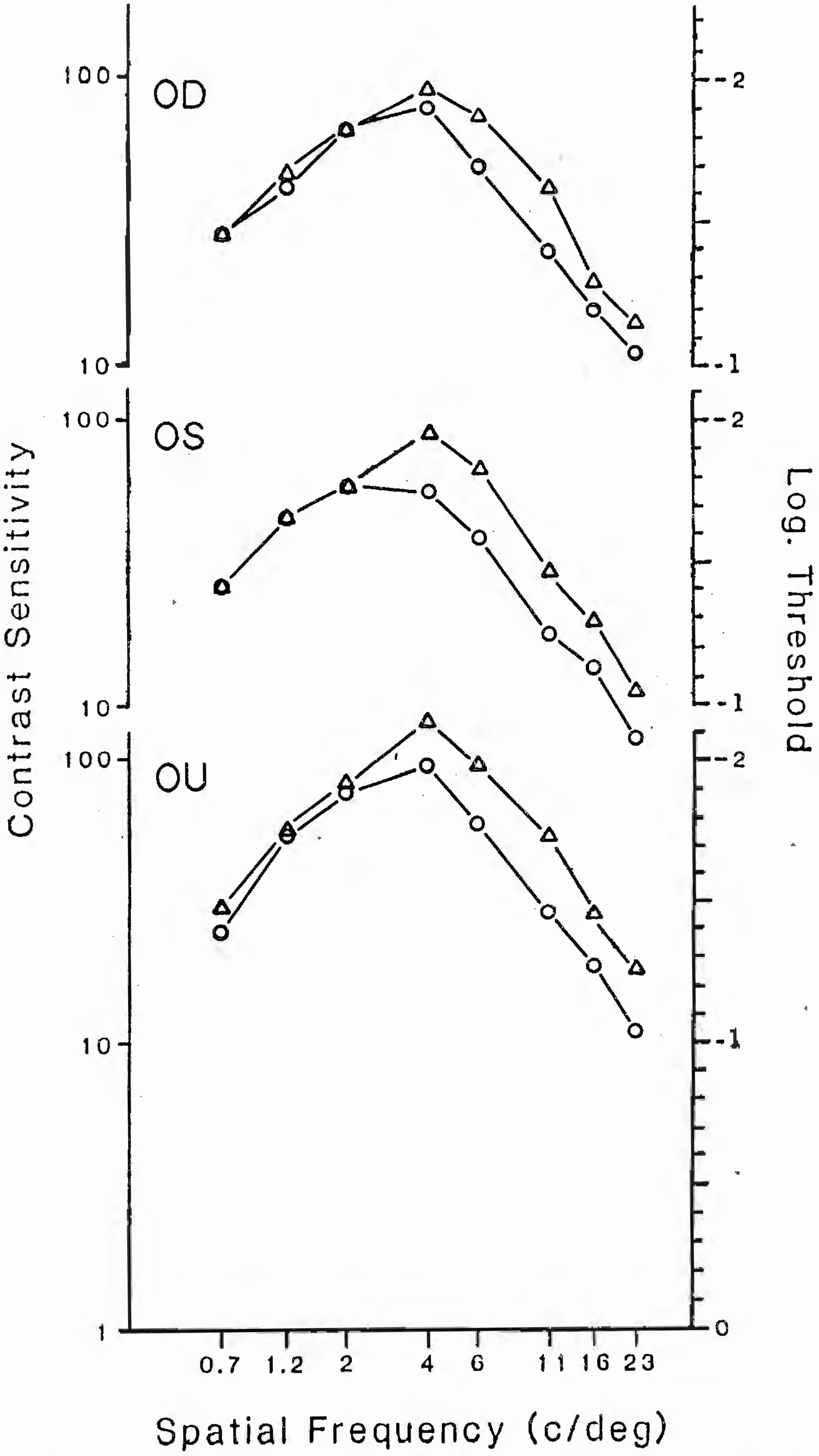

FIGURE 5. Mean contrast sensitivity functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 90 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

