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Spatial Contrast Sensitivity, the Frostig Figure-Ground Test, and Visual Performance in Persons with Macular Degeneration

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in
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ABSTRACT

Spatial Contrast Sensitivity, the Frostig
Figure-Ground Test, and Visual Performance
in Persons With Macular Degeneration

Peter G. Hill

The possibility that a loss of middle and high spatial frequency sensitivity in persons with macular degeneration is responsible for performance deficits on the Frostig Figure-Ground Test (FFG) was investigated. It was expected that, if a loss of sensitivity to these frequencies was the causal factor, it should be possible to reduce normally sighted individuals' performance down to the level of the maculopathic observers by filtering the "critical" frequencies from the test. Similarly, if the first hypothesis is true, one should be able to improve macular degeneration patients' performance on the FFG by enlarging it, which would in essence shift the spatial frequency content of the retinal image to an area where these individuals are more sensitive.

A total of 26 participants, 13 with macular degeneration and 13 controls, were required to complete the FFG under the following conditions: (1) 10 cpd low pass filtered, (2) 8 cpd low pass filtered, (3) 6 cpd low pass filtered, (4) no low pass filter, and (5) enlarged to two times the original size.

A 2 x 4 (Ocular Diagnosis x Filtering Condition) split-plot analysis of variance supported the hypothesis that performance deficits on the FFG were caused by a loss of specific bandwidths of spatial frequency information, $F(3,72) = 28.36$, $p < .0001$. A related groups t-test demonstrated that one could increase performance of maculopathic observers by enlarging the test, $t(9) = -6.03$, $p < .001$, thus confirming the second hypothesis.

The value of the FFG test as a diagnostic tool to assess the visual function of persons with low vision, and suggestions for its improvement are discussed.

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Finally, I dedicate this thesis to Karen who gave me the strength to endure this meandering journey.

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Statement of the Problem

With an ever-growing population of elderly persons there has been a substantial increase in the frequency of age-related health problems. One of the most common and traumatic of these is visual impairment, which often leaves the affected person with only a small amount of residual vision.

Traditional methods of assessing residual sight in persons with low vision are inadequate since they often underestimate, and sometimes even overestimate, visual capabilities. This suggests that traditional tests are measuring only part of the "global" process of vision and are therefore too narrowly focused to adequately assess the visual functions of individuals with low vision.

In recent years, psychophysical and visual-perceptual assessment techniques have proven to be more reliable indicators of residual vision. These testing techniques require the person being assessed to use more of the basic visual skills that are necessary for visual efficiency than do traditional testing procedures. The intent of the thesis is to link psychophysical and visual-perceptual assessment techniques to visual function in various visual tasks.

Review of the Literature

In general, the term residual vision refers to the amount of visual function an individual has left after some visual impairment has affected that person as well as to the types of tasks he/she can accomplish with it (Brown, 1981; Wild & Wolfe, 1982). Until recently, the standard method of assessing persons with low vision has been a combination of Snellen visual acuity and visual field perimetry. Snellen acuity is a measure of the smallest visual angle that can be resolved under optimal, high contrast conditions, usually at a distance of 6 m (20 ft). Research has demonstrated, however, that Snellen visual acuity assessment is not particularly sensitive to many components of visual function.

Marron and Bailey (1982) found that visual acuity had little relation to orientation and mobility performance, as evidenced by a correlation coefficient of .07. Similarly, it has been demonstrated that visual acuity is not a good predictor of performance on the Frostig Figure-Ground (FFG) test or other tests of visual performance such as reading (Faubert, Overbury, & Goodrich, 1986; Quillman, Mehr, & Goodrich, 1981). Finally, Snellen acuity has failed to detect subtle visual dysfunction in pathologies such as renal failure (Woo, Mandelman, Liu, & Haberstroh, 1986), glaucoma (Atkin, Bodis-Wollner, Wolkstein, Moss, & Podos, 1979), and multiple sclerosis (Regan, Whitlock, Murray, & Beverley, 1980).

It seems quite clear that the standard acuity test measures only a relatively small aspect of visual function. This is not surprising since Snellen visual acuity is meant to be no more than a parameter of the eye's resolving power. In the prescription of spectacles for "normal" vision, this may indeed provide a sufficient assessment, but it seems to be insufficient to quantify the functional level of the visual system. One reason is probably that during a usual eye examination only the visual capabilities under optimal conditions are tested. As a result, the external validity of the measure is in question since, in the natural environment, visual situations are rarely optimal.

Many factors interact to produce the environment(s) in which we use vision (Marmion, 1986). Of particular importance to the person with low vision are factors such as type, level, and direction of ambient illumination, task illumination, glare, and the type and degree of contrast between the object being viewed and its surround (Wild & Wolffe, 1982). In the standard Snellen test, few of these factors are taken into consideration; consequently, individuals will not perform as well in "real life" situations as the test predicts they should.

Spatial Contrast Sensitivity

In recent years a psychophysical assessment of vision, called spatial contrast sensitivity (SCS) testing, has emerged out of experimental laboratories and has gained recognition in the clinical domain (Arden, 1978). SCS testing requires observers to detect and resolve sinusoidal grating stimuli as opposed to the Snellen test of acuity which requires the recognition and resolution of letters or symbols which are at high contrast with their surround. Use of sinusoidal grating stimuli is a more basic test of vision than Snellen-type tests as an observer only needs to detect rather than recognize and name letters or symbols (Hess, Jacobs, & Vingrys, 1978). Furthermore, since the amount of processing required for recognition in Snellen acuity measures may be spatially and orientationally too complex for the peripheral visual system to handle (Hess *et al.*, 1978), sine wave grating detection should be more reflective of visual function *per se*.

Sinusoidal gratings resemble blurred black and white stripes and are commonly presented to observers by means of a computer and cathode ray tube screen, grating plates, or in the form of a wall chart (Corwin & Richman, 1986). These sine wave gratings can be varied along a number of dimensions, although the two most common variables are spatial frequency and contrast. Spatial frequency refers to the number of cycles or pairs of light and dark stripes per degree of visual angle (cpd). Contrast is a measure of the ratio of the difference between the highest and lowest levels of luminance in the test pattern to its mean luminance (Atkin, Bodis-Wollner, Wolkstein, Moss, & Podos, 1979). A "normal" SCS curve takes the form of an inverted U-shaped function, as shown in Figure 1, that is, it has a peak sensitivity (the

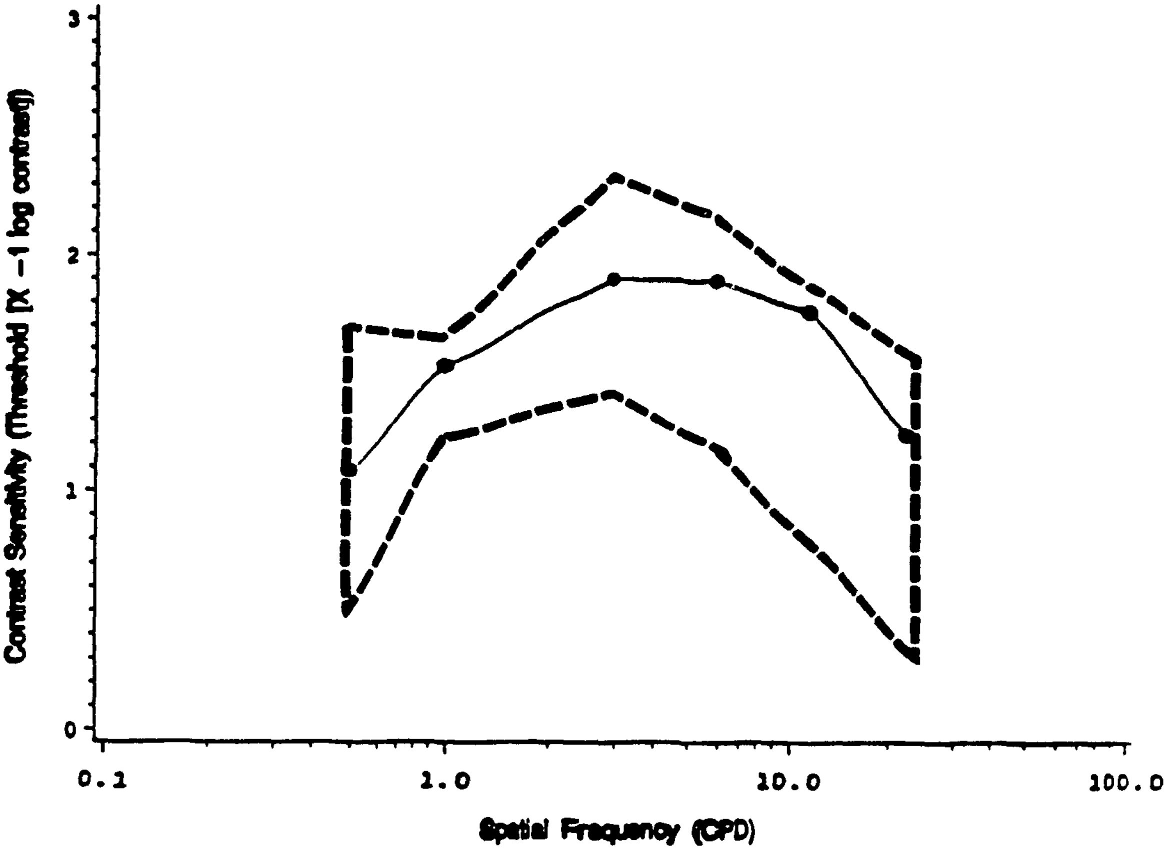

__Figure 1.__ A graph of a normal spatial contrast sensitivity function. The dashed line represents a two standard deviation range of normal variation which is based on mean data from this study.

reciprocal of threshold contrast) at middle spatial frequencies (approximately at 2-4 cpd) with sensitivity decreasing systematically until some cutoff point for both high and low spatial frequencies is reached (Beazley, Illingworth, Jahn, & Greer, 1980; Owsley, Sekuler, & Siemsen, 1983).

The high frequency cutoff of the contrast sensitivity curve, the point where it intersects at the upper end of the abscissa, is measuring the highest spatial frequency an observer can resolve at full contrast. The high frequency cutoff is roughly measuring the same aspect of vision as Snellen acuity charts (Brown, 1981). However, SCS measures a whole range of other conditions as well. Included in the SCS assessment is information about how much contrast is needed to detect low and medium spatial frequencies. While it is important to determine the smallest visual angle one can resolve at high contrast, as in Snellen acuity measures, one's contrast sensitivity to low and medium spatial frequencies is important, for example, in orientation and mobility skills (Marron & Bailey, 1982) as well as for the recognition of faces (Harmon, 1973; Leibowitz, Post, & Ginsburg, 1980).

SCS testing is useful in many different areas concerned with visual assessment and has been successfully used to quantify visual function in a number of situations where Snellen-type acuity measures yield inaccurate results. For example, children are typically hard to assess visually using letter charts since they can get bored and sometimes are not at a cognitive level of development which enables the naming of letters. Atkinson, French, and Braddick (1981) used SCS testing to assess visual function of pre-school children. A reward was placed under a cube with either a horizontal or vertical grating on it and children were instructed to run to, for example, the cube with the horizontal grating on it. In this way it was possible to keep the children amused and motivated as well as to determine their contrast sensitivity functions.

Jacobson, Mohindra, and Held (1981) demonstrated that using a two alternative forced-choice preferential looking technique they could assess vision in infants with congenital cataracts. Spatial sine wave gratings were randomly presented on one half of a presentation screen and the remaining side contained a homogeneous field. Testing started with low spatial frequencies and progressed to higher spatial frequencies. Sessions were stopped when an infant looked at the homogeneous field more than the field containing the grating. The spatial frequency one step below the termination frequency was taken as the threshold or "visual acuity" of that child.

A valid measure of vision should be dependent on the state of the visual system and not on the level of cognitive development of the individual being assessed. As evidenced from the studies mentioned above, spatial contrast sensitivity testing seems to satisfy this condition whereas Snellen acuity measures do not provide a test of these parameters.

SCS testing has been shown to be sensitive to subtle changes in vision due to different visual pathologies when Snellen acuities have predicted "normal function". Glaucoma is commonly diagnosed through a combination of visual field perimetry, ocular pressure measurements, opthalmoscopy, and Snellen acuity. Many researchers have demonstrated that glaucoma patients' contrast sensitivity to low and/or middle spatial frequencies may be attenuated even when high frequency contrast sensitivity, visual fields, Snellen acuity, and ocular pressure measurements are within normal range (Atkin, Wolkstein, Bodis-Wollner, Anders, Kels, & Podos, 1980; Atkin, et al., 1979; Faubert, Brussell, Overbury, Balazsi, & Dixon, 1986). These findings have been replicated by Ross, Bron, Reeves, and Emerson (1985) where a test/retest correlation coefficient of 0.88 or better on SCS measures for each spatial frequency was obtained. It was clearly demonstrated that 71% of glaucoma patients showed abnormal SCS at one or more spatial frequencies. These were two standard deviations different than normally sighted individuals. Moreover, 52% of ocular hypertensive patients showed the same abnormalities.

These abnormal results were obtained from eyes with good visual acuity and full visual fields. Ross and his colleagues conclude that there can be optic nerve fibre loss in ocular hypertension and glaucoma in the absence of loss of acuity as measured by standard tests. They therefore suggest that a more sensitive method, such as contrast sensitivity, for differentiating between glaucomatous and non-glaucomatous ocular hypertensive patients is needed to provide specific criteria for diagnosis and therapy.

Many haemodialysis patients complain about changes in their vision between treatment sessions even when no significant differences in Snellen acuity measures are observed (Woo _et al._, 1986). When SCS results of patients were compared before and after haemodialysis treatments, SCS improved after treatment. These authors concluded that SCS can monitor subtle changes in vision which are not detected by traditional tests.

Lennerstrand and Lundh (1980) found that SCS could monitor subtle changes in visual function of children undergoing therapy for amblyopia. Most children showed some increase in visual acuity for far and near; however, in quite a few cases visual acuity remained at a constant level even after 15 sessions. Increases in SCS occurred in children whose Snellen acuity showed improvement as well as those whose vision remained "unchanged". One interesting example is a child whose Snellen acuity was no different before and after treatment of his amblyopic right eye. SCS testing showed that a significant increase in sensitivity to middle and high spatial frequencies occurred after only 10 sessions. It was concluded that improvement of contrast sensitivity from amblyopia treatment occurs without parallel improvement of Snellen acuity.

Snellen acuity seems then to have limited value in the assessment of vision in the global sense. On the other hand much research has shown that SCS testing incorporates an assessment of Snellen-like acuity as well as providing researchers and clinicians with a much broader assessment of visual function. SCS testing includes the important factor of the degree of contrast necessary to detect objects of varying sizes which the more traditional measures do not consider. One final example of where this information is invaluable is for the prescription of low vision devices. Woo and Wessel (1982) assessed a person whose best corrected visual acuities for distance were 6/15 (20/50) and 6/30 (20/100) in the right and left eye, respectively, and whose near acuities were 1.0 M (20/50) in the right and 1.25 M (20/60) in the left eye. The individual was found to have early cataracts, a hazy vitreous, myopic crescents on the fundus of both eyes, and lattice degeneration specifically on the temporal quadrants of each retina. Although visual acuities seem to suggest that mere magnification of print should enable this person to read, the results of SCS indicated that this was not the case. The SCS test displayed an overall depression of sensitivity, with the right eye having a cut-off at 9 cpd and the left at 6 cpd. While optical devices magnify print, such an invidual needs enhancement of contrast as well as magnification. If this person's vision was assessed using the Snellen acuity charts alone, an incomplete, and in a sense inaccurate, prescription most probably would have been made. From the results of the SCS testing, it was clear that a closed circuit television which can magnify as well as enhance contrast would probably be the best device to improve this patient's visual function.

It is also possible to have loss of narrowly defined bandwidths of spatial frequency sensitivity. Sekuler, Hutman, and Owsley (1980) have shown that older subjects display a relative inability to see large and intermediate-size spatial frequencies. Weale (1986) claims that amblyopes display deficits at high spatial frequencies while sensitivity impairments to low spatial frequencies are weaker or non-existent. Glaucoma research has shown that individuals can have specific loss of low frequency information (Faubert, Brussell <u>et</u> <u>al</u>., 1986). People with central field deficits show loss of high and perhaps higher middle spatial frequencies (Marron & Bailey, 1982). Finally, Regan and his coworkers (1980) demonstrated that multiple sclerosis patients can have loss of frequencies between 10 to 20 cpd while higher and lower spatial frequency sensitivity is not attenuated.

Given that different tasks require use of different types of spatial information (Marmion, 1986) and the fact that specific loss of particular ranges of spatial frequency sensitivity can occur, one can assume that depending on the type and quantity of loss, different task-specific abilities could be impaired. For instance, the apparent divergence of the parallel lines seen against a herring-bone background in the Zoellner illusion would be expected to disappear when the background is not resolved (Weale, 1978). Weale found that when the spatial frequency of the background lines is too high, or if the person viewing it has a high spatial frequency loss, the apparent divergence of lines will not be perceived.

Thus, spatial contrast sensitivity testing assesses an individual's ability to detect visual stimuli as a function of both size and contrast which allows the test to be sensitive to many visual disorders that standard evaluation techniques are not.

Predicting Reading Ability in Low Vision

When one looks at persons with low vision as a group, or when one considers just those observers with intact central vision, acuity measures are a better predictor of reading speed than contrast sensitivity (Rubin, 1986). At face value this may seem surprising considering the overwhelming amount of evidence which suggests that SCS testing should be more "accurate" than traditional vision assessment techniques. This confusing finding can be addressed by looking at subsets of vision impairments in the low vision population.

This population contains individuals afflicted by central loss as in macular degeneration, peripheral loss as in glaucoma, overall sensitivity loss in cataracts, and irregular loss in retinitis pigmentosa. According to spatial contrast sensitivity theory, each of these conditions could potentially give rise to a number of discrete but predictable task-specific losses. For instance, if one loses the macular area of the retina which is used for reading in the normal case, one loses the ability to resolve high spatial frequency information (Arden, 1978). If an eye is affected by glaucoma where the peripheral retina is degenerated one may lose the ability to resolve low or middle spatial frequency information (Atkin, <u>et</u> <u>al</u>., 1979). Persons with spared macular areas may perform well on reading tasks whereas persons with central loss may not. If, however, one were to switch tasks and look at orientation and mobility skills which require the use of low and middle frequency spatial information, persons with central field loss would presumably perform much better than those persons with peripheral field loss (Marron & Bailey, 1982).

Rubin (1986) found that, when considering subjects with central field loss, acuity is a poorer predictor of reading capability than contrast sensitivity. In 1986, Ginsburg, Rosenthal, and Cohen reported that, in terms of predicting reading performance, standard visual acuities predicted 11 false positives whereas contrast sensitivity predicted only three.

Legge and his colleagues have extensively examined the process of reading in normally sighted individuals and persons with low vision (Legge, Rubin, Pelli, & Schleske, 1985; Legge, Pelli, Rubin, & Schleske, 1985). Among other things, they specifically looked at reading speed as a function of the visual angle subtended by letters. Through low-pass filtering techniques, it was discovered that the critical spatial frequency bandwidth required for reading is about two cycles per character regardless of character size. In other words, to be able to read characters of a given size one must be sensitive to the spatial frequency of which two cycles could be fit into that letter size. Therefore, to read 24 degree letters one must be sensitive to low frequencies (0.08 cpd) and to read 0.4 degree letters one has to be sensitive to relatively higher spatial frequencies (5 cpd). These findings were further substantiated by Legge, Rubin, and Schleske (1986). They found that readers with normal vision have a peak reading speed of approximately 250 words per minute (wpm) for letters between 0.4 and 2.0 degrees of visual angle and, furthermore, that reading speed drops off abruptly for letters of smaller visual angle and more gradually for letters of larger visual angle. This sounds much like the SCS function. More specifically, the visual system is most sensitive to middle spatial frequencies (middle sized letters) and decreases in sensitivity abruptly to higher frequencies (smaller letters) and more gradually to lower spatial frequencies (larger letters). Legge and his coworkers (1986), reported that individuals with central field loss had a peak reading speed of about 50 wpm for letters subtending 12 to 24 degrees. Individuals with peripheral field loss had a peak reading speed of approximately 100 wpm for letters subtending three to six degrees of visual angle. These data support the notion that reading does not only involve the resolution of high spatial information as evidenced by the fact that one can read larger letters even when loss of the ability to resolve fine detail is caused by central field loss. But, these data also suggest that one needs more than peripheral vision to reach reading speeds exceeding 100 wpm by any significant degree. However, since persons with central loss could still read larger letters at a rate of 50 wpm, one cannot rule out the possibility that low and middle frequency sensitivity does play a role in predicting success in their reading performance. Since they have peripheral sparing and can read large letters, their sensitivity to low and middle spatial frequency information must also be spared to some extent.

The Frostig Figure-Ground Test

The Frostig Figure-Ground test (FFG) was originally intended to be used as perceptual "exercises" to enhance development in language, sensory-motor functions, higher thought processes, integrative abilities, and social and emotional growth in children with learning difficulties (Frostig, 1972). Frostig noted that children with these difficulties often have deficits in figure-ground perception and that this skill could be enhanced by exercises which require the child to find or trace particular geometric figures in pictures in which two or more figures intersect. Through this perceptual or figure-ground training, she tried to facilitate the transfer of initial visual perceptual training to academic skills.

In the early stages of this extensive test battery, a child might be asked to find "birds in a forest", or "fish in a picture of the ocean floor". Later in the training procedure, he/she might be asked to find the root of a conjugated word, or particular syllables in a multi-syllabic word. Thus, Frostig claims that such exercises are useful in developing word analysis, arithmetic, as well as figure-ground perception skills.