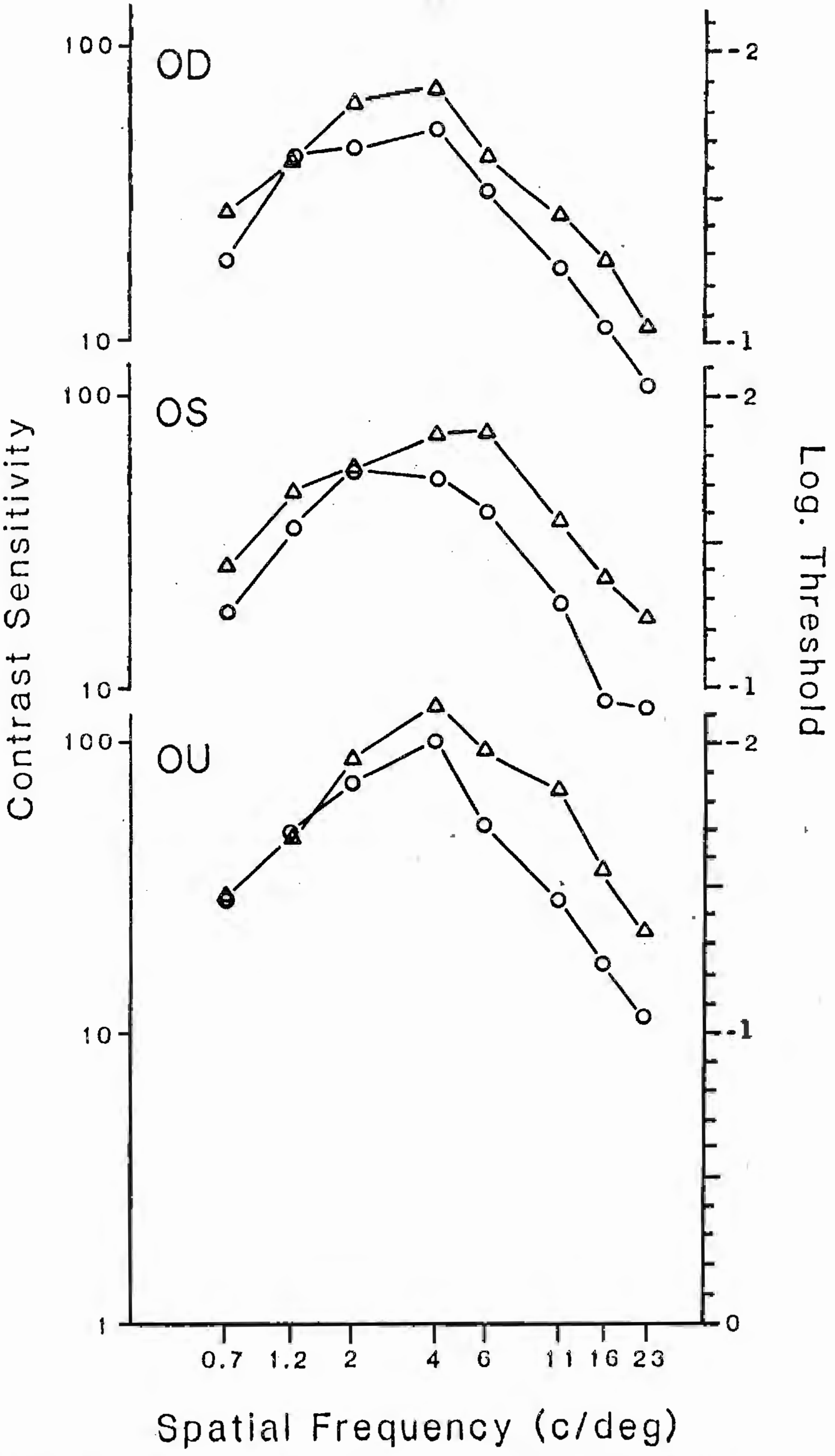

FIGURE 6. Mean contrast sensitivity functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 180 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

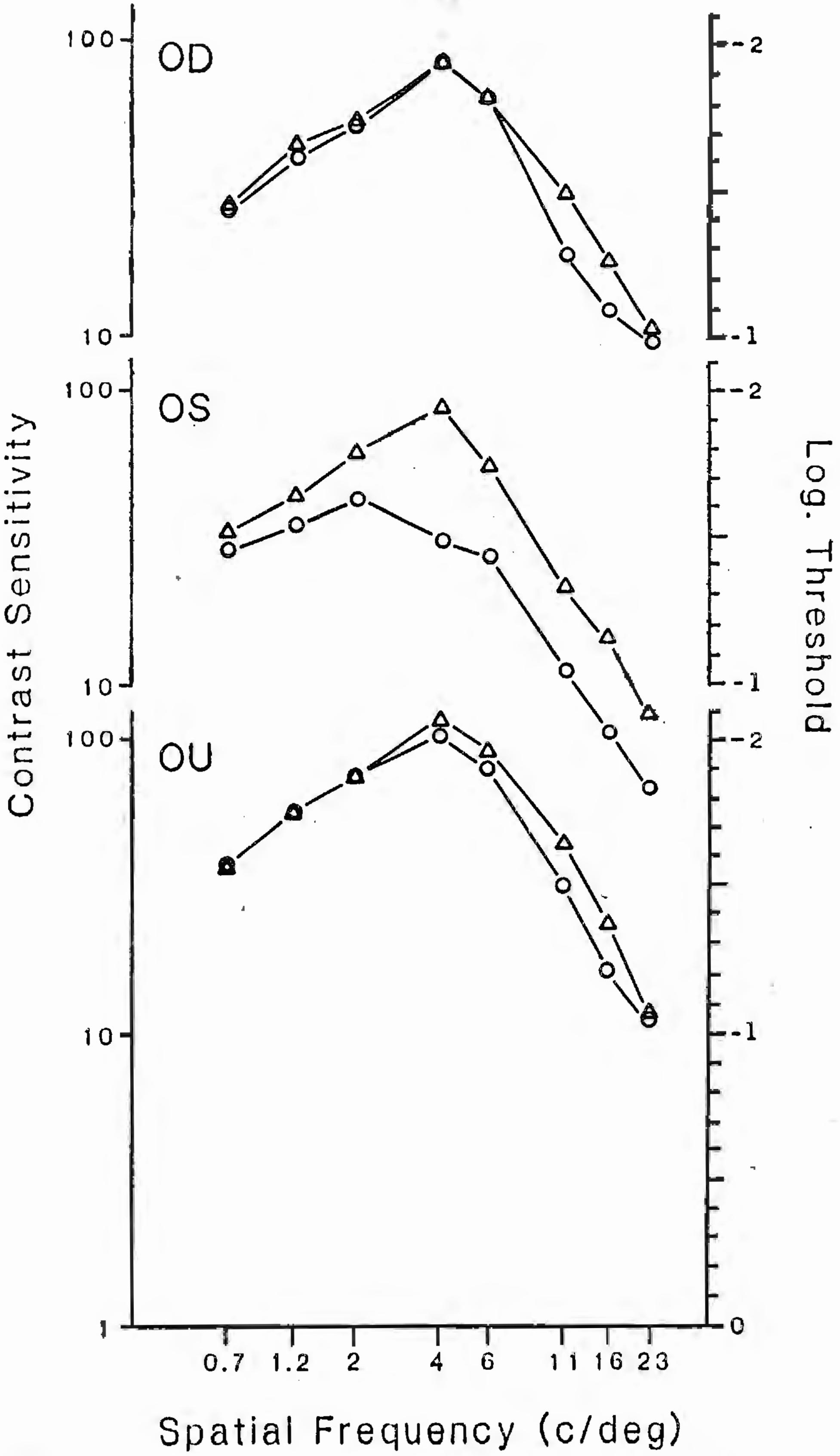

FIGURE 7. Mean contrast sensitivity functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 45 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