More recently, Quillman and his coworkers (1981) demonstrated that the FFG is a good predictor of visual function in persons with low vision, whereas Snellen acuity measures are, for the most part, inaccurate. They found that scores on the FFG correlated well with reading speeds and overall visual performance, whereas acuity measures yielded unreliable predictions.

Conrod, Bross, and White (1986) demonstrated that the FFG and other perceptual tests can be used to assess visual perception skills in low vision populations and, furthermore, that FFG scores are a useful predictor of successful adjustment in low vision functioning. In agreement with these findings was the discovery that correlations ranging from .56

to .80 existed between the FFG and reading performance as well as other related tasks such as word search, letter search, and target match (Faubert, Overbury, & Goodrich, 1986).

While the FFG was originally intended for the assessment and training of children with learning disabilities, it is interesting to note that it could be implemented and utilized to assess the state of the adult visual system in the case where ocular pathology has disrupted normal function. Assuming that persons with low vision are "normal" in terms of cognitive development and learning abilities, it follows that any decrement in performance on the FFG should be due to dysfunction of the visual system.

To perform well on the FFG, the observer is required to use many different aspects of spatial vision. To be successful on the first four panels of the test, it is probably not necessary to resolve fine detail, as can be seen in Figure 2. However, as one progresses to the last four panels, the observer must be able to resolve smaller visual angles to be able to resolve the borders of the figure of interest from the other figures in the panels.

Considering only Snellen acuity measures, one might predict that persons with good acuity will be able to perform quite well on this test and those with poorer acuity will not. This is, however, not the case. As evidenced by much research, persons with low Snellen acuity can perform quite well on earlier panels of the FFG but performance breaks down

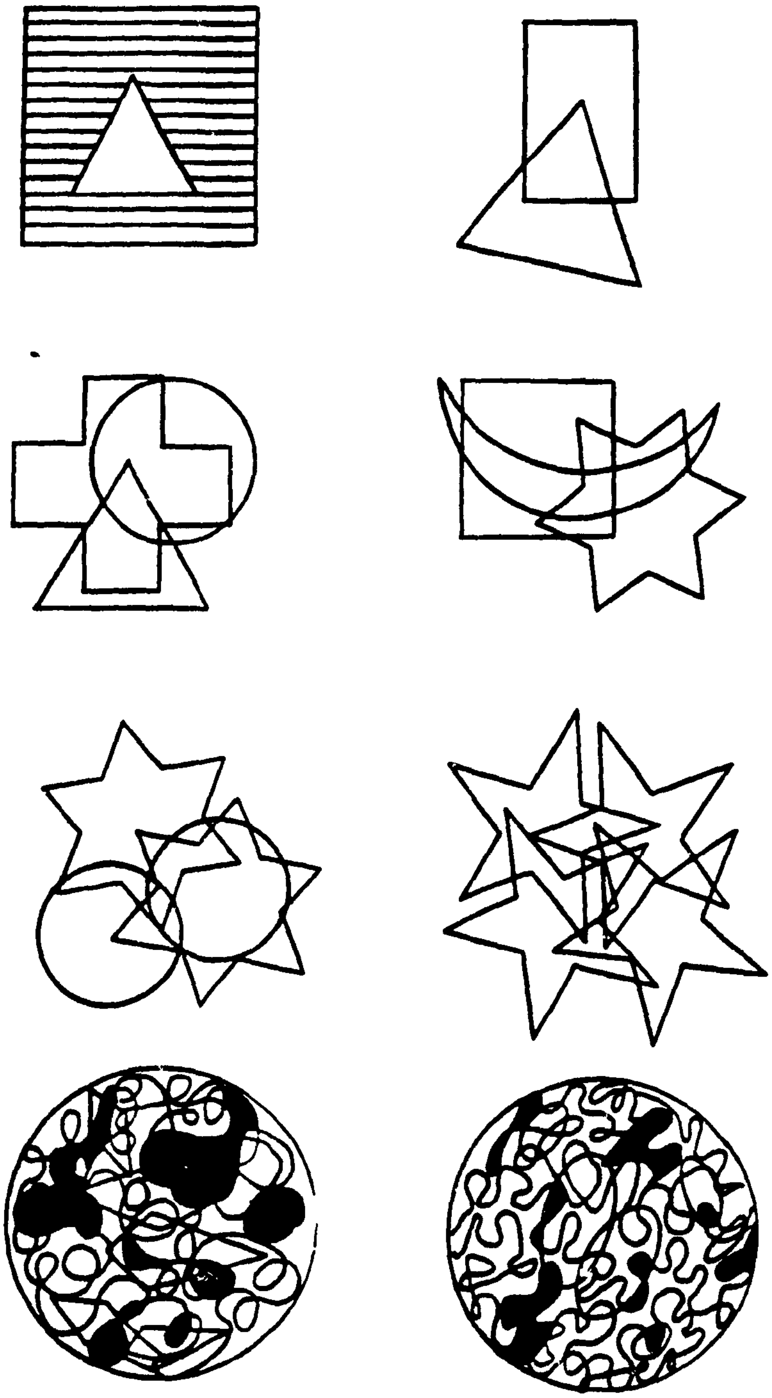

Figure 2. The Frostig Figure-Ground Test.

as the observer moves on to the latter panels of the test (Conrod, et al., 1986; Faubert, Overbury, & Goodrich, 1986; Overbury, Hill, Faubert, & Jackson, 1987; Quillman, et al., 1981).

In view of these findings, together with the SCS data, the present study was conducted to determine the relationship between visual performance on a perceptual test such as the FFG and the psychophysical assessment of SCS.

Present Study

In the studies reviewed above, a relationship between the FFG and reading performance was demonstrated. More recently, it has been established that spatial contrast sensitivity is also related to performance on the FFG (Hill, Overbury, Faubert, & Jackson, 1988; Hill, Overbury, Quillman, & Faubert, 1988; Overbury, et al., 1987). While these findings have been replicated, the causal relationship between FFG performance and SCS has not yet been identified. Therefore, the intent of the present research was to address the possibility that SCS may be the primary factor responsible for an individuals performance on the FFG. The rationale for this hypothesis derives from the finding that, as one progresses through the panels of the FFG, from panels 1 to 8, more detail must be resolved to successfully separate individual figures from their respective backgrounds. Likewise, as detail increases, the critical spatial frequency information needed for figure-ground discrimination shifts to the high end of the contrast sensitivity function where more contrast is needed to resolve it. Thus, if one were to have an impairment of medium and high frequency channels of the visual system, it would be expected that one would not be able to perform well on the latter panels of the FFG. Depending on the degree of middle and high spatial frequency impairment, one would therefore expect performance deficits at different points of the test. The greater the loss of sensitivity to the critical spatial frequencies, the earlier in the test performance should break down.

Upon first considering this notion, this appears contrary to the research findings of Sekuler and Owsley (1982) who claim that the low frequency information of a picture may carry the figure-ground relationship. However, the task in the FFG is not to decide if the entire panel is present or not, which would merely require low frequency information, but rather it involves picking a particular shape within the panel as being the figure and discriminating it from everything else which is considered ground at that point in time. Therefore, in this case, the frequencies which carry the essential information for discriminating figure from ground are relative to the panel under consideration. For instance, in the first panel, low spatial frequency information may well be essential for figure-ground discrimination, whereas in the last two panels, the critical information is more likely carried by medium or high spatial frequencies. This gives rise to the more specific hypotheses that (1) if visual performance depends on sensitivity to medium and high spatial frequencies, then one should be able to "impair" normal visual systems to the level of performance of persons with low vision simply by filtering these frequencies from the task, (2) one should be able to increase performance on the FFG for observers with low vision by increasing the size of the test stimuli since this, to some degree, compensates for losses in middle and higher spatial frequency sensitivity. The following study was conducted to test these hypotheses.

Method

Subjects

A total of 26 subjects, 13 individuals with macular degeneration and 13 normal controls, were recruited (with their informed consent) from the Department of Ophthalmology at the Royal Victoria Hospital. Normal control subjects were required to be free from ocular pathology and had to be optically correctable to an acuity of 6/9 (20/30) or better (see Appendix F). Macular degeneration patients were considered eligible to participate in the study upon being referred to the Low Vision Center by their ophthalmologist. The acuities of persons with macular degeneration were between 6/12 (20/40) and 6/133 (20/400) (see Appendix F). The mean age of the normal control sample and individuals with macular degeneration were 61 and 77, respectively (see Appendix F). All participants were refracted for their best corrected visual acuity and were corrected for the testing distance; one third of a diopter was added to their manifest refraction to avoid possible complications of accommodation (Meteren & Vos, 1972).

Materials

A portion of the Frostig Figure-Ground test, shown in Figure 2, was used to assess visual performance of all subjects. Snellen distance acuities were noted at the time of intake, using the Feinbloom Low Vision Distance Chart.

Contrast sensitivity functions of patients were determined using the Nicolet contrast sensitivity tester (Optronics, Model CS-2000). The method of increasing contrast was used and responses were controlled by the experimenter since many of the participants had poor manual dexterity and slow reaction times due to their age.

All panels of the FFG were digitized using a drum scanner (Optronics, Model P1000) using a sample line width of 100 microns, as shown in Figure 3. Each panel was then put through two-dimensional low pass filtering on a Sun Microsystems Computer (Model 3/160 Colour) using a software package developed by the Human Information Processing Laboratory (Department of Psychology, New York University, 1983). The FFG was subjected to the following low pass filters: 10 cpd, 8 cpd, and 6 cpd, as shown in Figures 4 to 6, respectively. All digitized images were printed on a DEC laser printer (Digital Equipment Corporation, Model LN01S) at

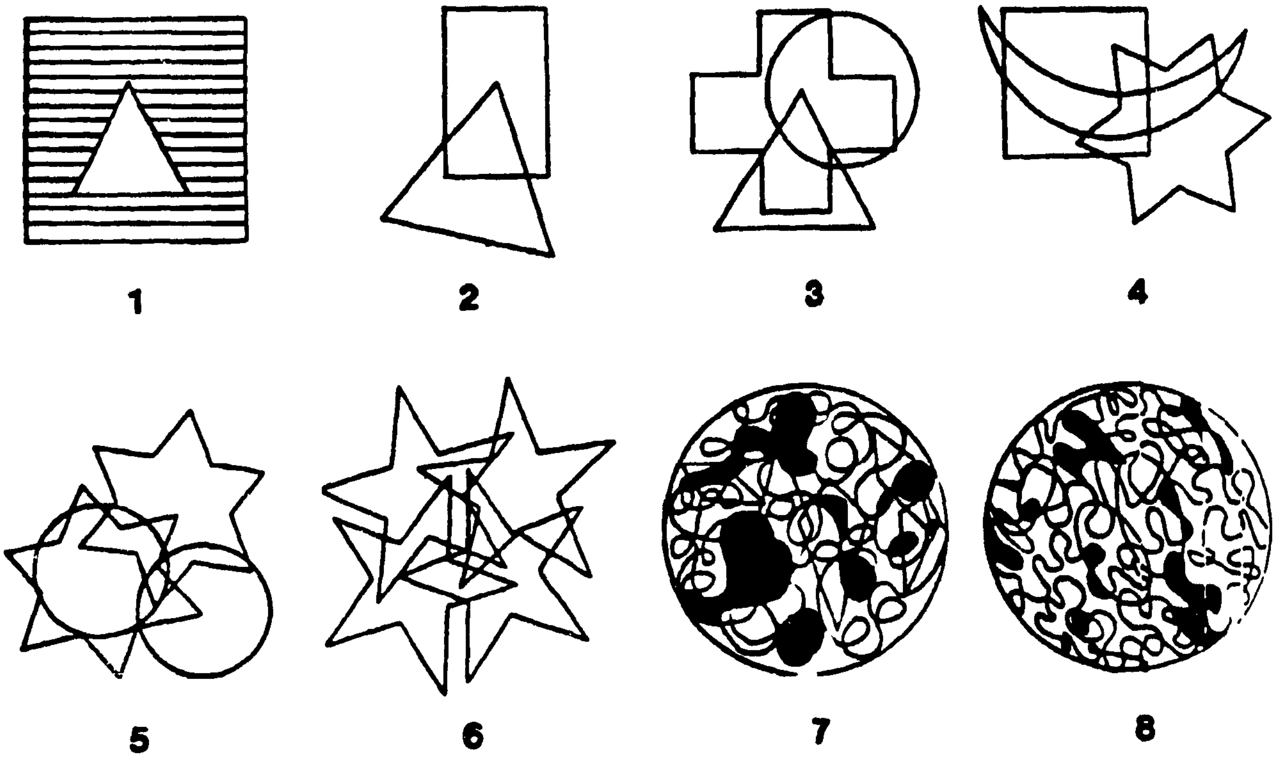

Figure 3. The digitized Frostig Figure-Ground Test.

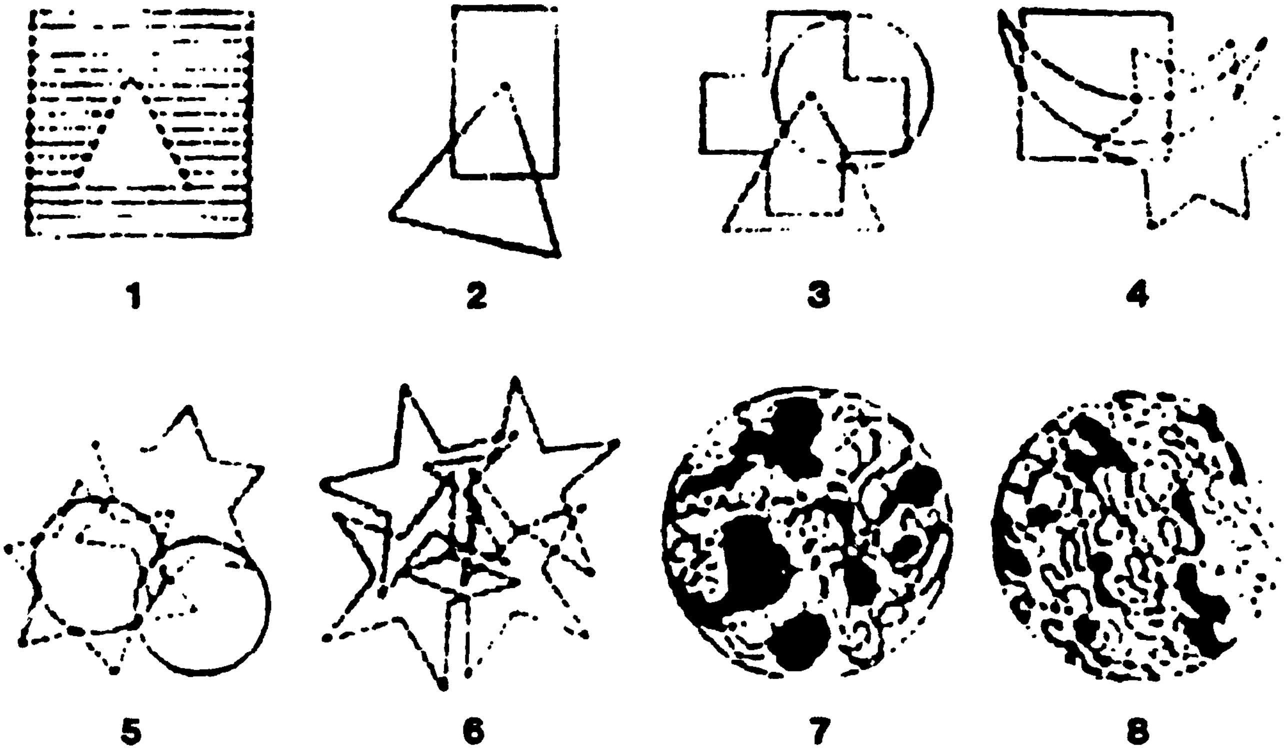

Figure 4. The Frostig Figure-Ground Test after a 10 cpd low-pass filter has been applied.

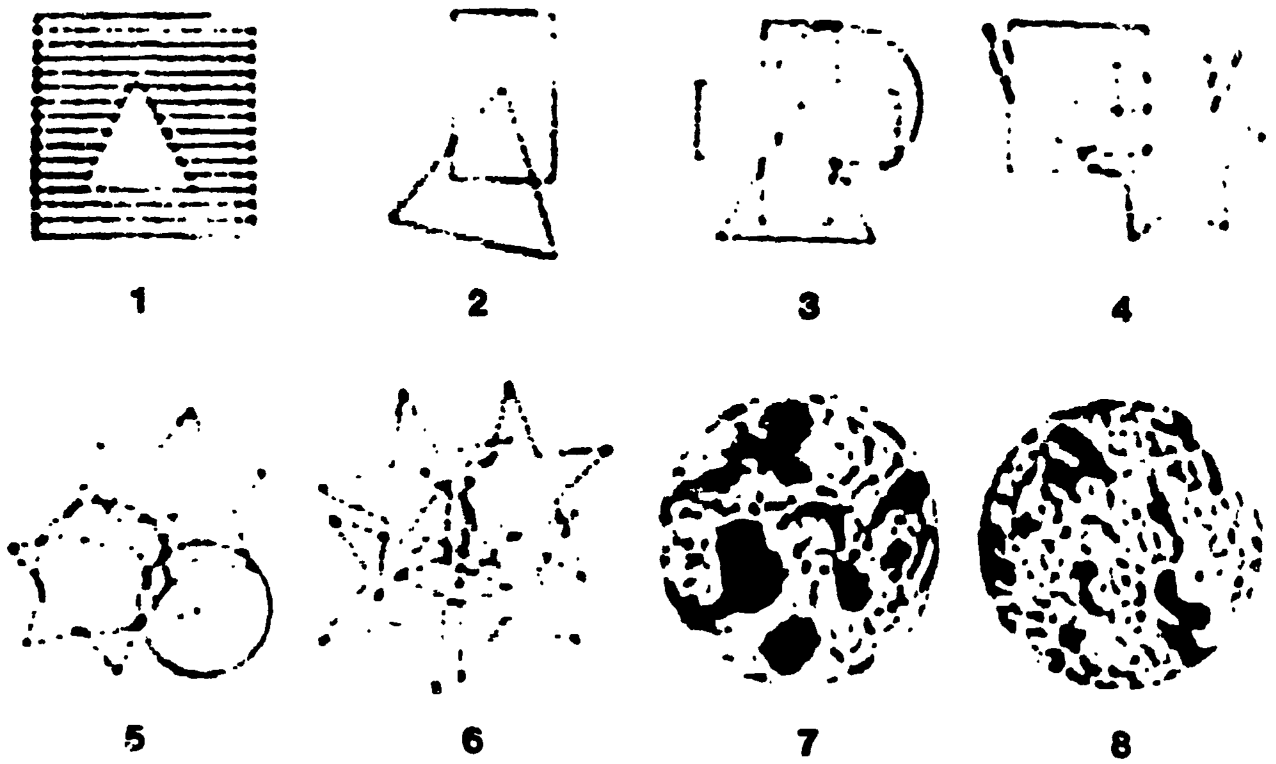

Figure 5. The Frostig Figure-Ground Test after an 8 cpd low-pass filter has been applied.

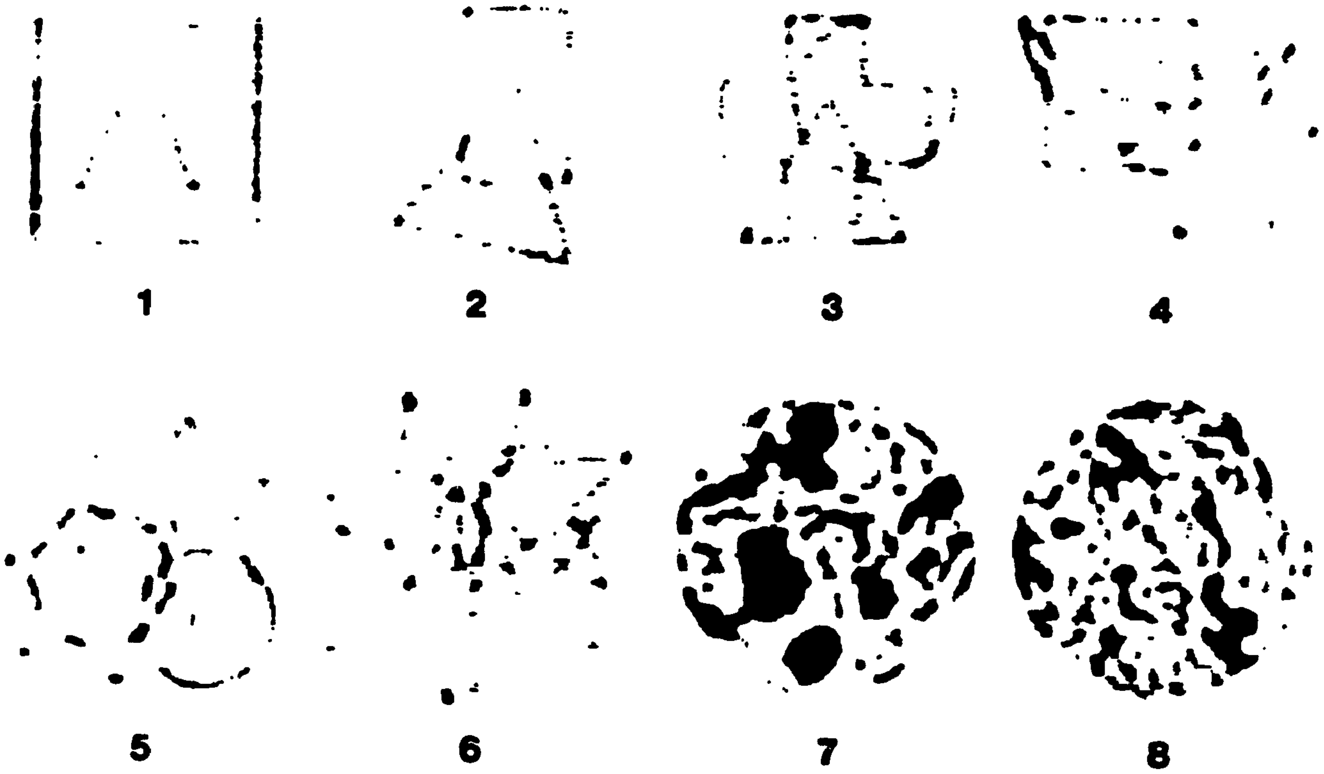

Figure 6. The Frostig Figure-Ground Test after a 6 cpd low-pass filter has been applied.

a resolution of 90,000 dots per square inch and were then photographed and enlarged to make them the same size as the original FFG test. A second copy of the unfiltered FFG stimuli was enlarged to twice its original size to test the second hypothesis.