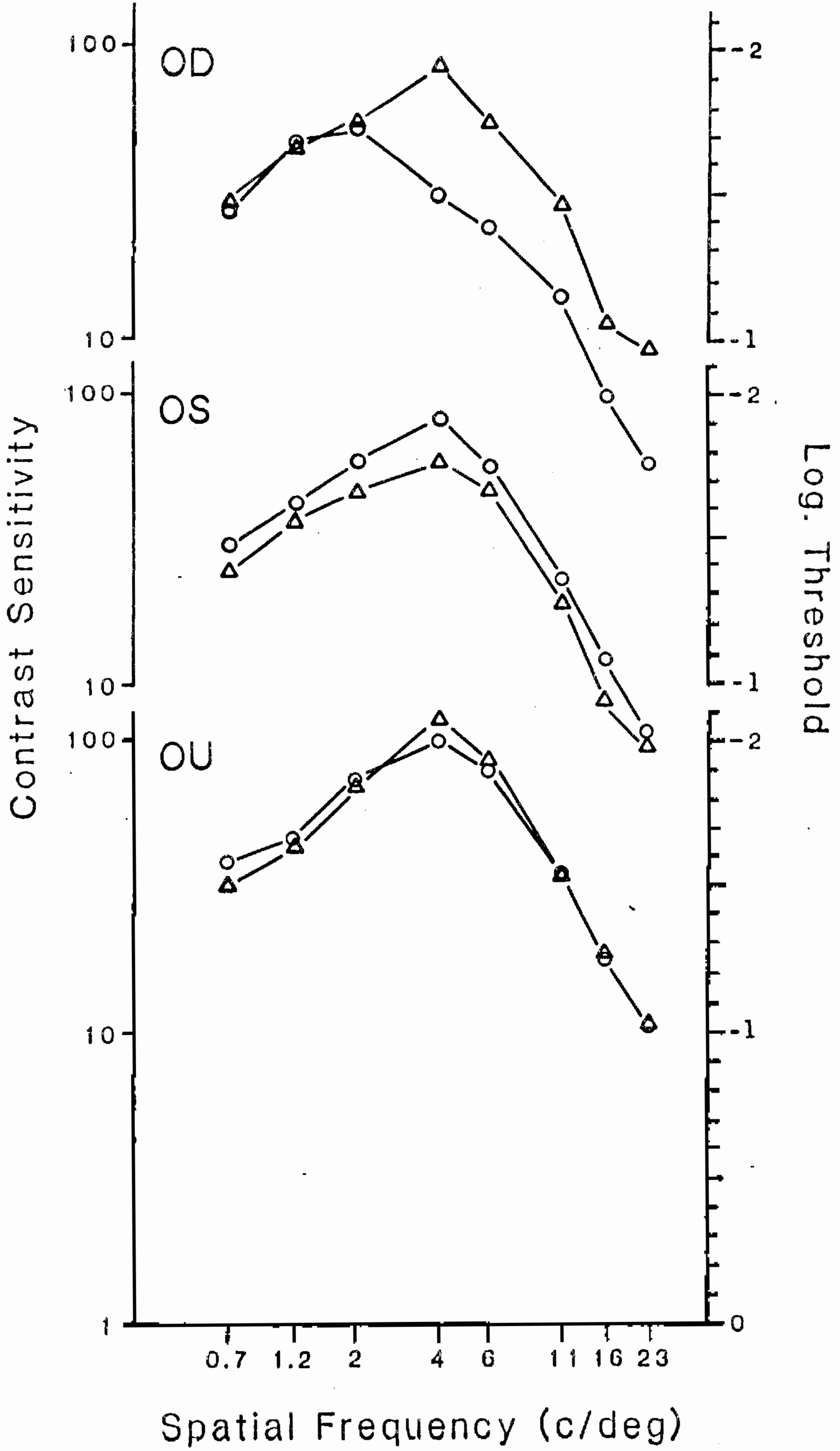

FIGURE 8. Mean contrast sensitivity functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 135 degrees. Circles represent the functions without astigmatic correction and triangles are with the correction in place.

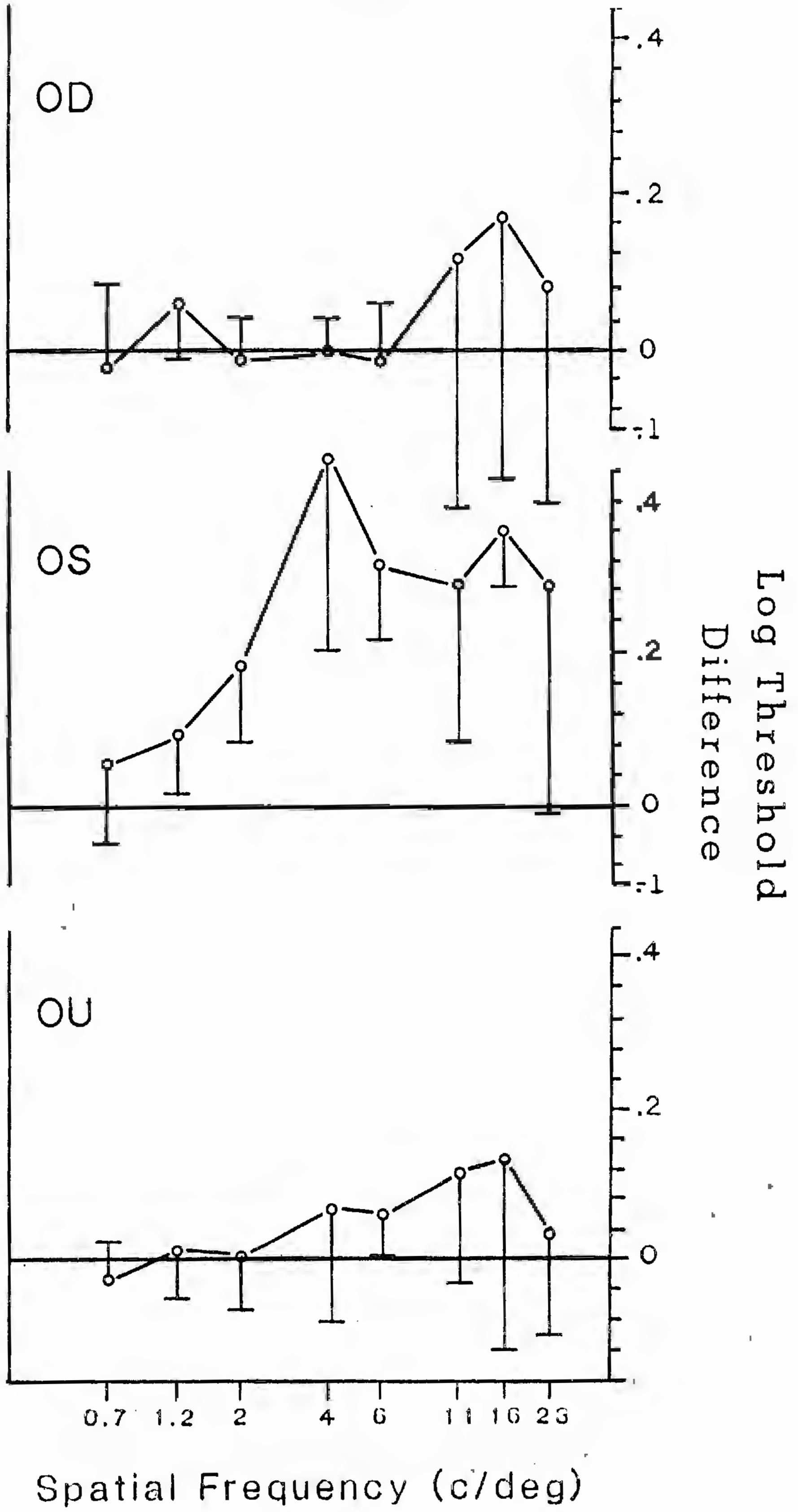

FIGURE 9. Mean contrast sensitivity difference functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 45 degrees. See text for explanation.