All stimuli were presented to participants at a distance of 40 cm using a modified version of the VCTS 6000 near vision testing system shown in Figure 7. Luminance of the white background of the photographs was adjusted to 8566 cd/m^2 for all conditions using an adjustable Luxo lamp and a Spectra Spot Meter.

Procedure

During the intake session in the Low Vision Center, subjects read and signed a consent form (see Appendix A). Upon completion of the form, best corrected Snellen acuities (both distance and near) were obtained (see Appendix F).

The following procedure was standard for obtaining distance visual acuities. Subjects were presented with the Feinbloom Low Vision Distance Chart at a viewing distance of 3 m with high illumination. The rationale for this was three-fold. First, the letter "E" is typical of acuity charts and is easy to identify whereas the Feinbloom chart uses numbers. Second, persons with macular degeneration do not perform well under conditions of low illumination due to reduced retinal sensitivity. Therefore, measures of vision in these conditions will not be affected by nuisance variables. Third,

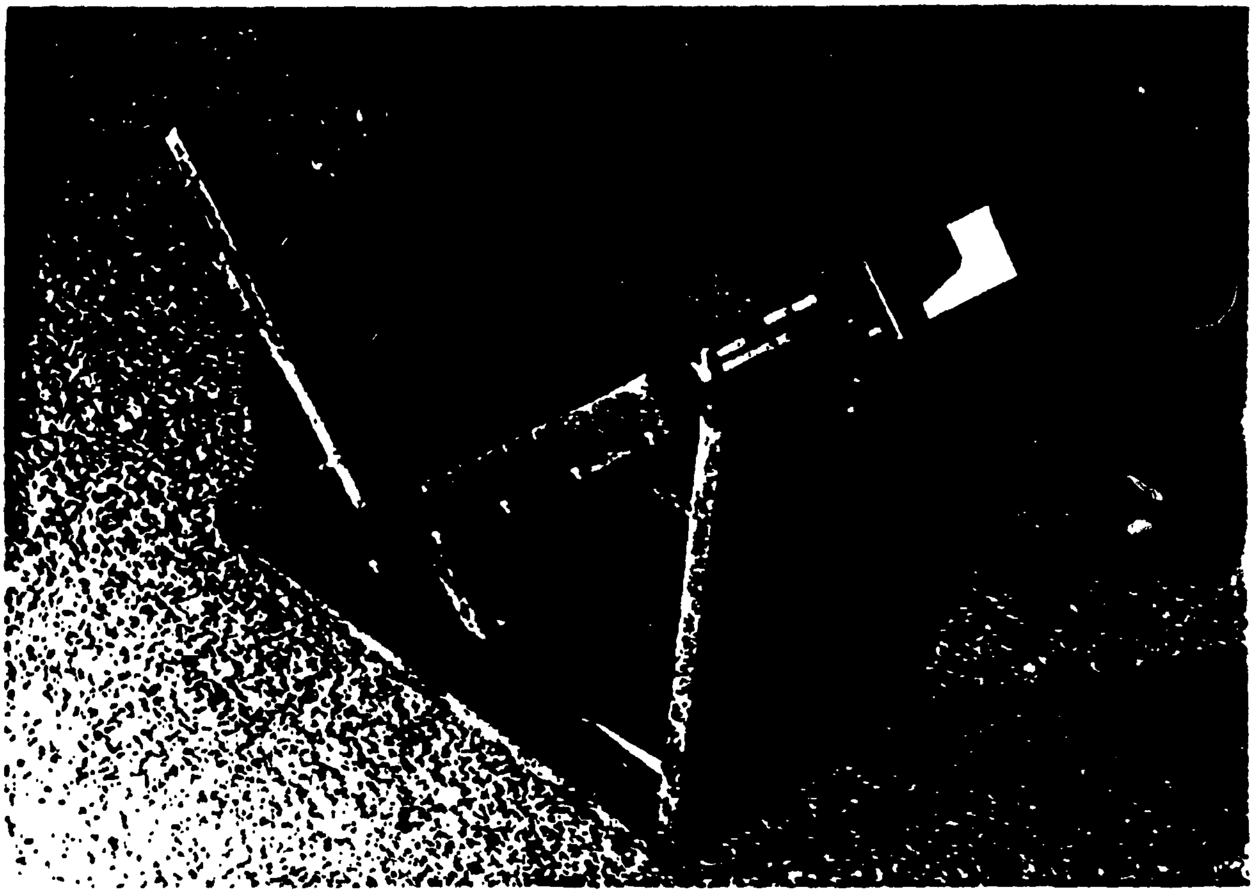

Figure 7. A photograph showing the testing apparatus used in the experiment.

Snellen charts contain only a few large letters whereas the Feinbloom chart has several at each acuity level. Since Snellen charts give so few chances to the person with low vision, who may only see the largest letters, it is not a "fair" assessment of their distance vision. If the subject still could not read the Feinbloom chart at 3 m, the testing distance was shortened to one meter and high illumination was still used. Finally, subjects who could not read the chart at one meter with high illumination were excluded from the study.

Subjects' SCS was then evaluated (for instructions to subjects see Appendix B). The Nicolet cathode-ray tube screen was viewed from the standard distance of three meters (10 ft). The method of increasing contrast was used to determine each participant's contrast threshold necessary to detect sine wave gratings of 0.5, 1.0, 3.0, 6.0, 11.4, and 22.8 cpd. The experimenter was responsible for pressing the response button when the observer vocalized to avoid as much individual difference interference as possible.

All participants, both with normal vision and with macular degeneration, completed the FFG under all filtering conditions (see Appendix C for instructions to subjects). Ten out of the original 13 persons with macular degeneration were available to complete the enlarged version of the FFG to test the second hypothesis. To eliminate sequence effects all trials were randomized for each participant.

Results

Results from the SCS testing demonstrated that all persons with macular degeneration were within the two standard deviation normal range of sensitivity for the 0.5 cpd spatial frequency, and below the normal range for 3.0, 6.0, 11.4, and 22.8 cpd gratings. Ten of these 13 individuals (77%) were more than two standard deviations less sensitive to the 1 cpd sine wave grating than the averaged normal control data. The high spatial frequency cut-off appeared at 11.4, 6.0, and 3.0 cpd for 6 (46%), 5 (39%), and 2 (15%) individuals, respectively. None of the participants in the macular degeneration sample perceived spatial frequencies above 11.4 cpd. Figure 8 is representative of the results mentioned above, however, all macular degeneration patients' SCS curves appear in Appendix D. It is of interest to note that the individuals with macular degeneration need more contrast to see the same spatial frequencies as normal observers and that the perception of higher spatial frequencies is attenuated for individuals with macular degeneration.

To test the hypothesis that one can impair FFG performance of normally sighted individuals to the level of those with macular degeneration, by filtering "critical" spatial frequencies, a 2 x 4 (Diagnosis x Filtering Condition) split-plot analysis of variance (ANOVA) was carried out. The number of figures traced correctly on the FFG was taken as the dependent measure.

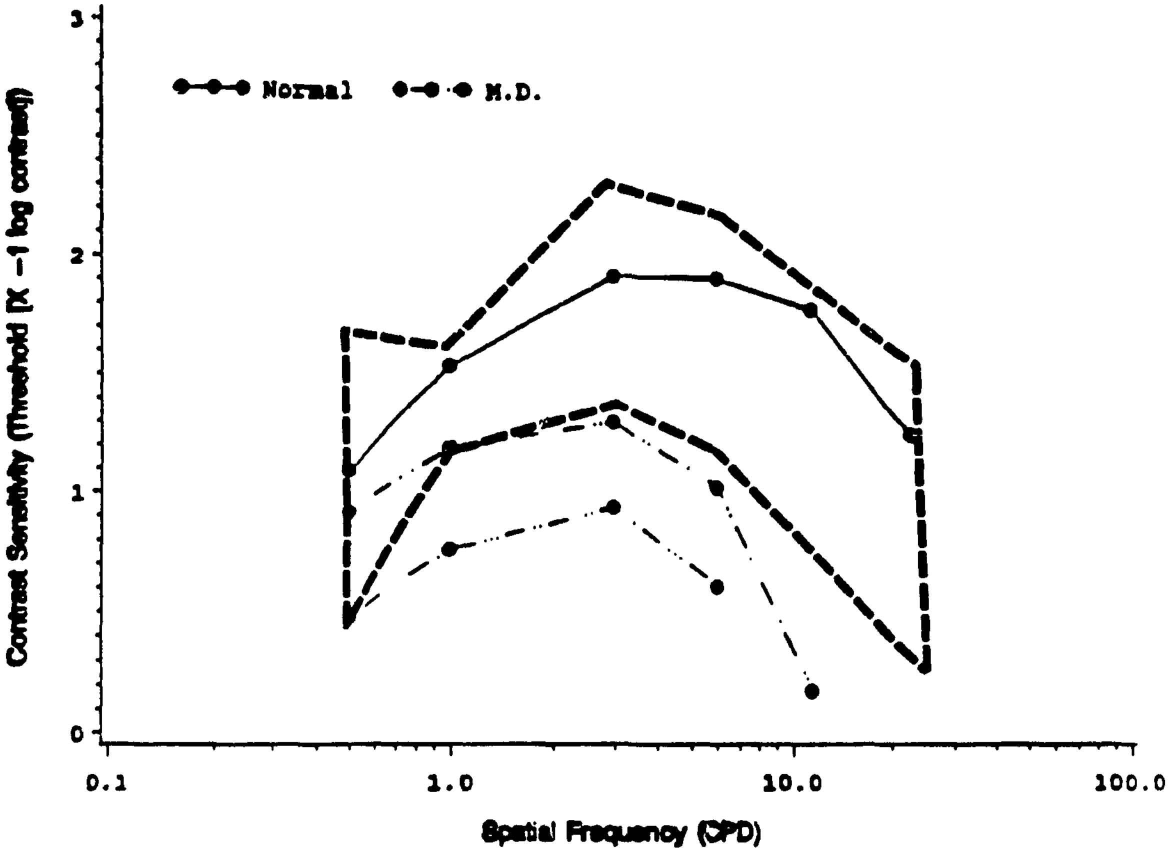

Figure 8. Spatial contrast sensitivity curves for two individuals with macular degeneration and one normally sighted observer. The dashed line represents a two standard deviation range of normal variation which is based on mean data from this study.

The ANOVA yielded a significant main effect of diagnosis, $F(1,24) = 53.30$, $p < .0001$, which established that the normal control subjects' overall performance was better than that of individuals with macular degeneration. A significant main effect for filter also existed, $F(3,72) = 116.69$, $p < .0001$, which suggests that the lower the cutoff of the low-pass filter the worse individuals performed (see Table 1). A Tukey's HSD *post-hoc* analysis demonstrated that significant reductions in performance were present when the 10 cpd low pass filter was implemented ($p < .01$). The 8 cpd filter did not cause any further significant reduction in performance compared to the 10 cpd filter. However, when the band of frequencies between 6 and 8 cpd was removed a further significant reduction of performance was observed ($p < .01$).

As shown in Table 1, a significant interaction of filtering condition and diagnosis existed, $F(3,72) = 28.36$, $p < .0001$, and the results from Tukey HSD tests indicate that removing spatial frequencies above 10 cpd affected normally sighted individuals but not those with macular degeneration. This effect is shown graphically in Figure 9. The *post-hoc* tests also demonstrate that a further reduction of performance occurred for normals but not individuals with macular degeneration as the frequencies between 6 and 8 cpd were removed ($p < .01$). It is important to note that normal control subjects' performance in the 6 cpd condition were not significantly different from macular degeneration patients in

Table 1

Source Table for Analysis of Variance

SOURCE	SS	df	MS	F
Diagnosis	1337.78	1	1337.78	53.30*
Error	602.35	24	25.10	
Filter	1041.80	3	347.27	116.69*
Filter x Diagnosis	253.18	3	84.39	28.36*
Error	214.27	72	2.98	

*$p < .0001$

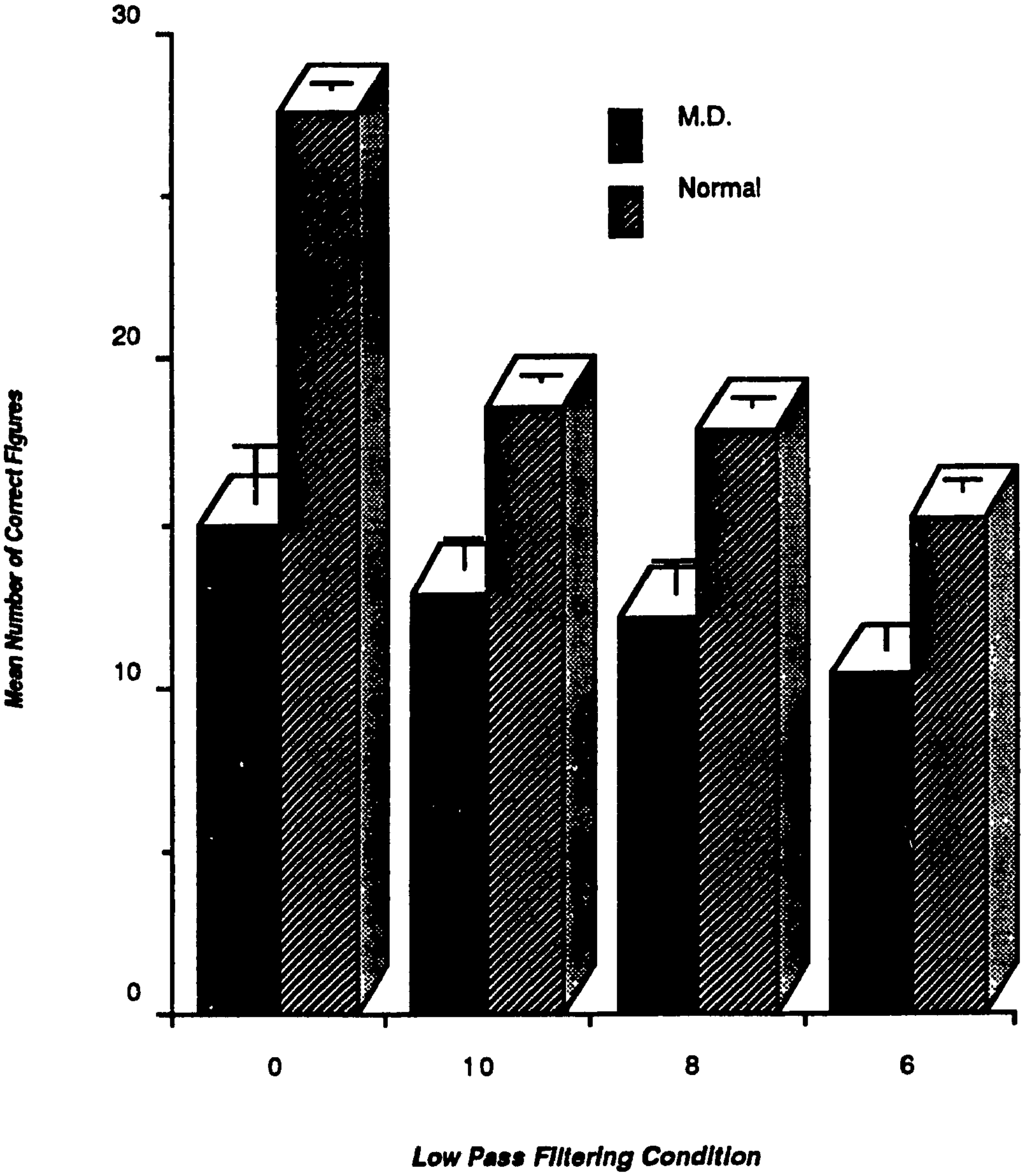

Figure 9. Mean number of figures traced correctly on the Frostig Figure-Ground Test as a function of ocular diagnosis and filtering condition.

the unfiltered condition ($p < .01$).

To test the hypothesis that performance of individuals with macular degeneration should improve when the spatial frequency content of the FFG is shifted towards lower spatial frequencies by enlarging the test, a related groups t-test was carried out, using the number of figures traced correctly as the dependent measure. The results indicate that individuals with macular degeneration perform significantly better on the enlarged version of the FFG than on the regular FFG, $t(9) = - 6.03$, $p < .001$. Figure 10 demonstrates these results.

As there were many panel conditions with no variance due to both ceiling and floor effects, and the variance/covariance matrix was determined to be unstable as evidenced by a severe violation of the sphericity assumption, the analysis of spatial frequency effect on individual panels of the FFG was not included in the analyses of variance. Since this effect is important, the issue will be discussed in a descriptive fashion.

From Figure 11 it can be seen that the filtering conditions do not affect all panels equally. Performance on the first four panels of both normally sighted subjects and persons with macular degeneration does not seem to be affected by any of the filters implemented in this study. By contrast, performance on panels five to eight appears to be dependent on what filter is utilized. More specifically, the lower the

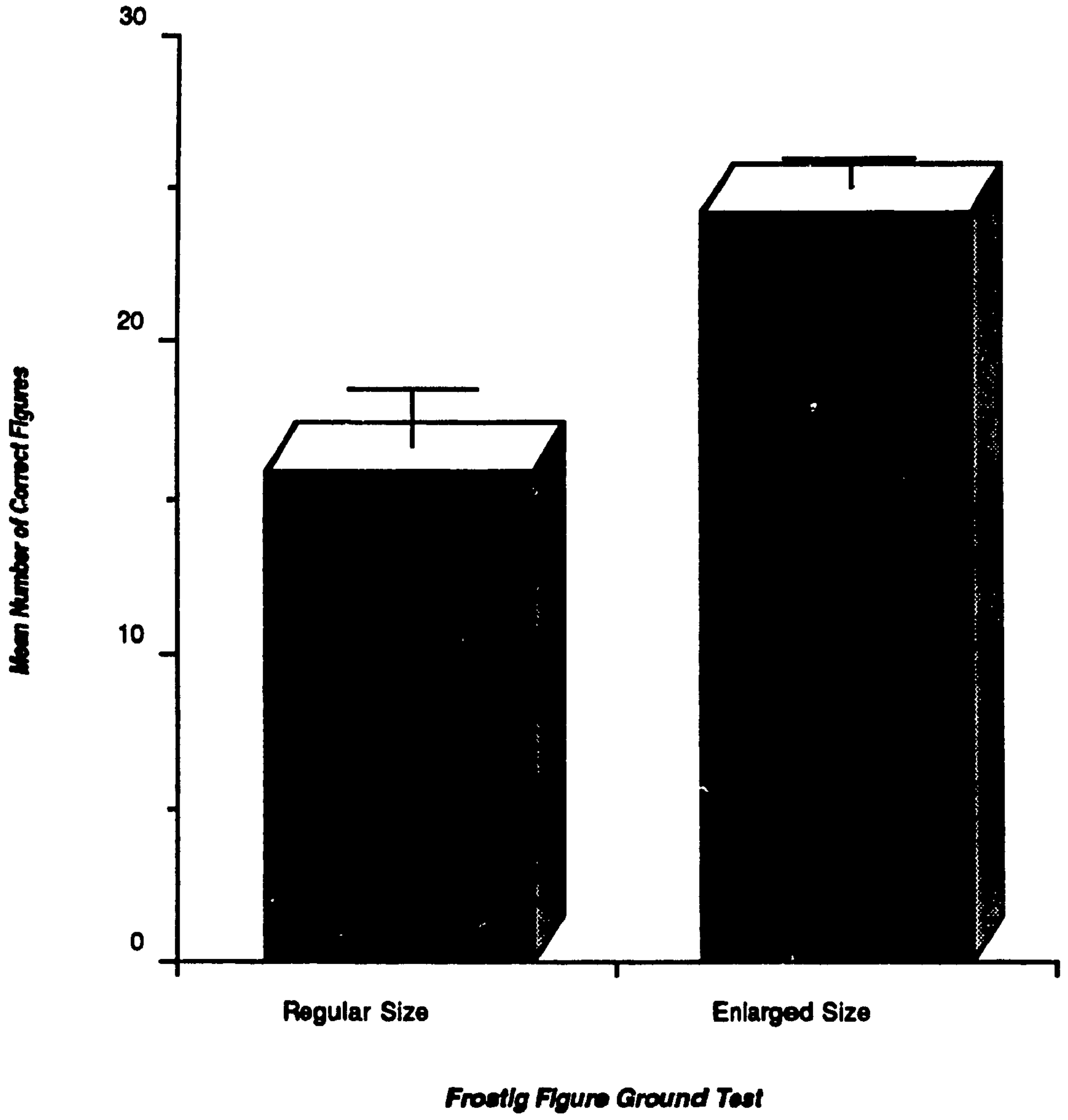

Figure 10. Mean number of figures traced correctly on the Frostig Figure-Ground Test as a function of test size. Data from individuals with macular degeneration.