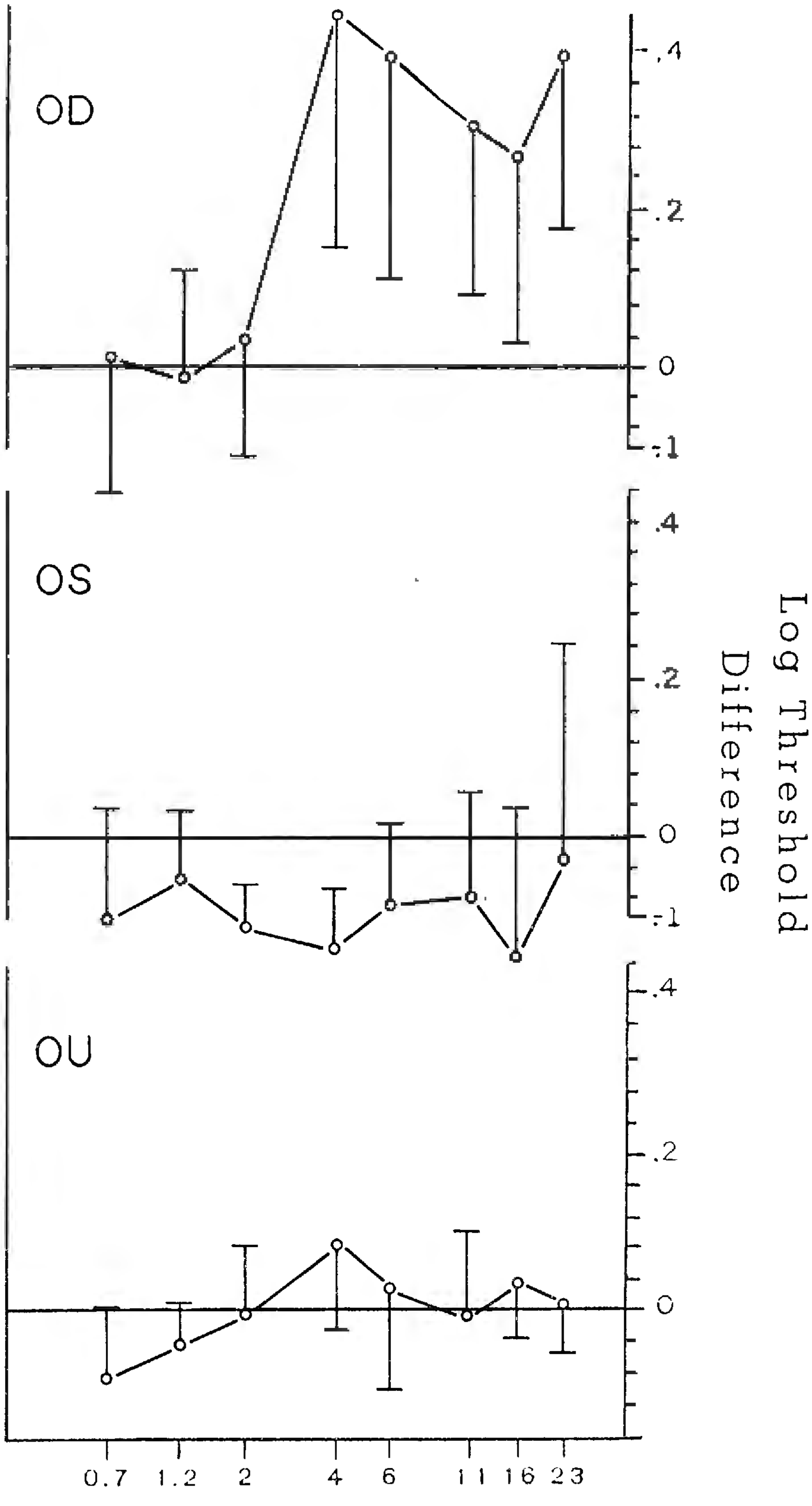

FIGURE 10. Mean contrast sensitivity difference functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 135 degrees. See text for explanation.

enhancement for frequencies of 4.0, 6.0, 11.4, 16.0, and 22.8 cpd; but there is no enhancement measured for the left eye or binocular viewing conditions.

Again, for all subjects, the axis of the left eye astigmatic correction was within 12 degrees of 45 degrees and the right eye axis was within 15 degrees of 135 degrees. Therefore, the findings shown in Figures 9 and 10 could be predicted from present knowledge, based on optics of astigmatic refractive errors, and the modulation transfer functions of such optics. What is not quite so readily predictable or intuitively obvious, however, are the findings when the test gratings are oriented at 90 and 180 degrees. Here, there are significant contrast sensitivity enhancements from the oblique axis cylinder correction under all viewing conditions. Figure 11 shows the mean difference scores for gratings oriented at 180 degrees; and it can be seen that there is a significant enhancement of contrast sensitivity at spatial frequencies of 6.0, 11.4, and 16.0 cpd, for right eye, left eye, and binocular viewing. The same findings hold true for gratings oriented at 90 degrees, as is illustrated in Figure 12. In both of these last two cases, while there are relatively large numerical differences in contrast sensitivity for 22.8 cpd, the variability of the psychophysical estimates at this spatial frequency was so great that consistent statistically measureable differences were not found.