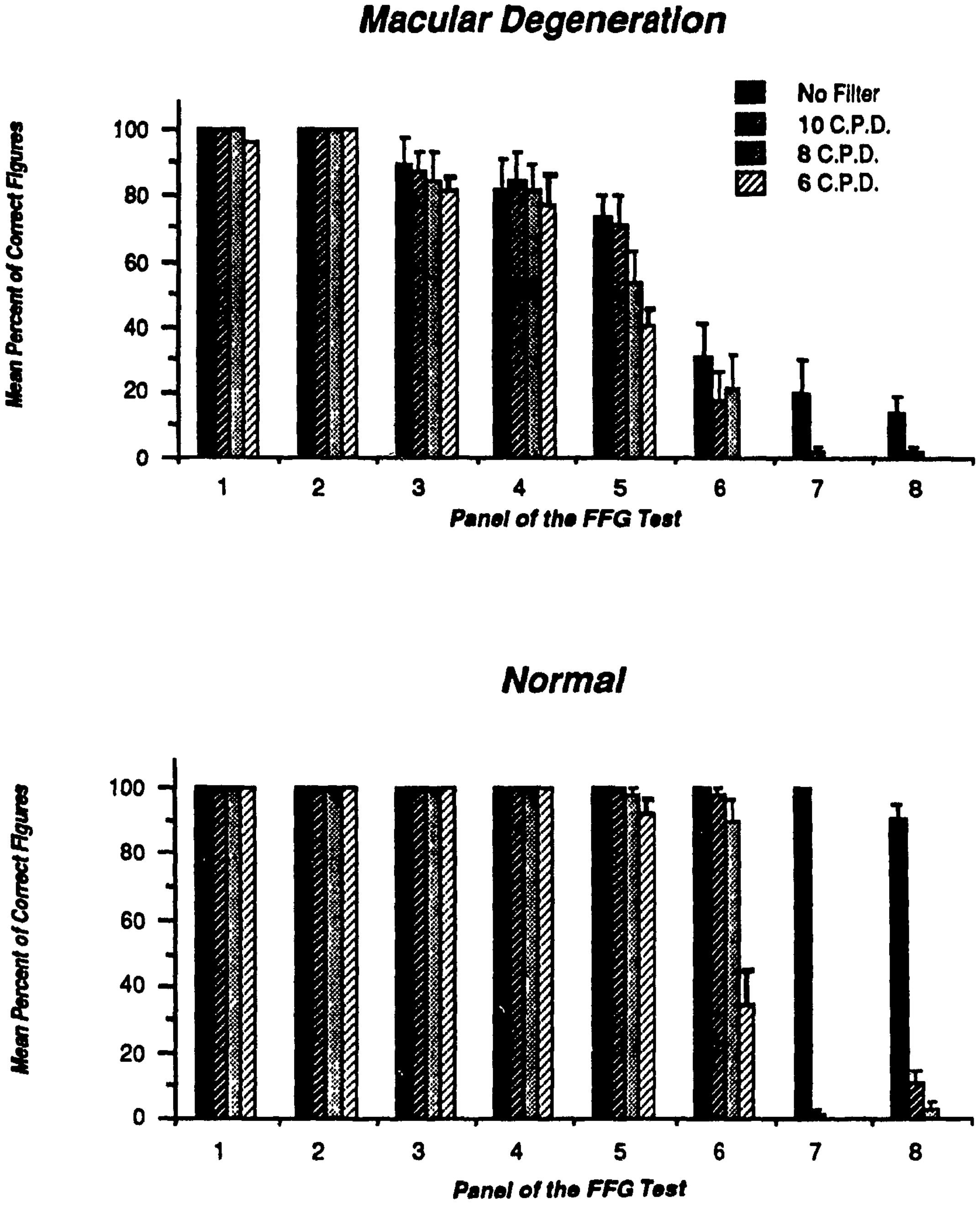

Figure 11. Mean percent of figures traced correctly on the Frostig Figure-Ground Test as a function of ocular diagnosis, filtering condition, and panel number.

cut-off frequency of the low pass filter, the earlier the performance is disrupted on the FFG test. This effect looks similar for both those with macular degeneration as well as for normally sighted observers (see Figure 11). Similarly, performance on the last four panels of the FFG is significantly increased if the spatial frequency content of the test is shifted (see Figure 12).

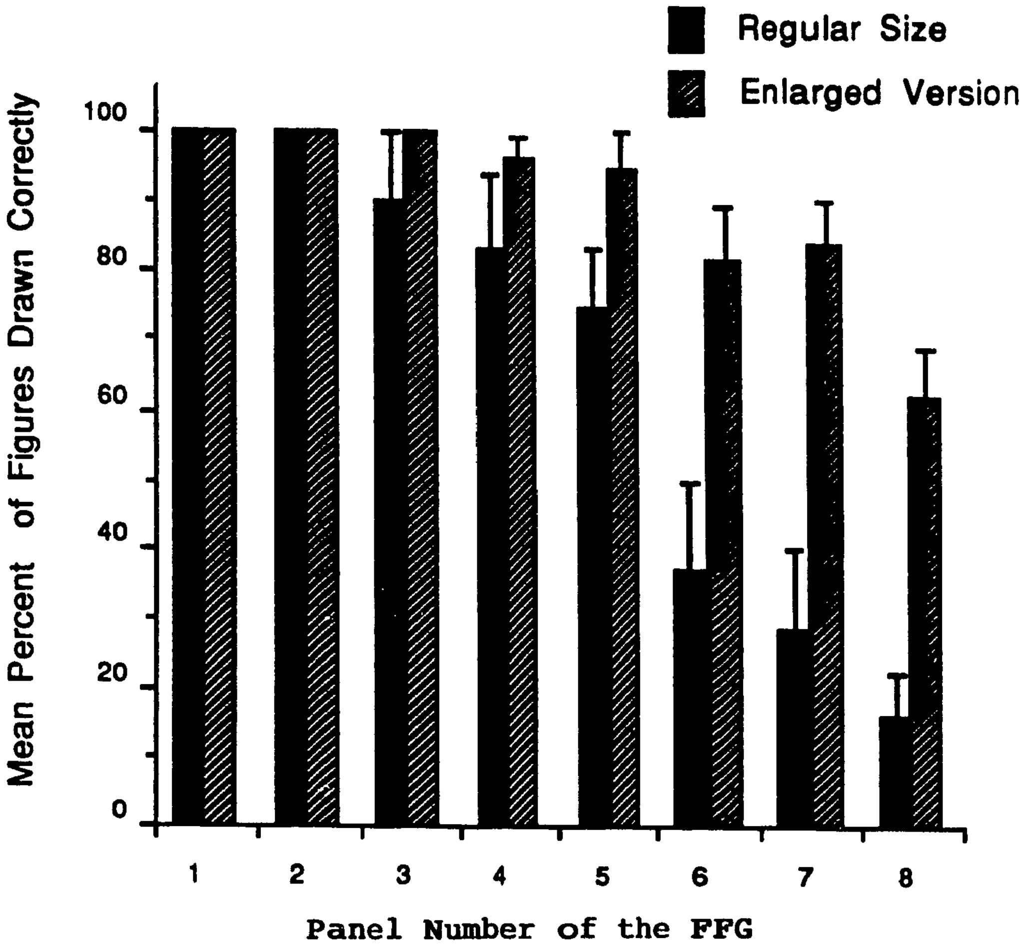

Figure 12. Mean number of figures traced correctly on the Frostig Figure-Ground Test as a function of size of the test and panel. Data from individuals with macular degeneration.

Discussion

As is clearly demonstrated by the results, the inability of individuals with macular degeneration to perform well on the FFG is largely due to decreased sensitivity to medium and high spatial frequencies. Additional support for this conclusion stems from the finding that normally sighted individuals' performance on the FFG, with all spatial frequencies above 6 cpd removed, was not significantly different from that of individuals with macular degeneration on the unfiltered version. These results are in agreement with the findings of previous studies which demonstrate a relationship between spatial contrast sensitivity and performance on the FFG and other perceptual tests (Hill, Overbury, Faubert, et al., 1988; Hill, Overbury, Quillman, et al., 1988; Overbury, et al., 1987).

Contrary to the original hypothesis, however, was the finding that medium and high spatial frequencies have significant but different effects on performance. It appears that the FFG may be more sensitive to specific spatial frequency loss than was previously thought. More precisely, it appears that if an individual does not perceive spatial information above 10 cpd, or is forced not to perceive these frequencies through spatial frequency filtering, he/she will be unable to complete the last two panels of the FFG. Moreover, if a person is not able to perceive frequencies above 6 cpd, performance decreases starting at the sixth panel of the test.

Further support for the last two statements comes from a visual inspection of panels 6, 7, and 8 over the levels of the low pass filtering condition. As soon as frequencies above 10 cpd are removed, panels 7 and 8 become too blurry to complete, while one could presumably still complete panel 6. These effects can be seen in Figures 5 and 6. If the 6 cpd low pass condition is considered, however, it can be seen that panel 6 then becomes extremely difficult, especially in the central part of the figure.

It is interesting to note that when normally sighted observers were trying to complete the sixth panel, in the 6 cpd filtering condition, many described the difficulty with this task as due to the fact that ". . . all the figures are there but the lines get lost in the center". It is argued that the "lines in the center get lost" because the spatial frequency content of this portion of the panel falls in a bandwidth to which observers are relatively insensitive.

Given that individuals with "normal" vision performed better than persons with macular degeneration when filtering condition was disregarded, suggests that sensitivity to medium and high spatial frequencies is essentially responsible for differences in performance between the two groups. Individuals with macular degeneration used in this study were all more than two standard deviations less sensitive to spatial frequencies at and above three cycles per degree than the averaged normal data (see Appendix D). Thus, even when the filtering condition is disregarded, individuals with macular degeneration are always receiving filtered or blurry images, consequently it should be expected that they would perform worse than persons with normal vision.

A second reason why normally sighted observers always performed better than those with macular degeneration is simply because they do not have to contend with a macular scotoma which constantly causes parts of the image to be "blocked out". However, it was possible to reduce normals' performance on the FFG down to levels not significantly different from performance of individuals with macular degeneration only by removing the critical frequencies. Therefore, the effect of a macular scotoma per se is less important to performance on the FFG than the degraded state of the image being received by the observer.

An interesting finding was that performance of individuals with macular degeneration increased significantly when they were given an enlarged version of the FFG to complete where the spatial frequency content is in effect shifted toward lower spatial frequencies. Therefore, if it is true that persons with macular degeneration are relatively insensitive to frequencies inherent in the original form of the FFG, enlarging the test should to some degree compensate for the losses in spatial contrast sensitivity. The results of the present study strongly support this finding. It should be noted, however, that the actual frequency content of the enlarged FFG was not analyzed. Therefore it cannot be concluded with any certainty that this is the reason for the increase in performance. Enlarging the FFG test also reduces the area of the image that the scotoma covers at one time which could, in turn, reduce the extent of eccentric eye movements necessary to place the image on an area of the retina which is still functioning normally. It may be that the smaller the eccentric saccades an individual with macular degeneration needs to view the FFG the less they will lose their place while tracing a figure, thus reducing errors not in perception of the figure but in the tracing task *per se*.

The results of this study which considered the FFG in a strict experimental situation allows for its appraisal as a clinical/experimental tool to evaluate the visual function of persons with low vision. It is clear that the FFG has an inherent ability to detect impairments in spatial contrast sensitivity: one needs to be sensitive to specific spatial frequency information in order to perform successfully on certain panels on the test. There are, however, a number of problems with the test that limit the interpretation of results obtained from it.

The first problem is that spatial frequency content of the panels is confounded with both number and type of shapes across panels. This confound does not allow full confidence for the conclusion that performance deficits are due only to the loss of spatial frequency information. Second is the fact that the first part of the test is too easy for most visually impaired individuals. Evidence for this observation comes from the observation that even under the most extreme low pass filtering condition, the 6 cpd condition, macular degeneration patients' performance was unaffected for panels 1 and 2 and was only slightly affected for panels 3 and 4. The third problem is the evidence that the last two panels of the FFG are tapping perceptual phenomena which are unrelated to visual impairment in that even normally sighted persons do not always find all of the embedded figures. Thus, it is unrealistic to attribute poor performance on these panels solely to spatial frequency loss. Some of the kite and oval shapes may not be detected because some individuals are better at figure-ground tasks than others, regardless of the state of the visual system. Perhaps the amount of exposure individuals have had to these types of "puzzles" may be another factor. Conrod et al. (1986) have shown that FFG performance does improve with practice. Indeed, psychological variables such as persistence are certainly related to performance on these panels.

Considering these shortcomings of the FFG, future research should attempt to devise a Frostig-like test which more accurately taps the domain of spatial contrast sensitivity. The utility of such a test would be to allow more clinicians to include an efficient evaluation of spatial vision in their low vision examinations. For example, if one were to take the sixth panel from the FFG and vary the degree of overlap of the stars, one would be able to pick up losses of any of the spatial frequencies that a typical spatial contrast sensitivity test would detect. One could create such a test by determining the degree of overlap necessary to cause a normally sighted observer to be unable to trace the stars when a low pass filter, with a cut-off frequency of 3 cpd for example, was applied.

The completed test would consist of six panels with the critical frequencies necessary to complete each panel consisting of the standard 0.5, 1.0, 3.0, 6.0, 11.4, and 22.8 cpd, respectively. The test would then be given in unfiltered form to persons suspected of having a deficit in spatial contrast sensitivity to see where, if anywhere, the person's performance breaks down. While a pencil and paper test like the one described could not replace a proper spatial contrast sensitivity evaluation, it certainly would be an inexpensive, clinically efficient tool available to virtually all practitioners.

The results of this study and the research of Legge and his colleagues (1985) suggest that the cause of performance deficits on the FFG and reading-type tasks, in individuals afflicted by macular degeneration, is a decrease in sensitivity to particular spatial frequencies, where the "critical" spatial frequencies appear to be task-specific. To imply that figure-ground perception (Sekuler, et al., 1982) or performance on reading tasks (Brown, 1981) are dependent on single bandwidths of spatial frequencies is not supported by the current study.

It seems likely that the relationship between reading and performance on the FFG will only hold up when the critical information necessary for both tasks is similar. Earlier correlations existing between these two visual tasks may be spurious since testing distance was not accounted for. If one allows observers to move closer or further away from the visual tests, it seems reasonable to assume that they will move to a distance which shifts the spatial frequency content of that test to an area which they are sensitive. Therefore, it is possible that under these conditions both tests are largely measuring observers' sensitivity to a relatively narrow bandwidth of spatial frequencies. Future research should certainly keep testing distance constant for all visual tasks to ensure that this type of adjustment is not occurring. Until this contaminating factor has been controlled it will be impossible to make sound conclusions about the relationship between these variables.

The "critical" spatial frequencies for any task will be directly related to the exact conditions of that task. The two cycle per character rule that Legge and his coworkers put forth seems to capture this notion. Following their logic, being sensitive to a single bandwidth of frequencies does not necessarily mean that one will be able to read, but rather, it implies that one will be able to read text with a specific size character. The present findings further elucidate this problem by showing that being sensitive to medium spatial frequencies is not in itself a sufficient condition for good performance on the FFG test.

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Appendix A

Consent Form

The study you are about to participate in is concerned with the assessment of residual vision in low vision patients. You will be required to complete a number of tests including the Frostig figure-ground, spatial contrast sensitivity, and near as well as distance acuity tests.

Results of this research may be published in a professional journal, however, the identity of all individual participants will remain strictly confidential.

It should be clearly understood that at any time before or during the study you may terminate your participation. It should also be understood that it will not affect the quality of service given to you at the Low Vision Center.

I understand the purpose of the study I am about to participate in. I also am aware that I may terminate my participation at any time before or during the study.

Signature of Participant	Date (MM/DD/YY)

Appendix B

Instructions for Contrast Sensitivity Testing

The machine that you are about to be tested on is called a contrast sensitivity tester.

You may turn your head to the left or the right during testing but please do not move closer or farther away from the screen as it will invalidate the results.

The test requires you to look at the "television screen" and tell me when you see "stripes".

At first you will be shown a sample of what you are supposed to look for. These stripes will then disappear. After this, the stripes will slowly get darker and darker until finally you can see them. As soon as you can see the stripes, no matter how dim they are, just say the word "yes". We will repeat this procedure three times for different widths of stripes. The test will be done using both eyes, with your left eye, and finally with your right eye.

Is your task perfectly clear?

(if answer is 'no' instructions repeated)

Appendix C

Instructions for the Frostig Figure-Ground Test

The test you are about to complete is called the Frostig figure-ground test. Basically, it is an assessment of how well you can use your vision.

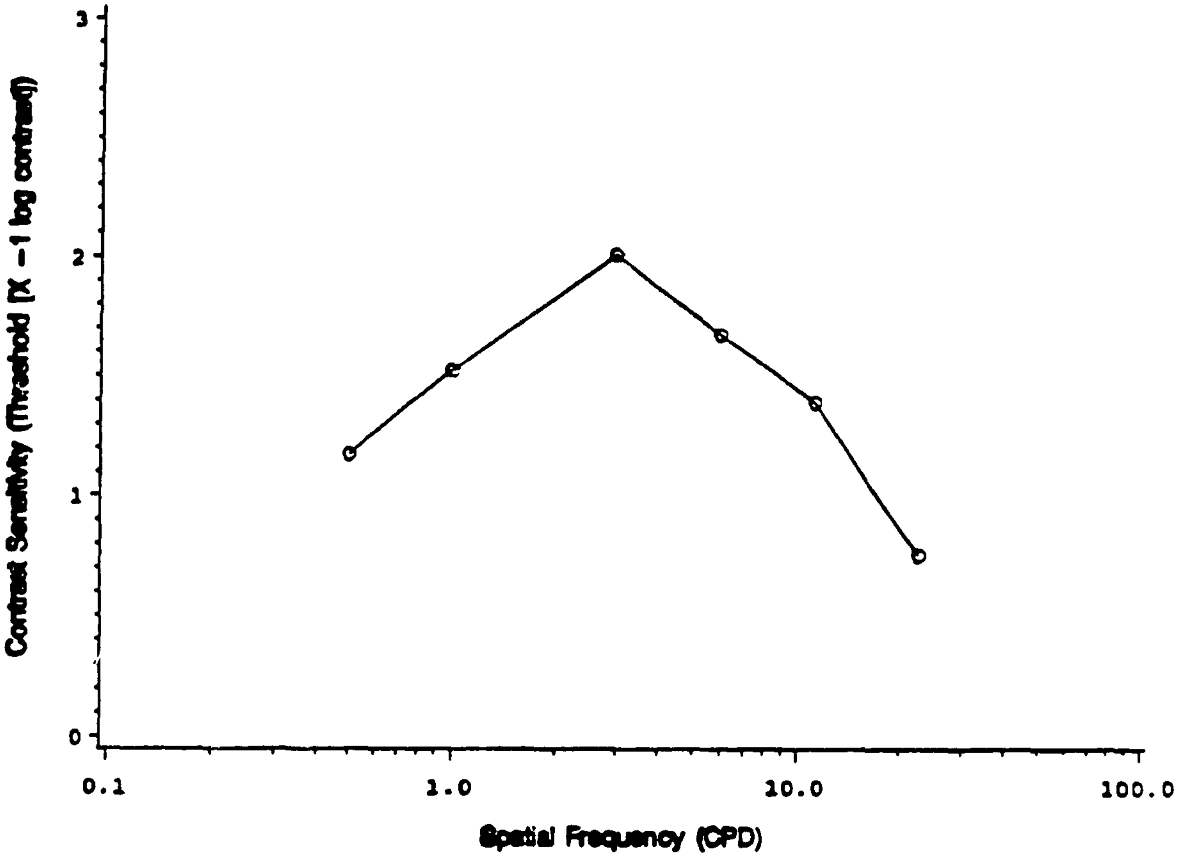
Instructions for Panels 1 - 6:

Your task is simply to look at the drawings here (experimenter points to the first panel of the FFG) and tell me how many separate figures you see. After this you simply trace the outline of each separate figure in a different colour. I will give you a different colour marking pen when you tell me you have finished the figure you are working on.

Instructions for Panels 7 & 8:

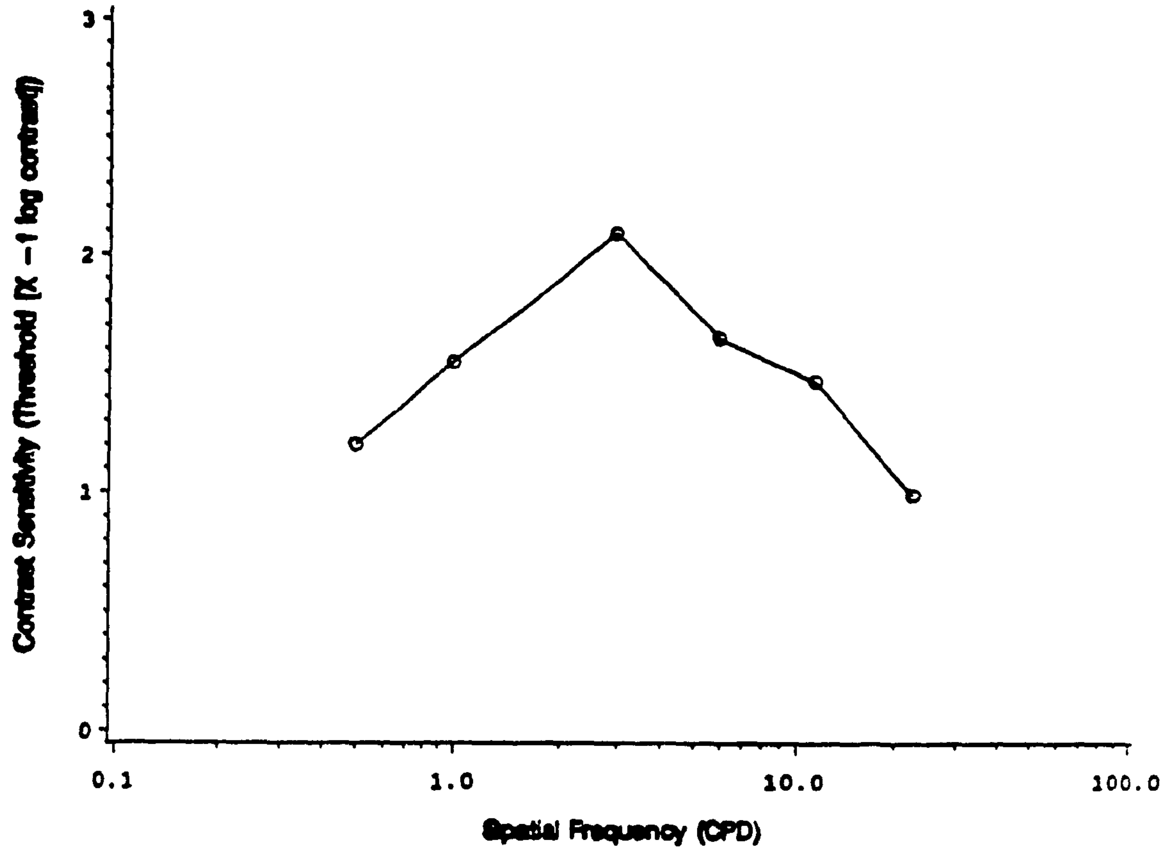
In this panel your task is to pick out and trace each "kite shape" (for panel #7) / oval or "egg" shape (for panel #8) in a different colour. Please tell me when you think you have found them all.

SUBJECT=N1

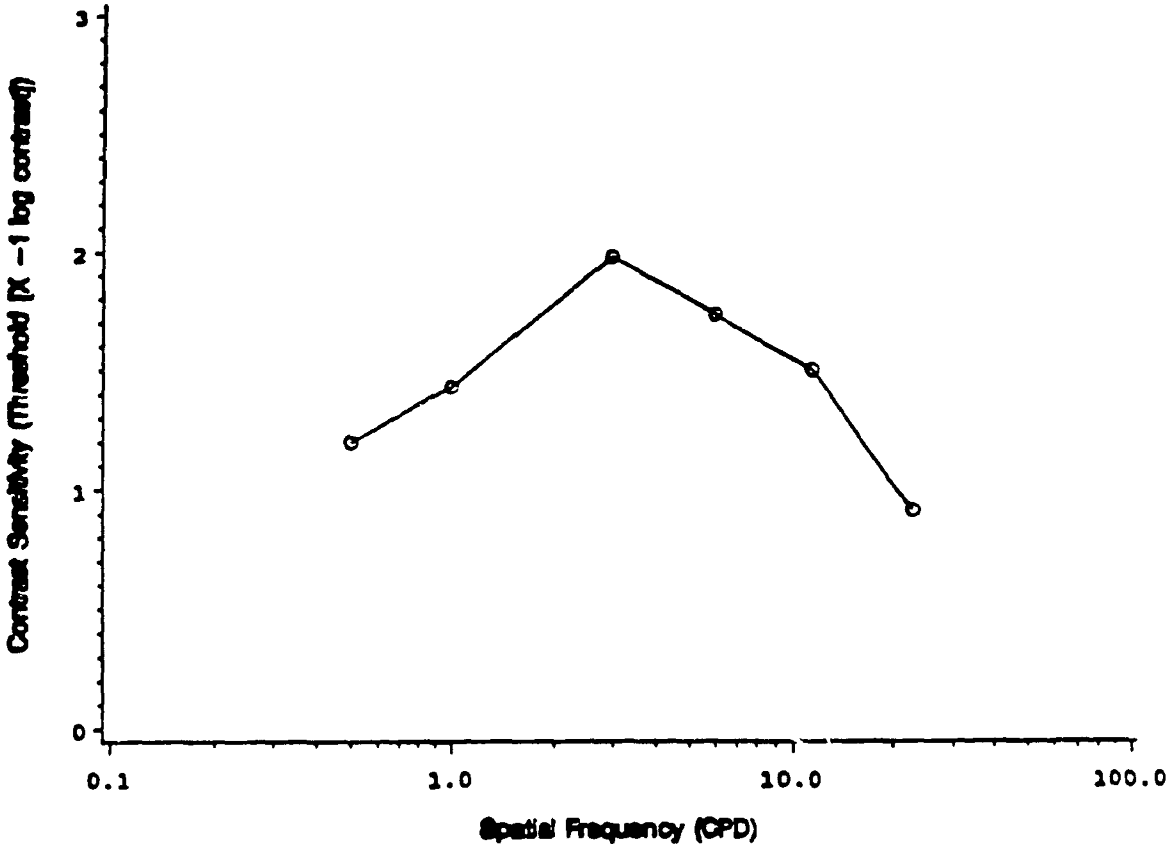


3
2
1
0
Contrast Sensitivity (Threshold [X −1 log contrast])
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

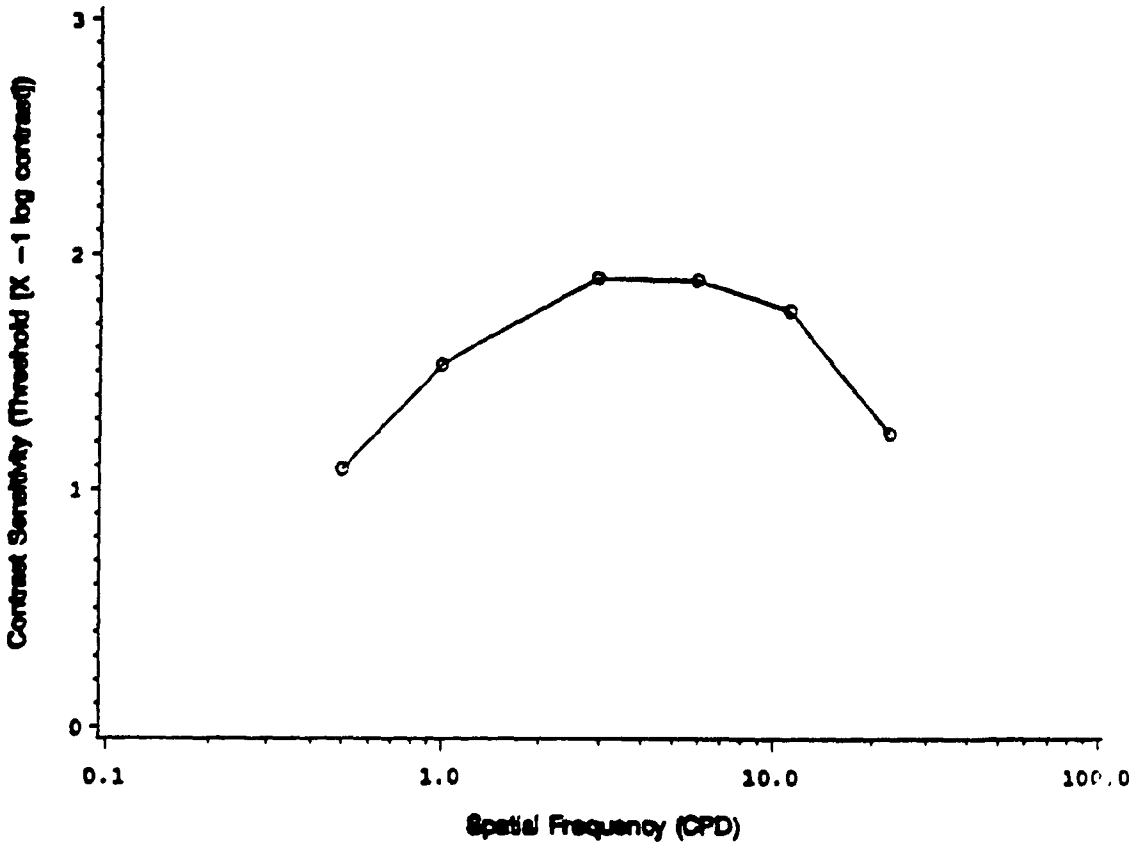
SUBJECT=N2


Contrast Sensitivity (Threshold [X -1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

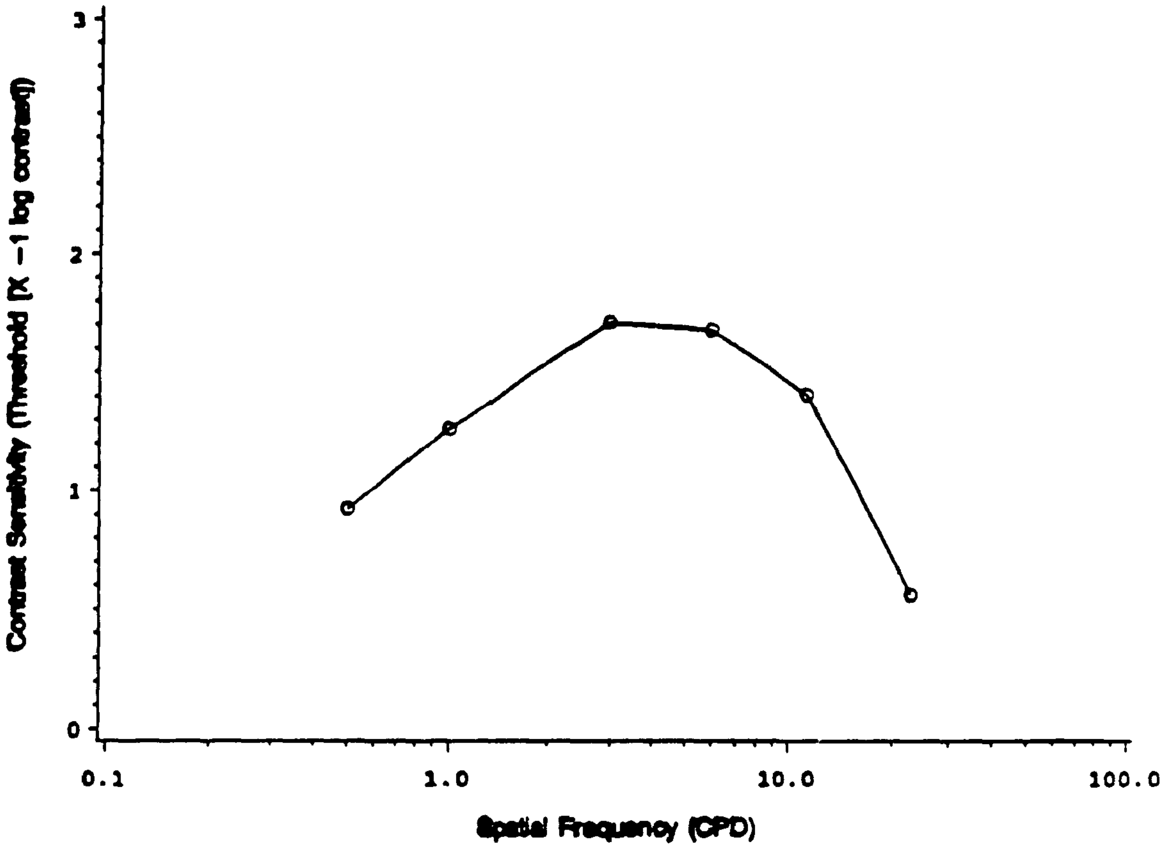
SUBJECT=N3


3
2
1
0
0.1
1.0
10.0
100.0
Contrast Sensitivity (Threshold [X -1 log contrast])
Spatial Frequency (CPD)

SUBJECT=N4

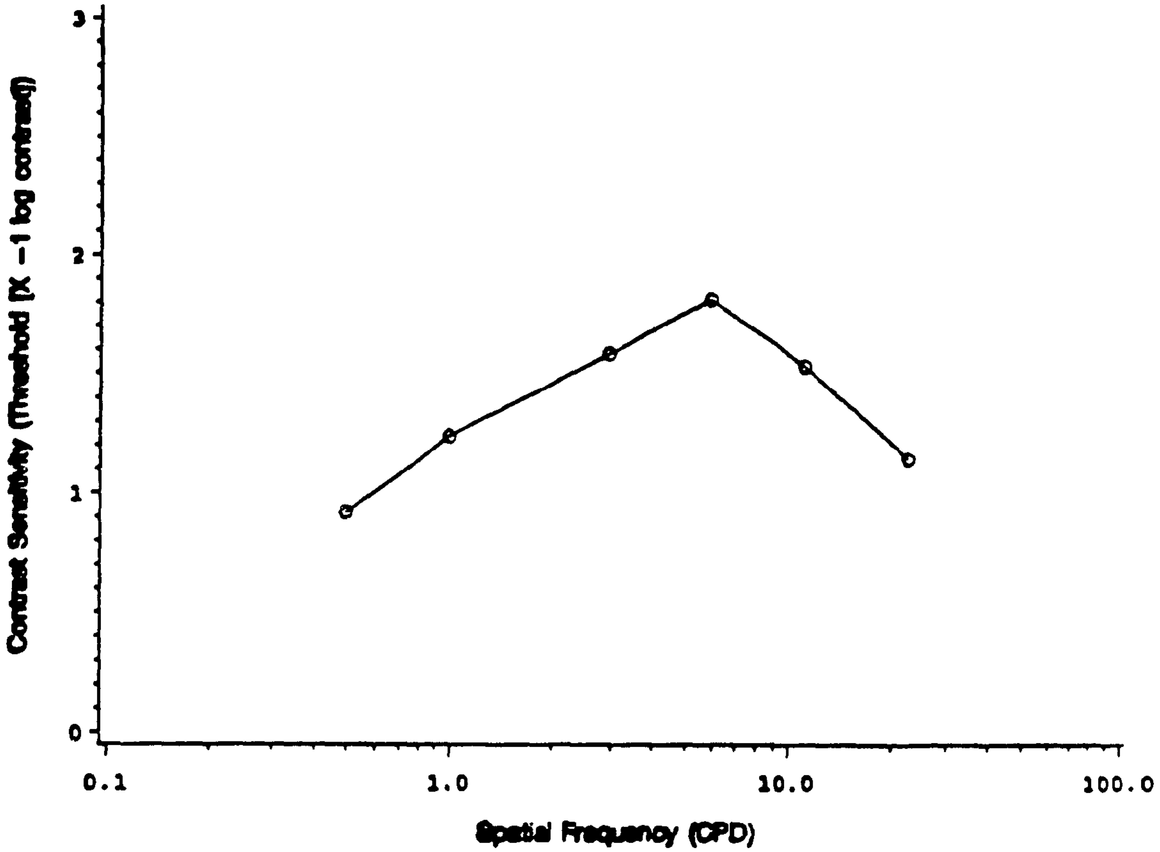

Contrast Sensitivity (Threshold [X -1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=N5



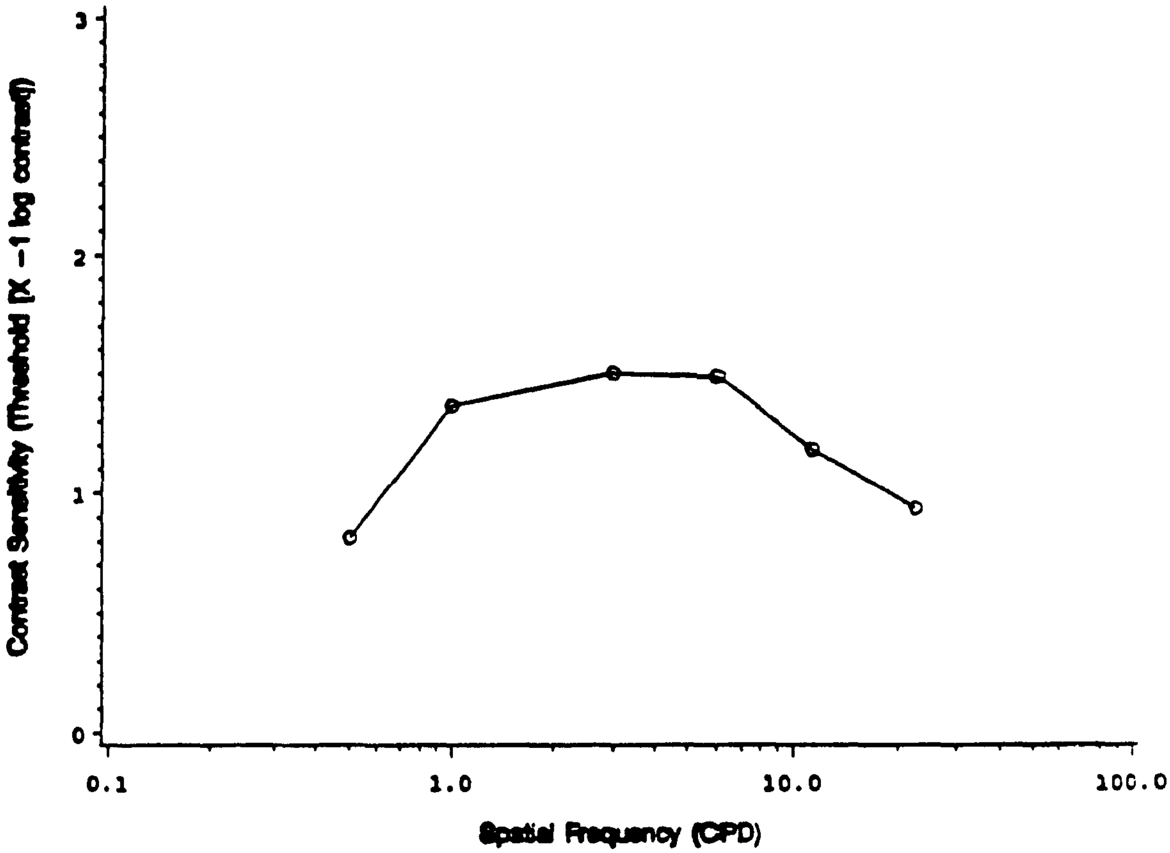
Contrast Sensitivity (Threshold [X −1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=N6

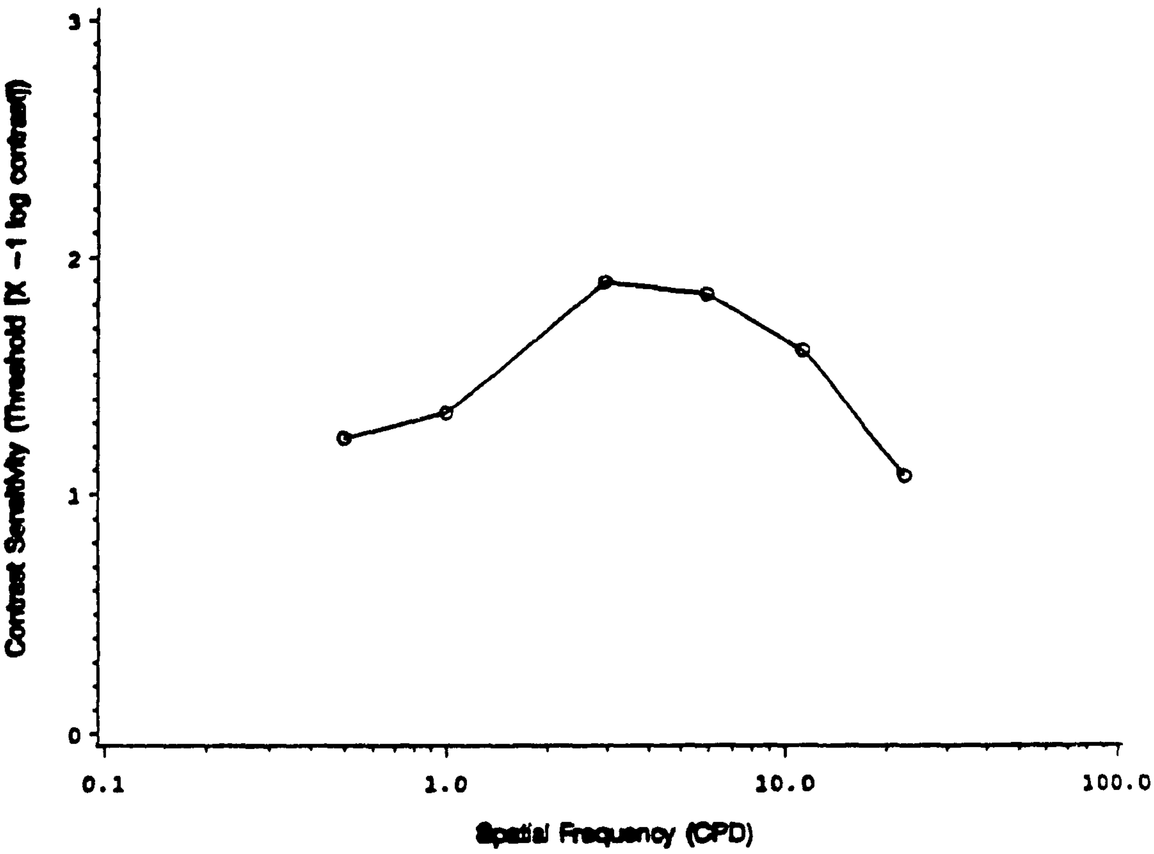


3
2
1
0
Contrast Sensitivity (Threshold [X -1 log contrast])
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