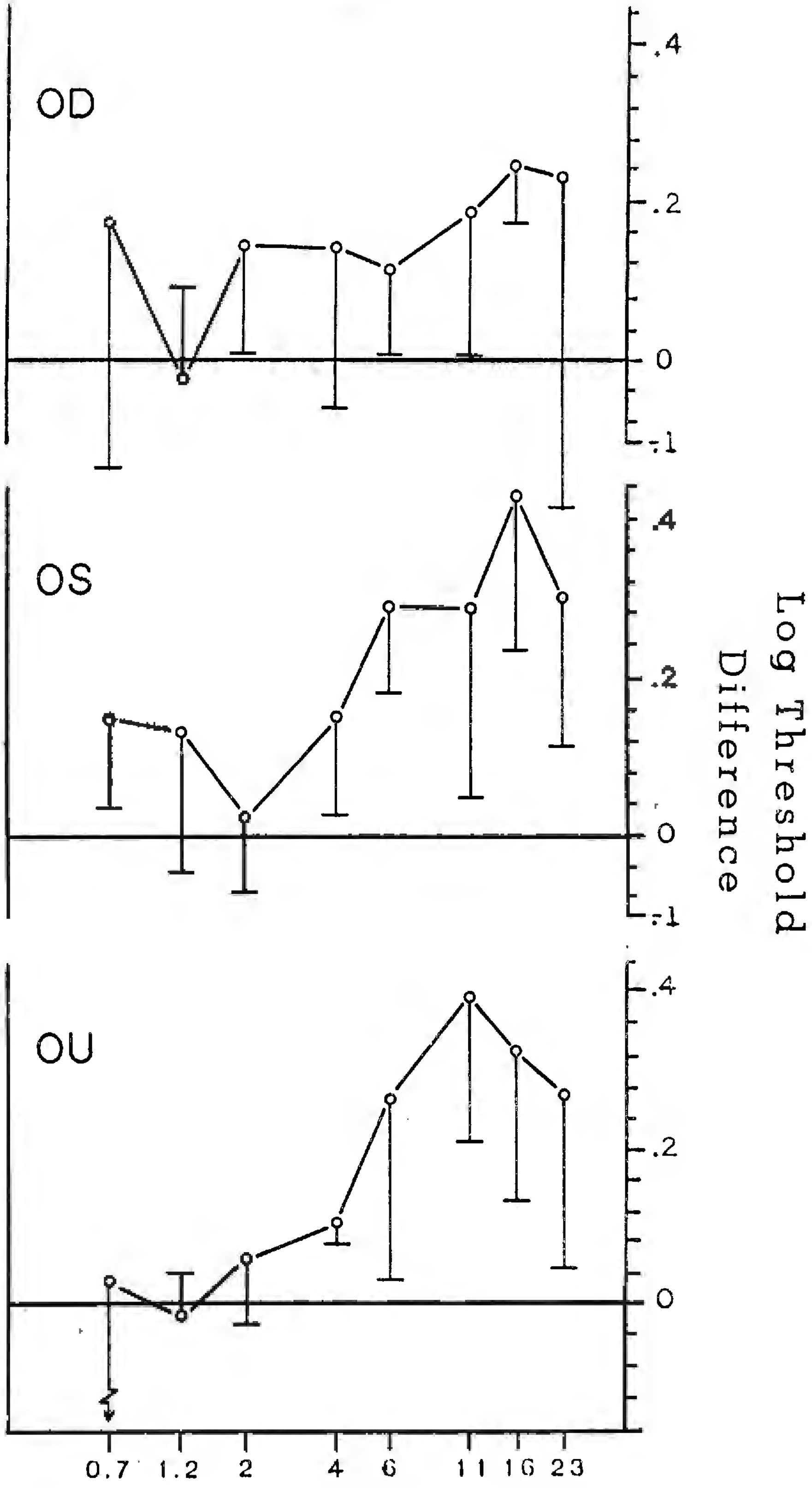

FIGURE 11. Mean contrast sensitivity difference functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 180 degrees. See text for explanation.