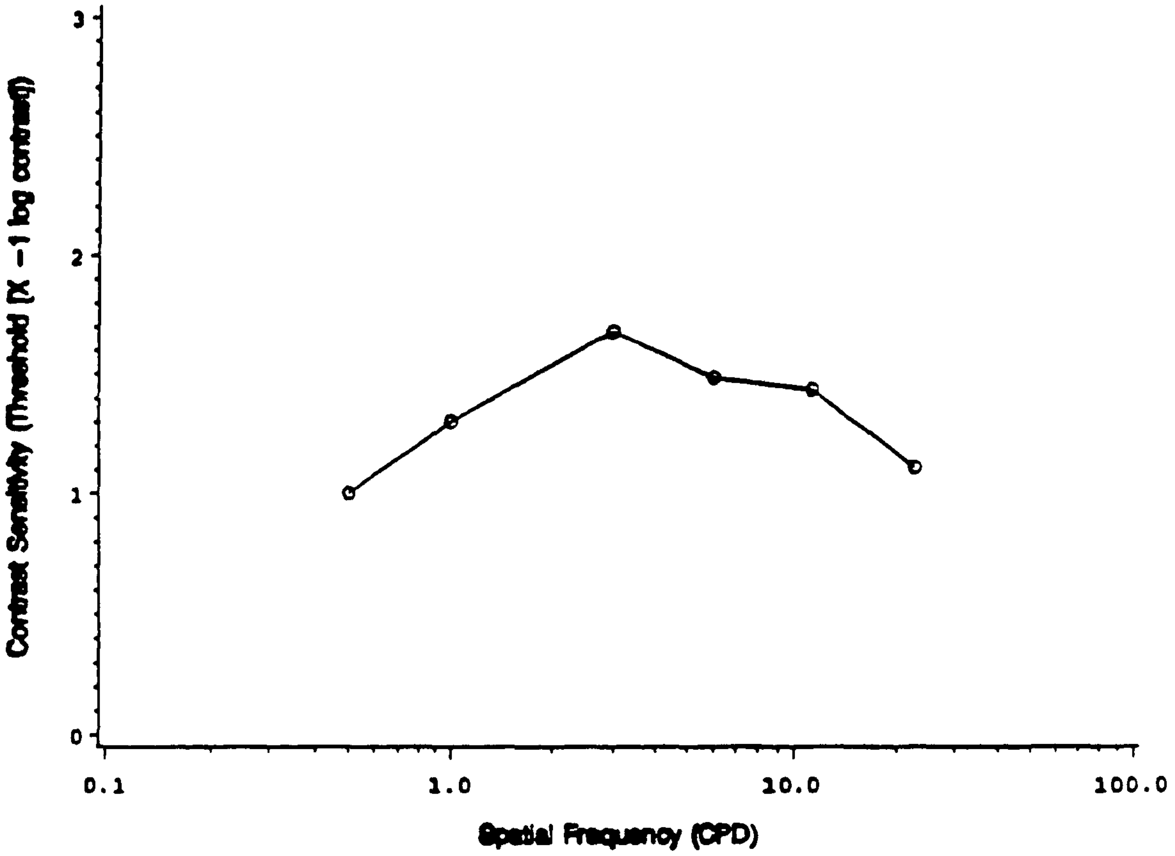
SUBJECT=N7

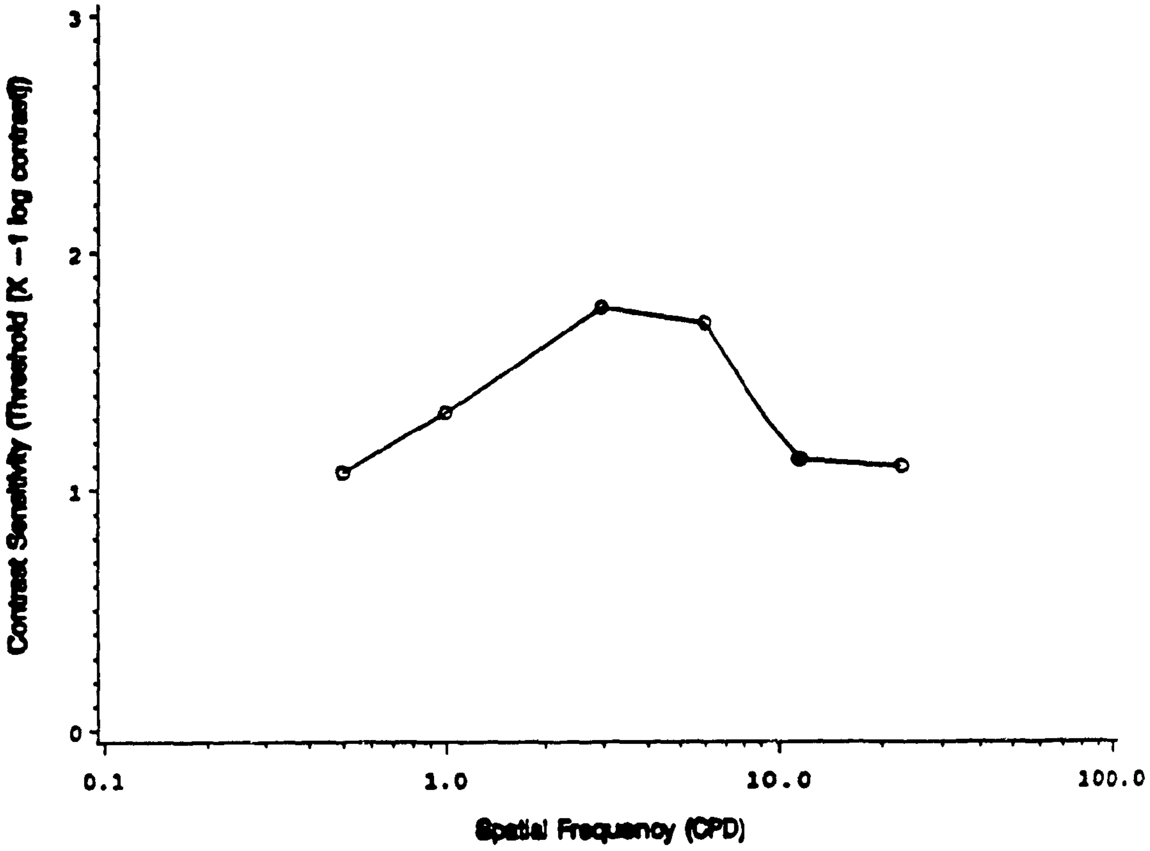

3
2
1
0
Contrast Sensitivity (Threshold [X -1 log contrast])
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=N8


Contrast Sensitivity (Threshold [X −1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=N9

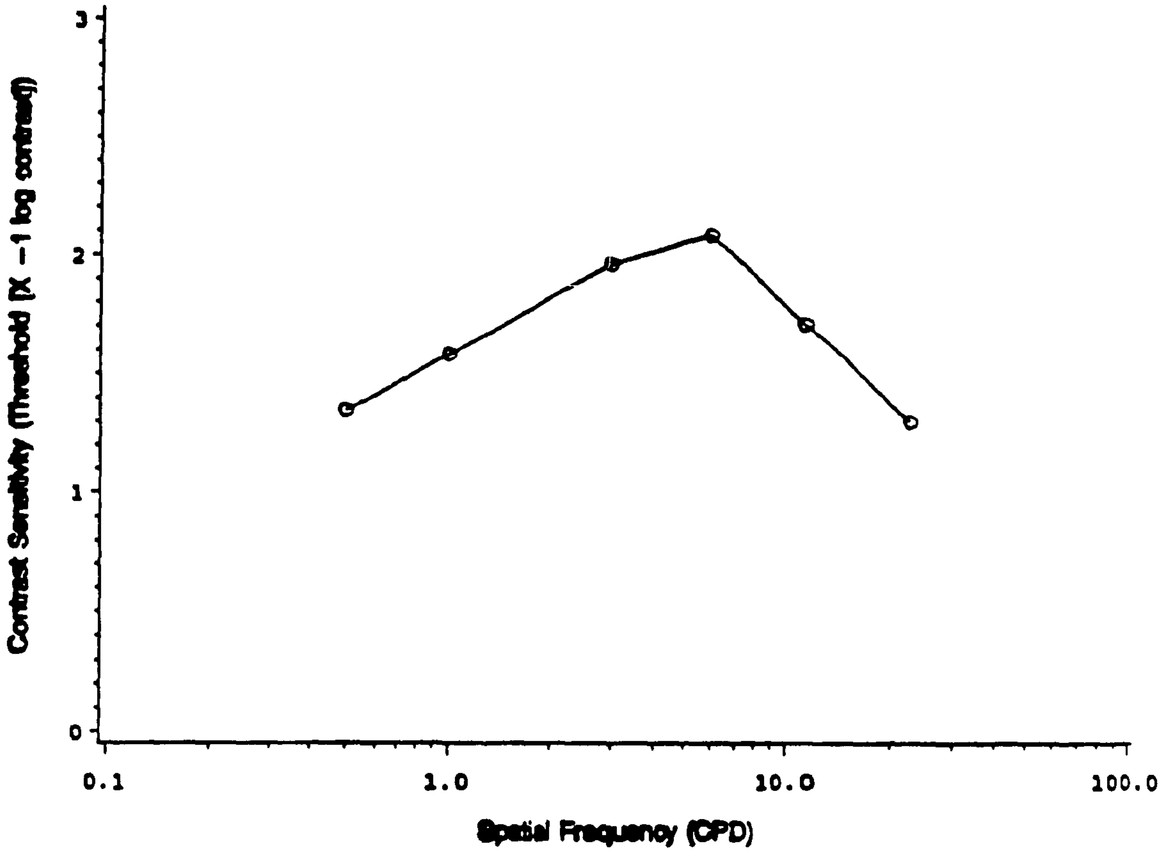

Contrast Sensitivity (Threshold [X −1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)



SUBJECT=N10

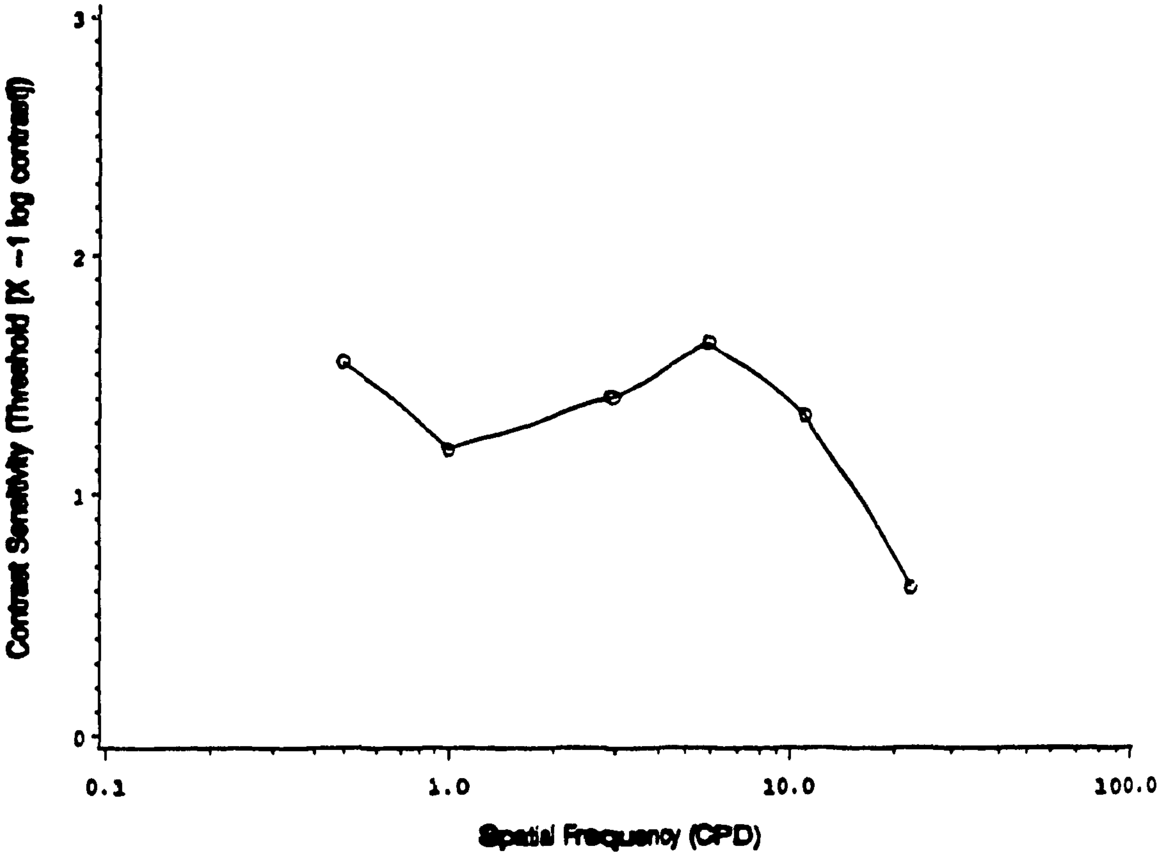
Contrast Sensitivity (Threshold [X −1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=N11

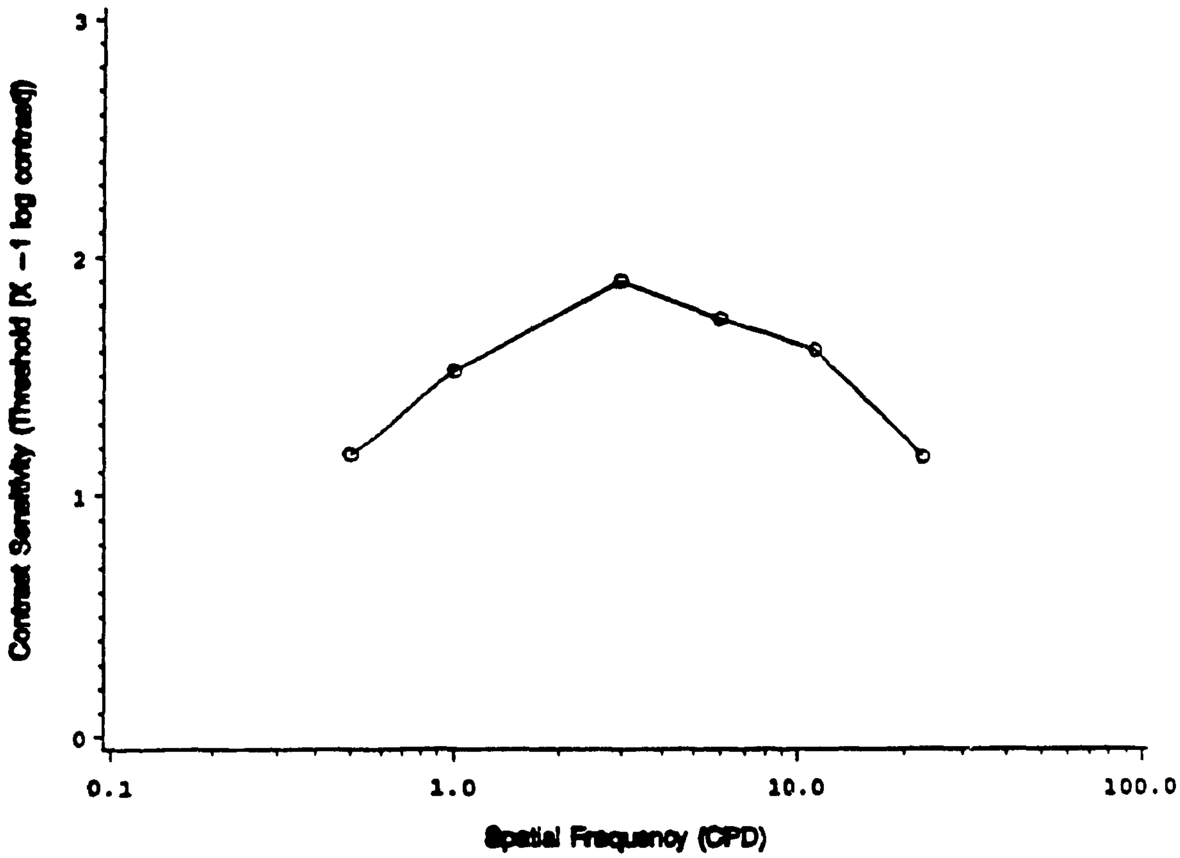


3
2
1
0
0.1
1.0
10.0
100.0
Contrast Sensitivity (Threshold [X -1 log contrast])
Spatial Frequency (CPD)

SUBJECT=N12

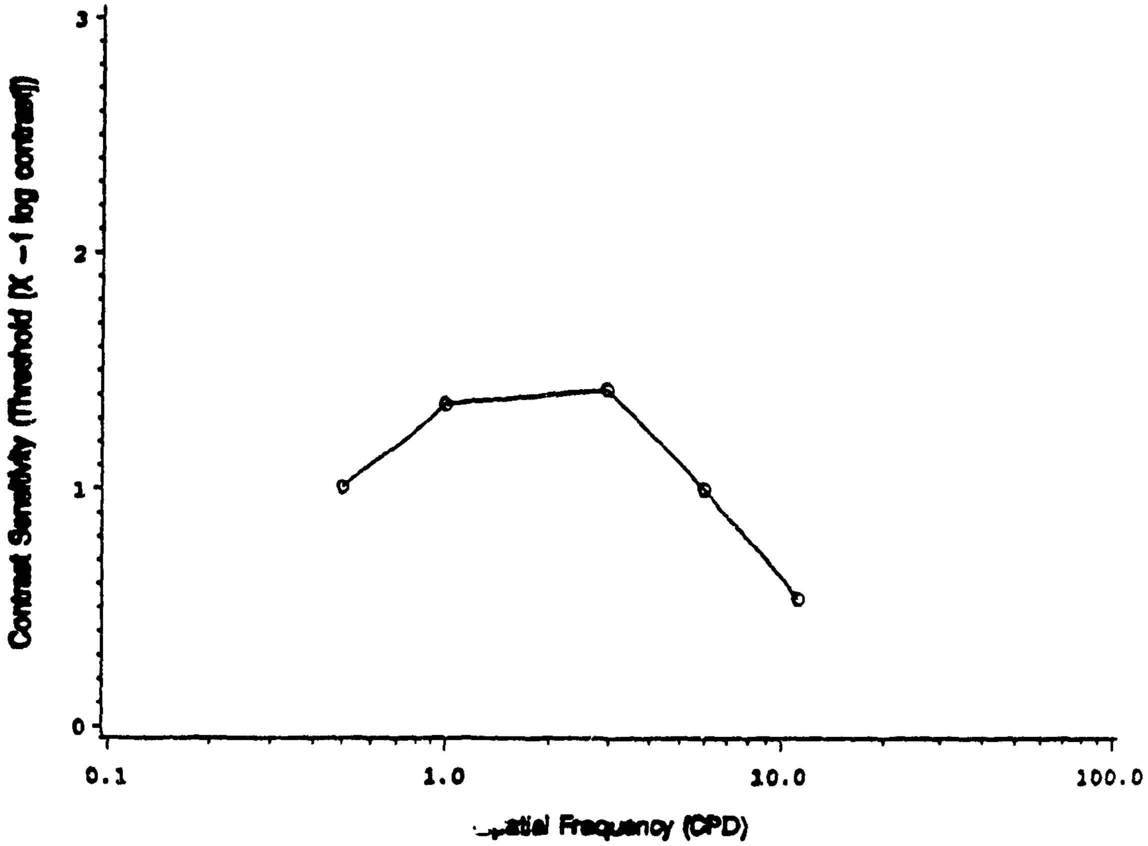

Contrast Sensitivity (Threshold [X -1 log contrast])
0
1
2
3
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=N13

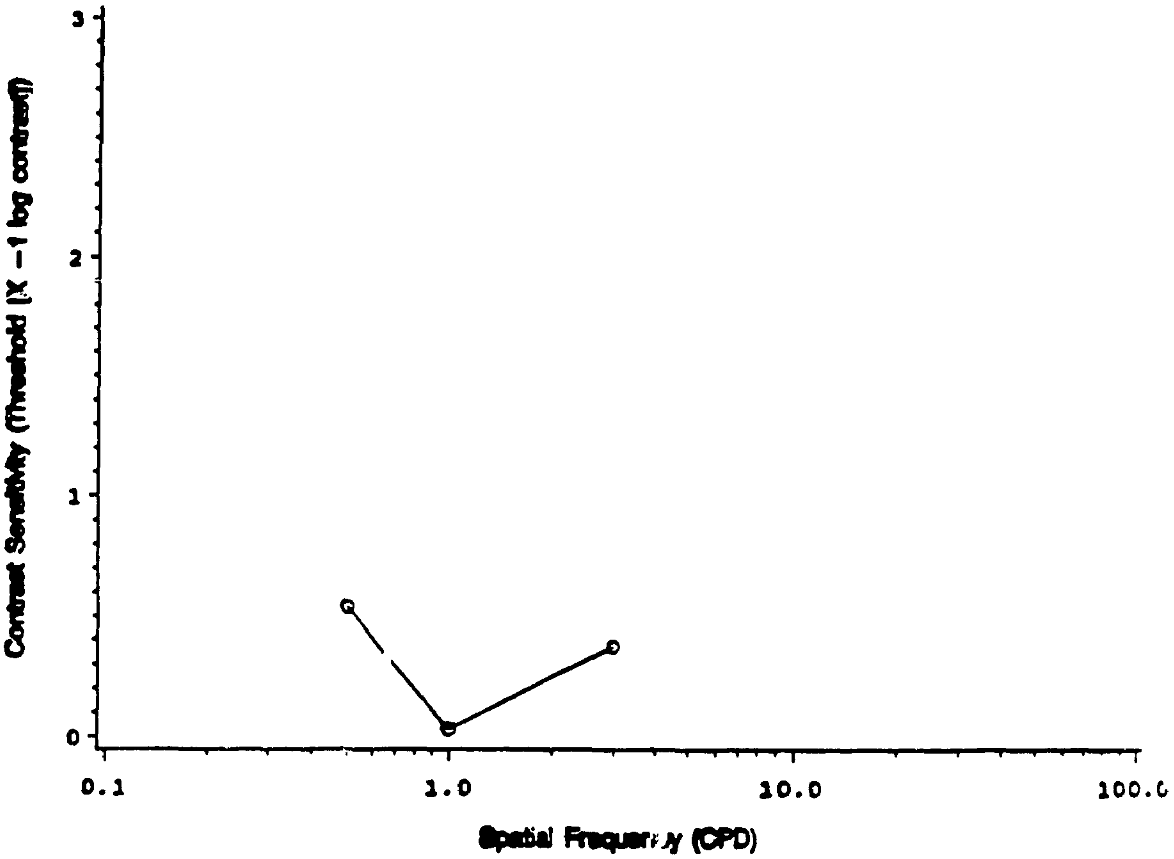


Contrast Sensitivity (Threshold [X −1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