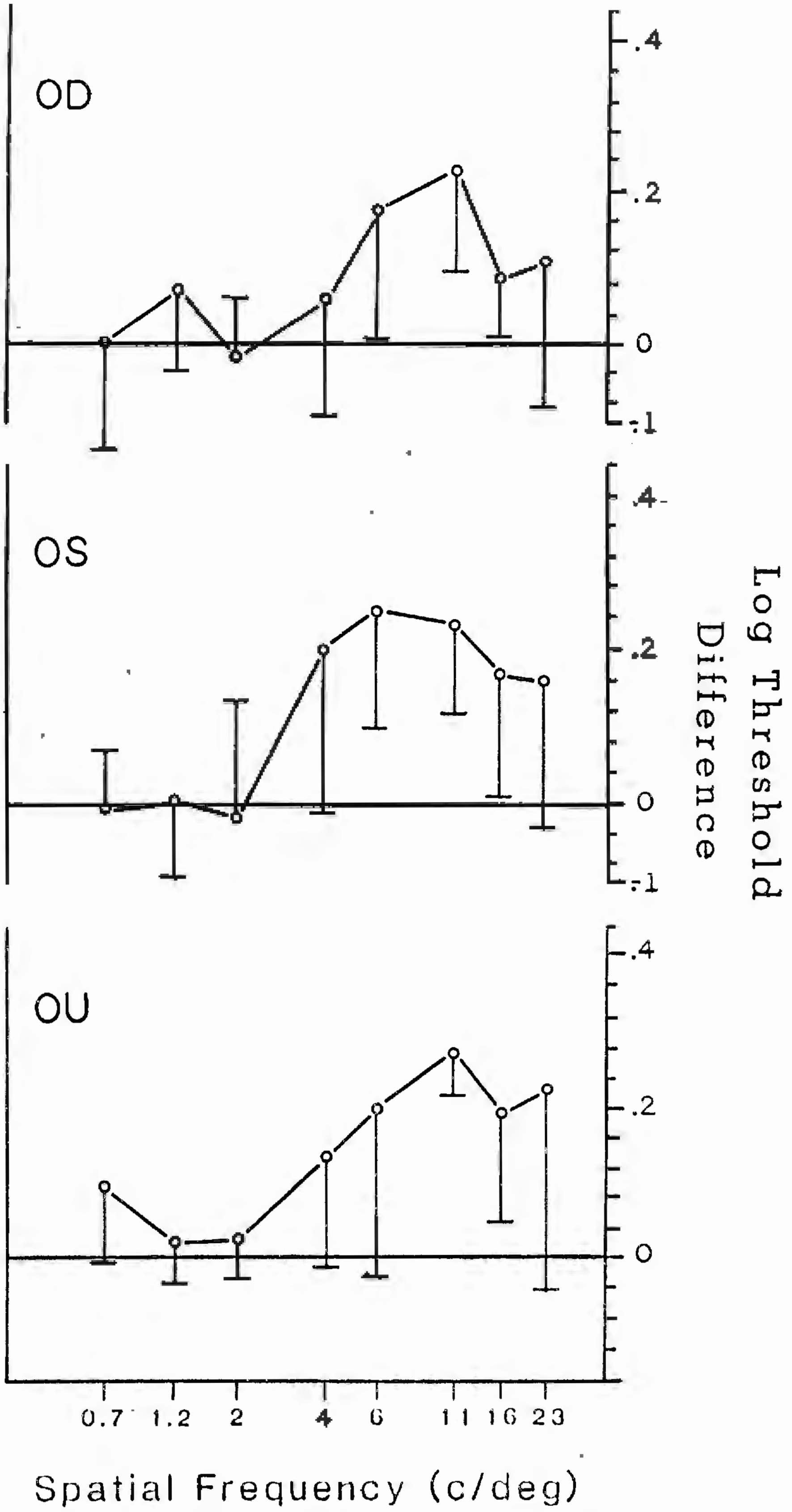

FIGURE 12. Mean contrast sensitivity difference functions under monocular (OD and OS) and binocular viewing conditions, with the gratings oriented at 90 degrees. See text for explanation.

DISCUSSION

The results suggest a clear contrast sensitivity gain in the mid to upper spatial frequency ranges when small amounts of oblique axis astigmatism are corrected. The finding of a high degree of variability in the contrast sensitivity measurements at 22.8 cpd may have been a result of the subjects not being confident of their judgments at this spatial frequency, thus reducing the likelihood of a psychophysically measureable difference in contrast sensitivity. That is, the subjects were apparently doing more "guesstimating" at this spatial frequency. The same phenomenon may also be occurring in the measurements of Snellen acuities.

Therefore, it can be concluded that the correction of small amounts of oblique axis astigmatic refractive error may not provide a patient with a reliably measureable improvement in Snellen acuities; but that correction is still very important for the patient's best full range of contrast sensitivity appreciation and overall improvement of the quality of visual perception.

There should be no doubt in the minds of researchers and clinicians alike that contrast sensitivity testing can provide verification of subtle changes in a patient's visual system. The new, refined photographic charts (Vistech Contrast Test System) are available to clinicians without the requirements of highly trained staff, large blocks of clinic time, and great financial resources to conduct contrast sensitivity testing. The findings of this study suggest an important clinical use of the contrast sensitivity testing in prescribing for oblique axis astimatism. An additional suggestion for future clinical research is the need for gathering extensive normative data using the more clinically applicable contrast sensitivity photographic charts. Such normative data would allow for more widespread clinical and research use of CSF measurements and evaluation.

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