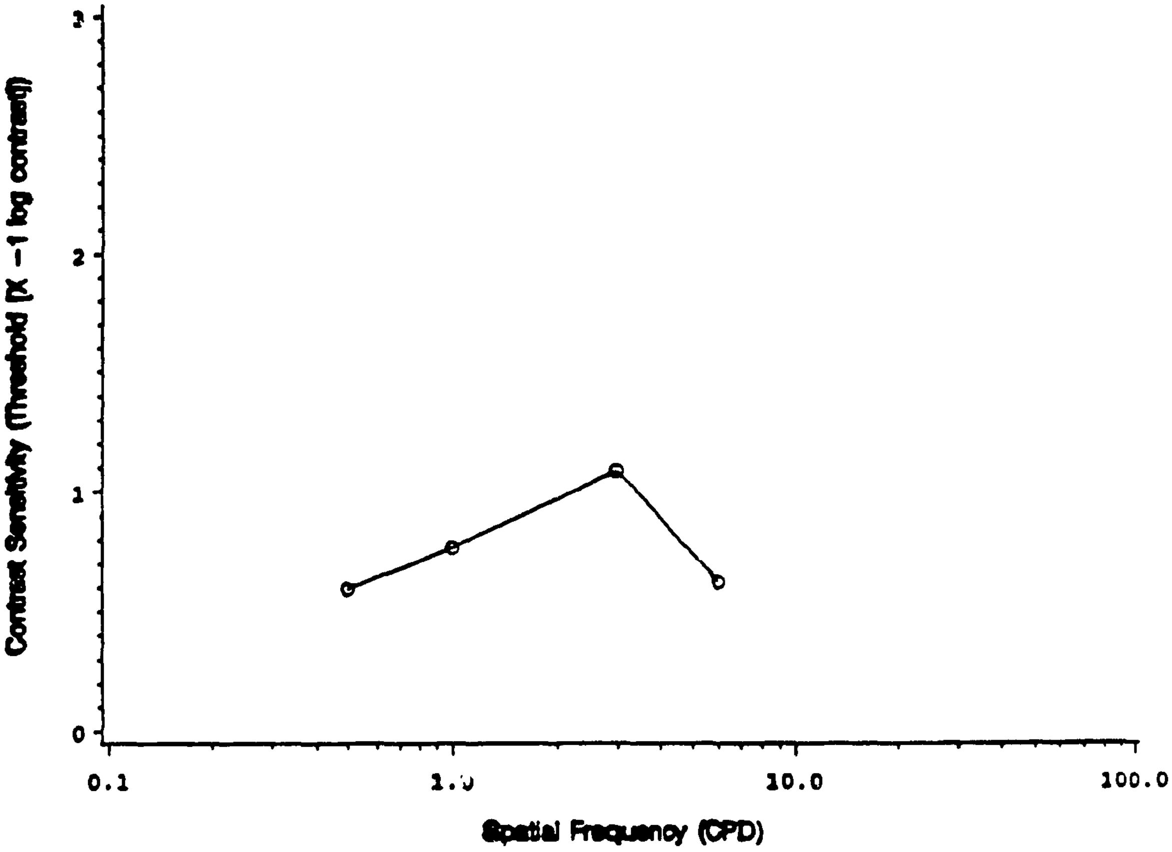
SUBJECT=MD1


3
2
1
0
0.1
1.0
10.0
100.0
Contrast Sensitivity (Threshold (X -1 log contrast))
Spatial Frequency (CPD)

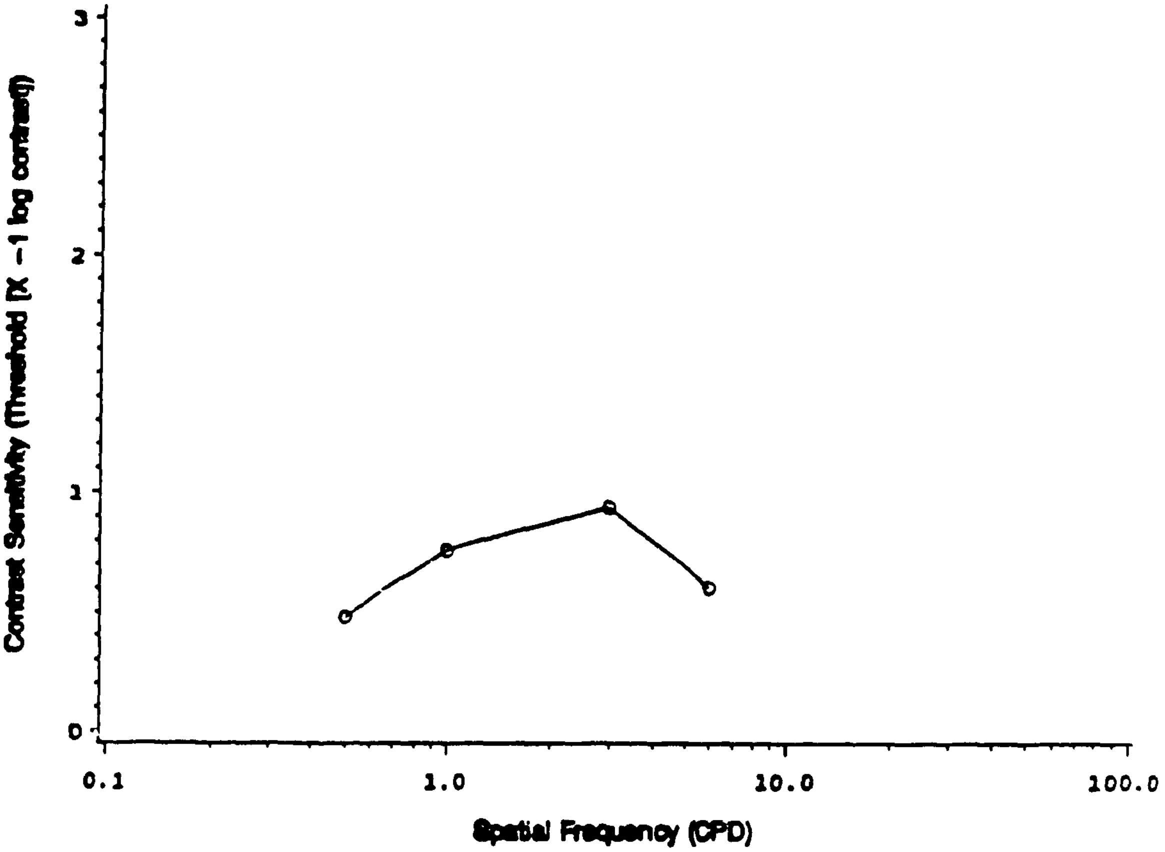
SUBJECT=MD2


Contrast Sensitivity (Threshold [X -1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

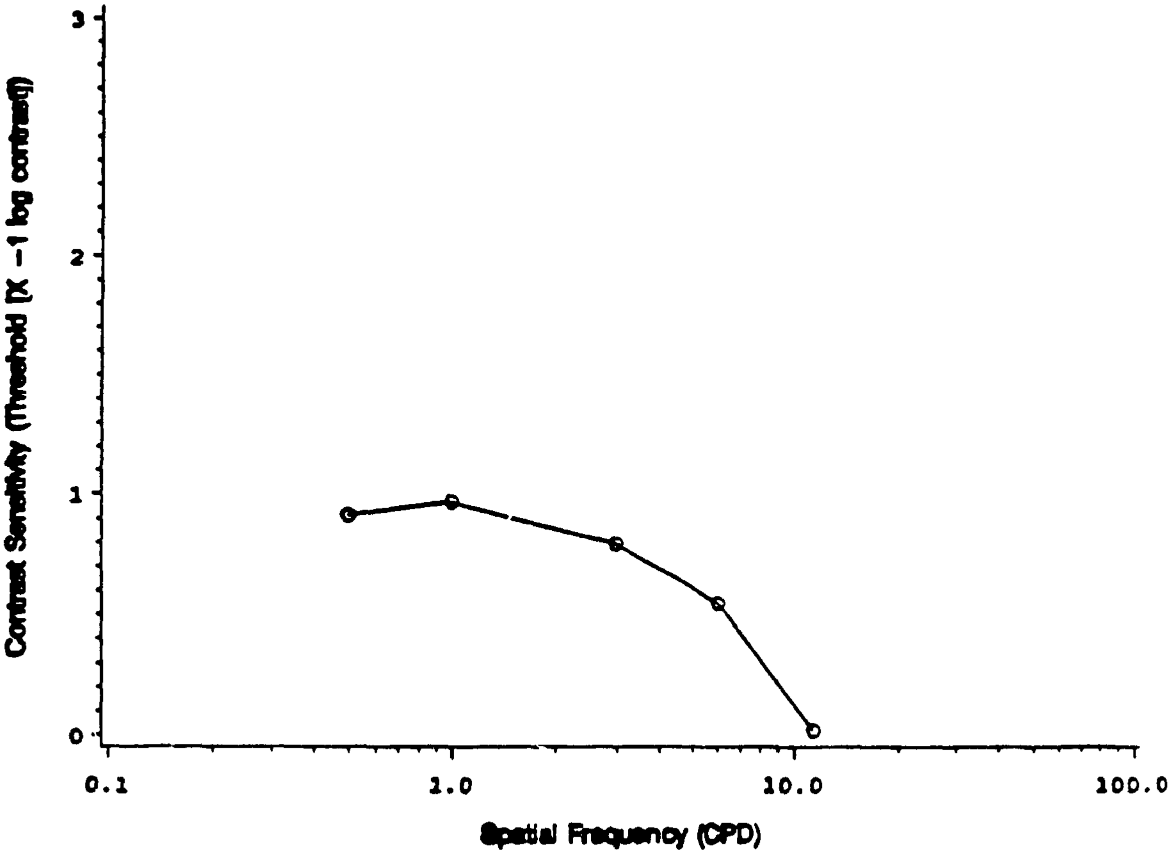
SUBJECT=MD3


Contrast Sensitivity (Threshold (X -1 log contrast))
0
1
2
3
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

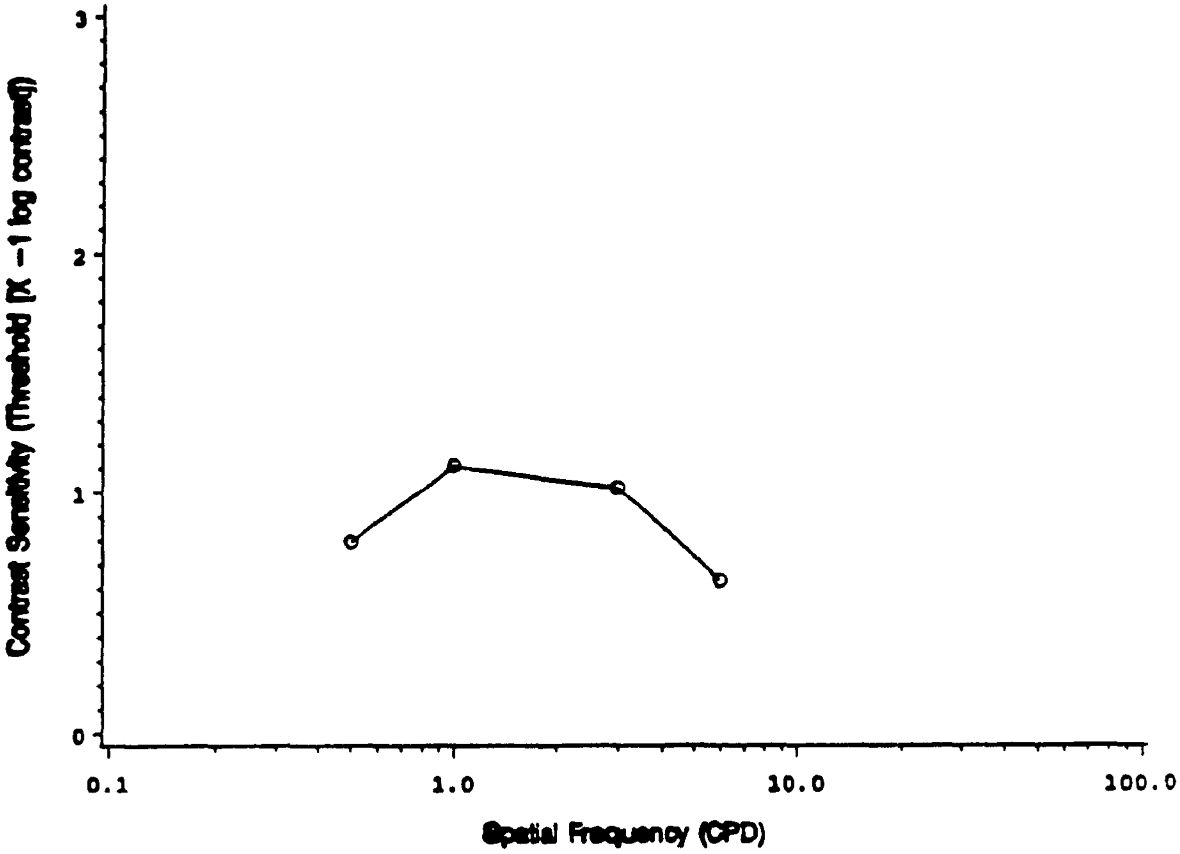
SUBJECT=MD4


3
2
1
0
Contrast Sensitivity (Threshold [X -1 log contrast])
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

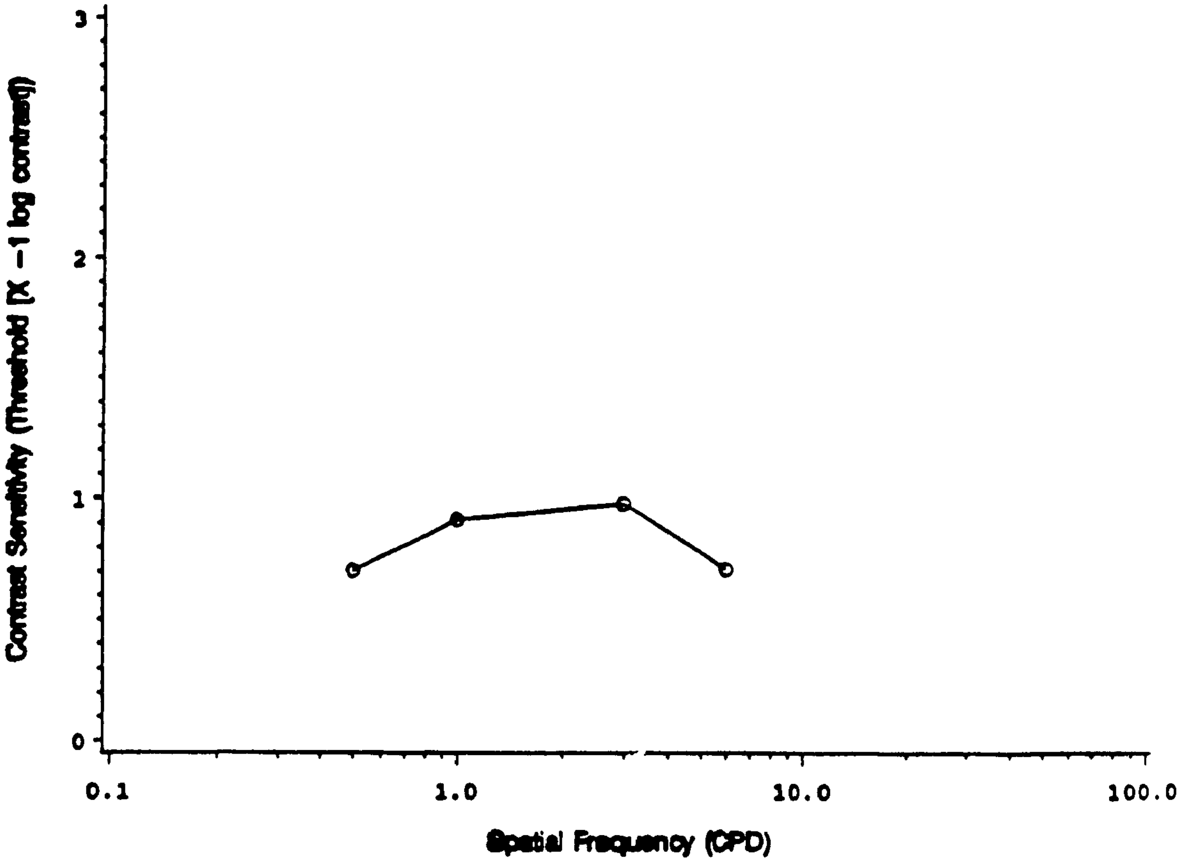
SUBJECT=MD5


3
2
1
0
Contrast Sensitivity (Threshold [X -1 log contrast])
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

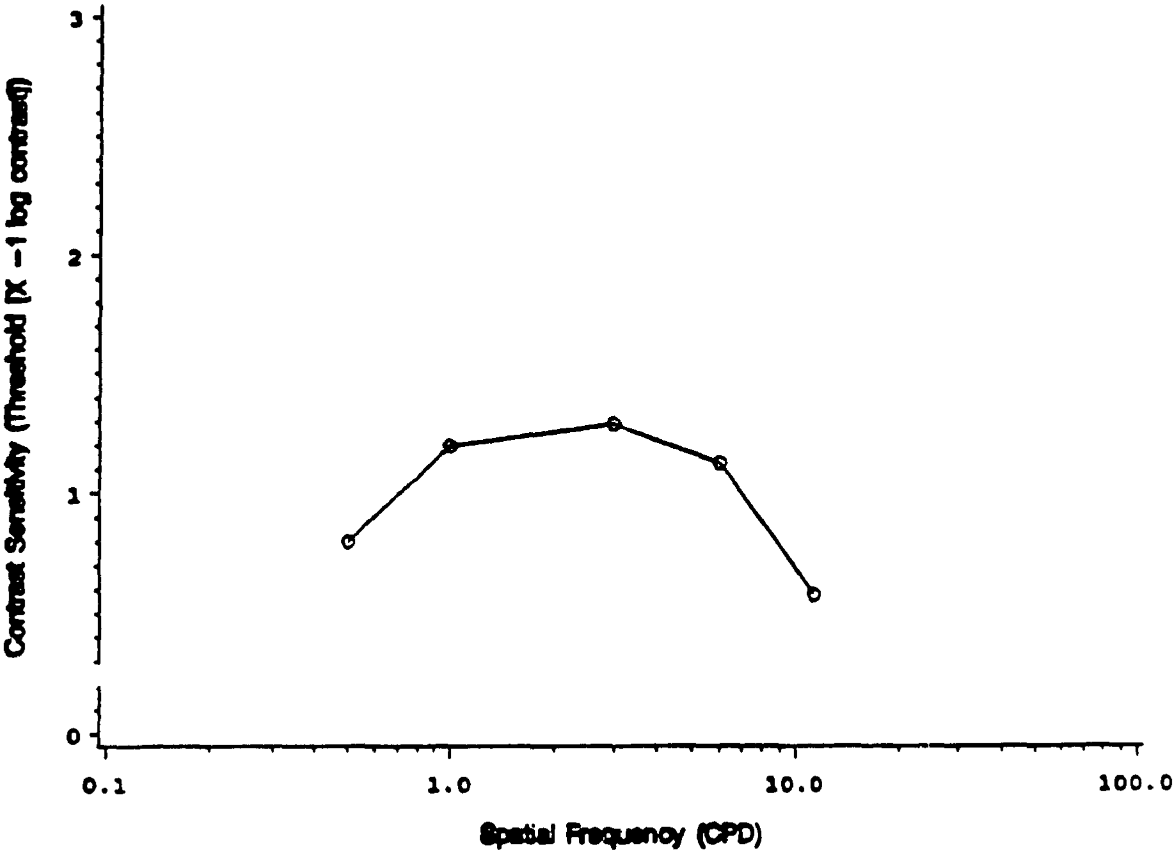
SUBJECT=MD6

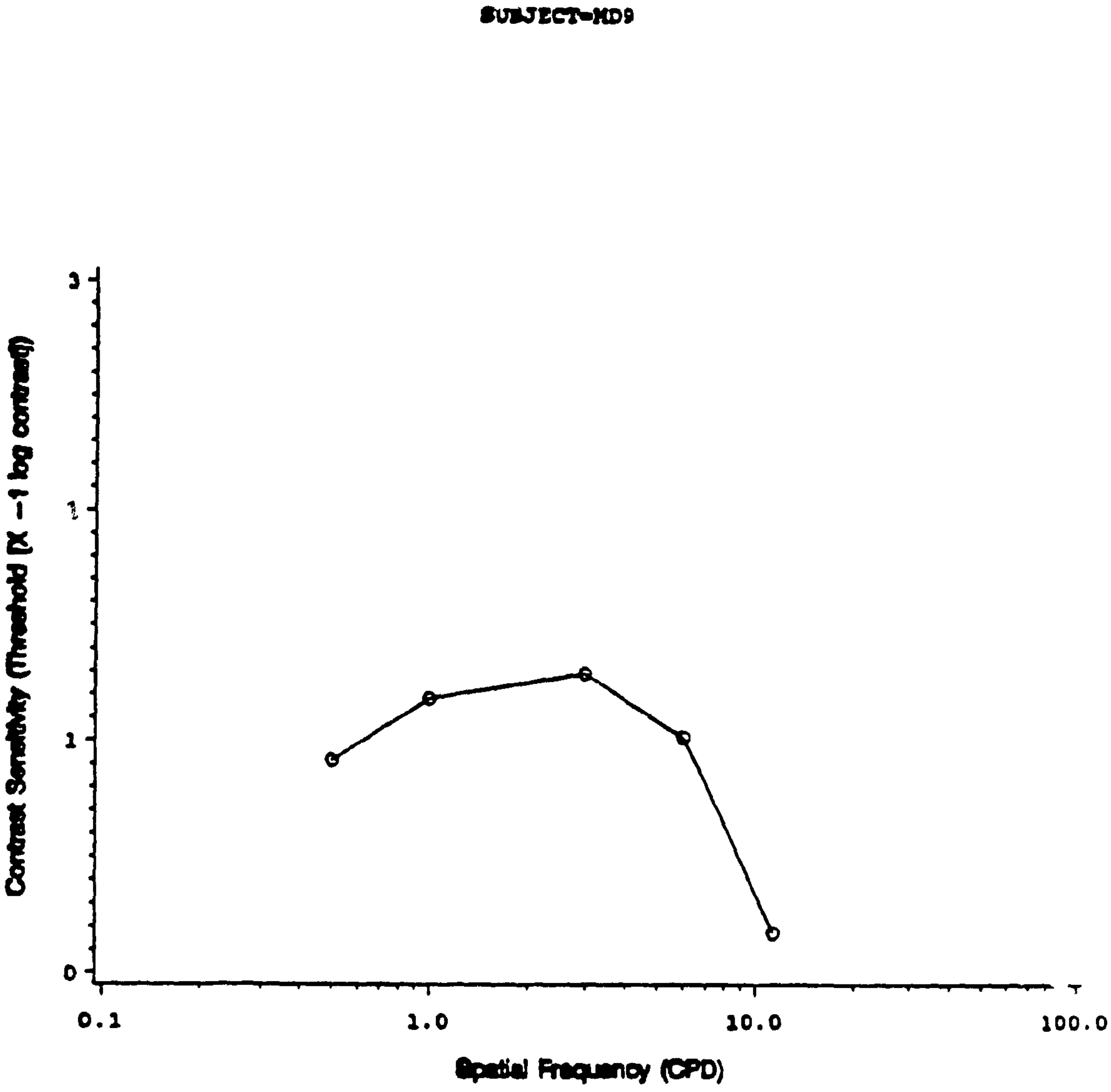

Contrast Sensitivity (Threshold [X −1 log contrast])
0
1
2
3
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=MD7

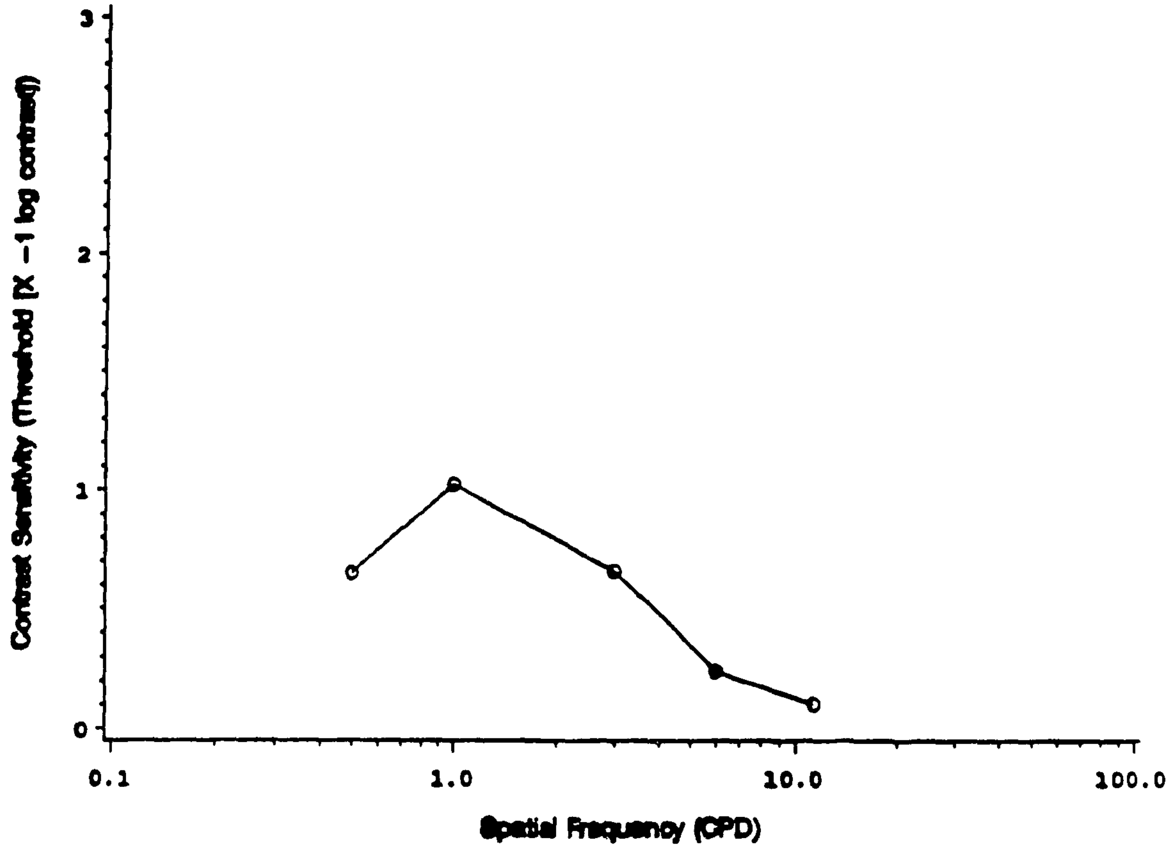

Contrast Sensitivity (Threshold [X –1 log contrast])
0
1
2
3
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=MD8

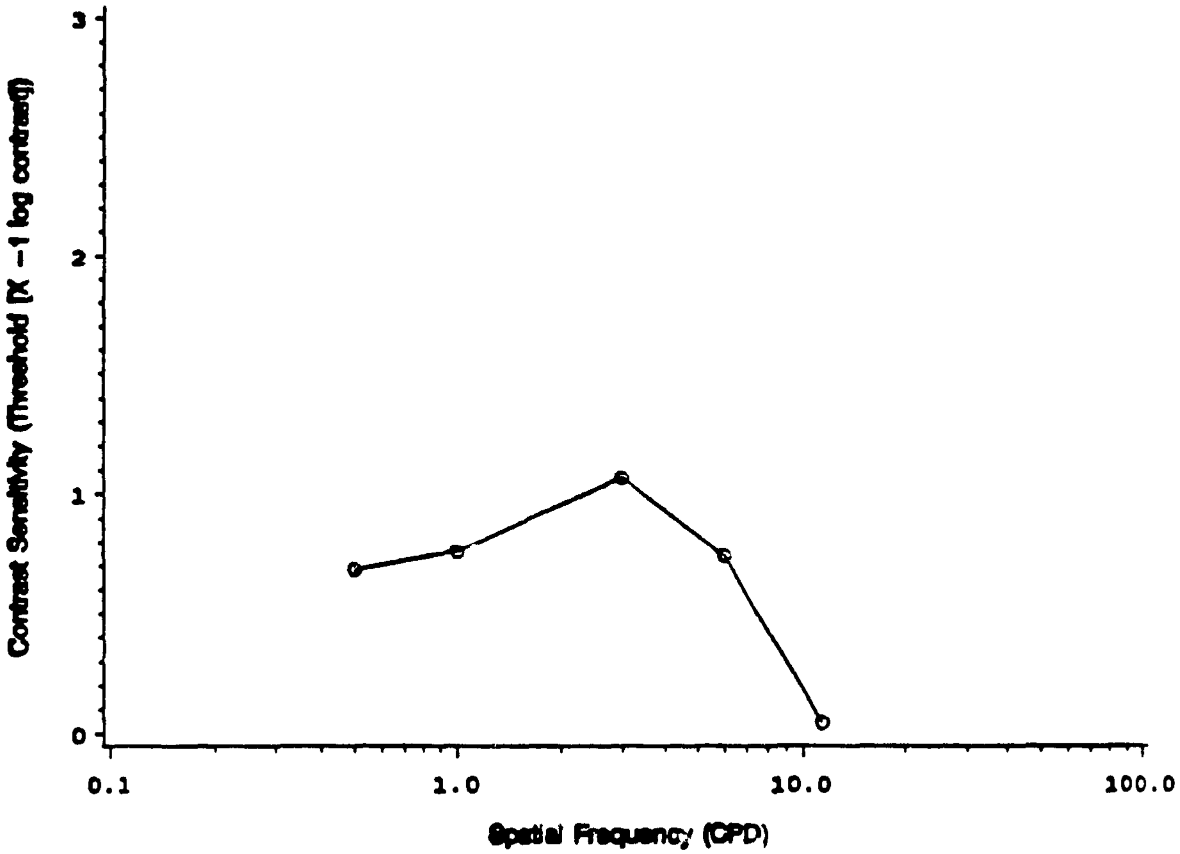

Contrast Sensitivity (Threshold (X -1 log contrast))
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

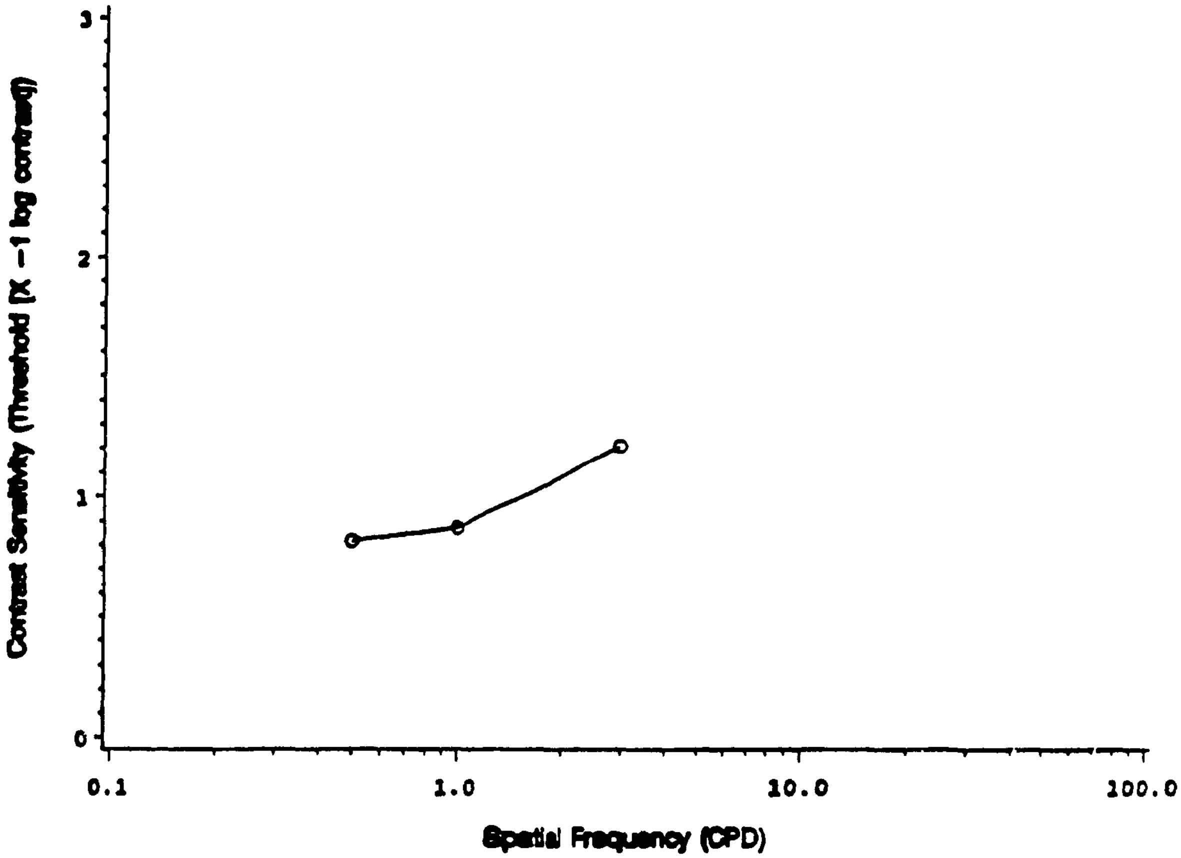

SUBJECT=MD9
Contrast Sensitivity (Threshold [X -1 log contrast])
3
2
1
0
0.1
1.0
10.0
100.0
Spatial Frequency (CPD)

SUBJECT=MD10



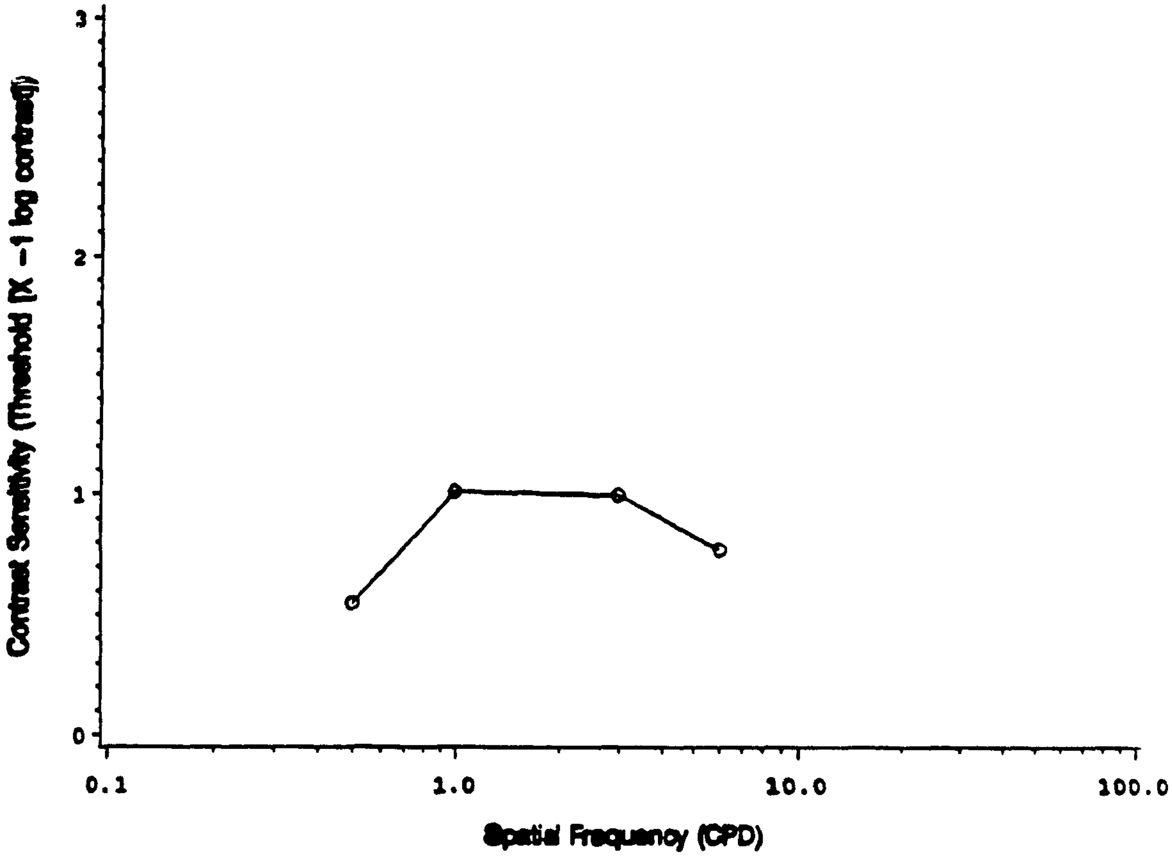
SUBJECT=MD11





SUBJECT=MD12

SUBJECT=MD13



APPENDIX E

Raw Frostig Figure-Ground Scores

#	No Filter	10 cpd Low-Pass	8 cpd Low-Pass	6 cpd Low-Pass
MACULAR DEGENERATION				
01	2 2 3 3 4 1 1 1	2 2 3 3 4 0 0 0	2 2 3 3 4 1 0 0	2 2 3 3 2 0 0 0
02	2 2 0 0 1 0 0 0	2 2 1 0 0 0 0 0	2 2 0 1 0 0 0 0	1 2 0 0 0 0 0 0
03	2 2 3 1 2 0 0 0	2 2 2 1 2 0 0 0	2 2 3 1 2 0 0 0	2 2 1 1 2 0 0 0
04	2 2 3 3 3 4 3 0	2 2 3 3 4 4 0 0	2 2 3 3 4 4 0 0	2 2 3 3 2 0 0 0
05	2 2 3 3 4 3 0 1	2 2 3 3 4 2 0 0	2 2 3 3 2 1 0 0	2 2 3 3 1 0 0 0
06	2 2 2 2 2 0 0 1	2 2 2 3 1 0 0 0	2 2 1 2 1 0 0 0	2 2 2 2 2 0 0 0
07	2 2 3 2 2 0 0 0	2 2 2 2 2 0 0 0	2 2 3 2 1 0 0 0	2 2 3 2 2 0 0 0
08	2 2 3 3 4 4 5 3	2 2 3 3 4 0 0 0	2 2 3 3 3 0 0 0	2 2 3 3 2 0 0 0
09	2 2 3 3 3 0 0 0	2 2 3 3 4 0 0 0	2 2 3 3 1 0 0 0	2 2 3 2 0 0 0 0
10	2 2 3 3 4 2 0 1	2 2 3 3 4 0 0 0	2 2 3 3 4 4 0 0	2 2 3 3 2 0 0 0
11	2 2 3 3 3 1 0 0	2 2 3 3 3 1 0 0	2 2 3 2 3 1 0 0	2 2 3 2 2 0 0 0
12	2 2 3 3 2 0 0 0	2 2 3 3 2 0 0 0	2 2 2 3 2 0 0 0	2 2 2 3 2 0 0 0
13	2 2 3 3 4 1 4 2	2 2 3 3 3 2 1 1	2 2 3 3 1 0 0 0	2 2 3 3 2 0 0 0
AGE-MATCHED NORMAL CONTROL				
01	2 2 3 3 4 4 5 4	2 2 3 3 4 4 0 0	2 2 3 3 4 4 0 0	2 2 3 3 4 1 0 0
02	2 2 3 3 4 4 5 4	2 2 3 3 4 4 0 0	2 2 3 3 4 4 0 0	2 2 3 3 2 2 0 0
03	2 2 3 3 4 4 5 5	2 2 3 3 4 4 0 2	2 2 3 3 4 3 0 0	2 2 3 3 4 0 0 0
04	2 2 3 3 4 4 5 5	2 2 3 3 4 4 0 1	2 2 3 3 4 4 0 1	2 2 3 3 4 3 0 0
05	2 2 3 3 4 4 5 3	2 2 3 3 4 4 0 1	2 2 3 3 4 4 0 1	2 2 3 3 4 3 0 0
06	2 2 3 3 4 4 5 5	2 2 3 3 4 4 0 0	2 2 3 3 4 4 0 0	2 2 3 3 3 0 0 0
07	2 2 3 3 4 4 5 5	2 2 3 3 4 4 0 1	2 2 3 3 4 4 0 0	2 2 3 3 4 0 0 0
08	2 2 3 3 4 4 5 5	2 2 3 3 4 4 0 1	2 2 3 3 4 4 0 0	2 2 3 3 4 2 0 0
09	2 2 3 3 4 4 5 5	2 2 3 3 4 4 0 0	2 2 3 3 4 4 0 0	2 2 3 3 4 1 0 0
10	2 2 3 3 4 4 5 4	2 2 3 3 4 4 0 1	2 2 3 3 3 4 0 0	2 2 3 3 3 0 0 0
11	2 2 3 3 4 4 5 5	2 2 3 3 4 3 0 0	2 2 3 3 4 3 0 0	2 2 3 3 4 2 0 0
12	2 2 3 3 4 4 5 4	2 2 3 3 4 4 0 0	2 2 3 3 4 1 0 0	2 2 3 3 4 0 0 0
13	2 2 3 3 4 4 5 5	2 2 3 3 4 4 1 0	2 2 3 3 4 4 0 0	2 2 3 3 4 4 0 0

Appendix E (Cont'd)

SUBJECT	REGULAR FFG	ENLARGED FFG
01	2 2 3 3 4 1 1 1	2 2 3 3 4 4 5 3
02	2 2 0 0 1 0 0 0	2 2 3 3 2 2 3 3
03	2 2 3 1 2 0 0 0	2 2 3 2 4 2 2 1
04	2 2 3 3 3 4 3 0	2 2 3 3 4 4 5 3
05	2 2 3 3 4 3 0 1	2 2 3 3 4 4 5 2
08	2 2 3 3 4 4 5 3	2 2 3 3 4 4 5 5
09	2 2 3 3 3 0 0 0	2 2 3 3 4 4 5 4
11	2 2 3 3 3 1 0 0	2 2 3 3 4 3 4 4
12	2 2 3 3 2 0 0 0	2 2 3 3 4 2 4 3
13	2 2 3 3 2 1 1 1	2 2 3 3 4 4 4 3

APPENDIX F

Ages and Snellen Acuities of All Participants

Subject #	Age	Snellen Acuity		Eye
Macular Degeneration				
01	69	20/50	+1	Right
02	73	20/400		Right
03	72	20/240		Left
04	65	20/40	-3	Left
05	76	20/40	-1	Left
06	81	20/50		Left
07	78	20/120		Right
08	72	20/50		Right
09	84	20/60		Right
10	84	20/80		Right
11	79	20/120		Right
12	79	20/60		Left
13	91	20/80	-4	Left
Age-Matched Normal Controls				
01	56	20/30	+2	Right
02	60	20/30		Left
03	55	20/20		Left
04	55	20/20		Right
05	58	20/25		Left
06	58	20/30		Right
07	72	20/25		Right
08	59	20/30		Right
09	74	20/20		Right
10	70	20/20		Left
11	54	20/20		Left
12	54	20/25		Right
13	64	20/20		Right