Pacific University

CommonKnowledge

College of Optometry

Theses, Dissertations and Capstone Projects

3-1977

Refinement of a method to assess visual resolution and contrast sensitivity in the presence of ocular opacities

Christer J. Blomberg
Pacific University

Abstract

Refinement of a method to assess visual resolution and contrast sensitivity in the presence of ocular opacities

REFINEMENT OF A METHOD TO ASSESS VISUAL RESOLUTION AND CONTRAST SENSITIVITY IN THE PRESENCE OF OCULAR OPACITIES

A Dissertation

presented to

the Faculty of the College of Optometry

Pacific University

In Partial Fulfillment of

the Requirements for the Degree

Doctor of Optometry

Submitted by

Christer J. Blomberg

March 1977

APPROVED

Niles Roth

Niles Roth OD, PhD

Advisor

PLACE

Forest Grove, OR

DATE

28 Feb 1977

ACKNOWLEDGEMENT.

I would like to express my sincerest appreciation to my advisor Dr. Niles Roth for the never failing interest he displayed during the course of the present investigation.

My thanks are also due to Dr. Joy Hirsch for solving problems related to the statistical treatment of the data.

I also wish to thank Dr. Chris Johansen whose technical assistance was a great help.

Furthermore, I wish to thank Dr. Clifton Schor for his involvment in the developing of the experimental design. Finally, I thank the students who served as subjects.

TABLE OF CONTENTS.

INTRODUCTION, BACKGROUND AND SIGNIFICANCE OF THE STUDY

The principal problem posed by the examination of every cataract patient has always been: will the patient be able to see considerably better after a successful operation than before it ? Following this the question arises whether retinal function is good enough to justify surgery. Goldmann, (1972) says: "the conscientious surgeon will advise an operation only if he can promise - quite apart from the operational risk - that not only the doctor, but also the patient, will benefit from the operation".

When opacification of the ocular media, and an associated decrease in visual acuity is present, one is faced with the question of what portion of the visual loss is produced by the ocular opacities. Commonly used clinical methods of testing visual resolution, such as two-light discrimination, test-targets, color discrimination and electroretinogram are at the best estimates of gross retinal function.

Laser interferometry.

A coherent light method, using, e.g. the helium-neon laser has been used to produce interference bands on the retina in patients with the above mentioned problems. This technique utilizes the phenomenon of constructive and destructive interference fringes on the fundus, avoids opacities, and produces these fringes independently of the ocular refractive power.

It has been shown that laser interferometry is a reliable means of predicting the visual outcome of cataract extraction in the majority of the patients tested (Green and Cohen, 1971).

Gratings without Maxwellian View system.

The most frequently used technique here is the Cathode Ray Tube-displayed sinusoidal grating pattern, introduced by Schade in 1956. Campbell and Green, (1965) modified this technique to investigate the spatial contrast sensitivity and it is this modification that is used today.

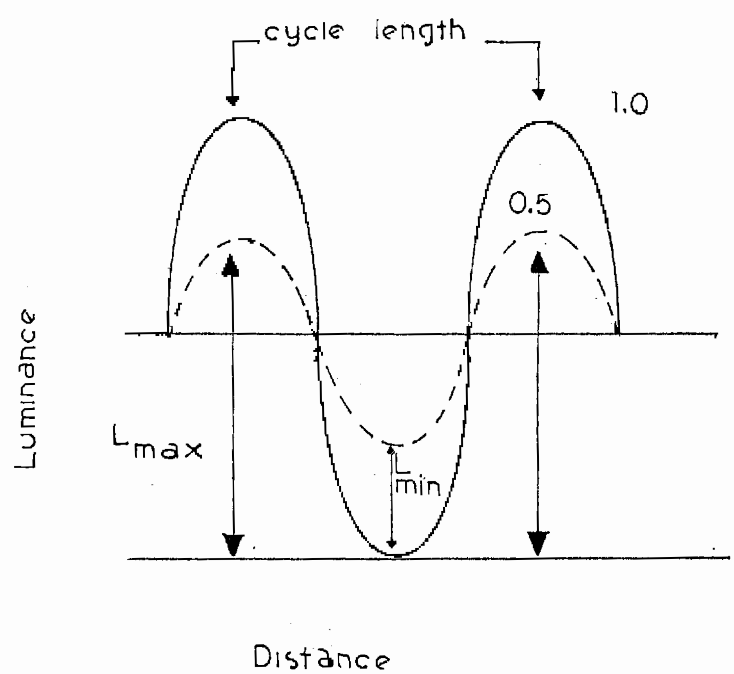
Two basic parameters may be altered: See Figure 1

1. spatial frequency, this is the reciprocal of cycle length. A higher spatial frequency will result in there being more bars displayed per unit length.

2. <u>contrast</u>, in this context contrast (modulation) is defined in terms of the luminance (L_{max}) at the center of the bright bars and the luminance (L_{min}) at the center of the dark bars, such that, contrast = $(L_{max} - L_{min}) / (L_{max} + L_{min})$. Then, for a given average luminance, $(L_{max} + L_{min}) / 2$, the modulation threshold is measured by increasing the contrast to the level at which the fringes are just visible. The maximum value for contrast occurs when L_{min} = zero and from this level the modulation can be reduced downwards to zero level at which $L_{max} = L_{min}$, thus representing a homogeneous field.

The sinusoidal grating pattern is particularly simple, in that it contains only one spatial frequency presented in one meridian and is readily applicable to Fourier transformation and linear systems analysis.

Figure 1:



This figure represents the luminance change with respect to distance of a sinusoidal grating. Contrast is defined as: $(L_{max} - L_{min}) / (L_{max} + L_{min})$. Two contrast ratios are illustrated: 1.0 and 0.5. Note that the mean luminance level remains constant. Spatial frequency is defined as the reciprocal of the angular distance between successive maxima in the sinusoidal intensity distribution. The highest spatial frequency that just can be detected is thus a measure of visual function.

Grating patterns with Maxwellian View system.

One limitation of the above mentioned technique is that opacities in the media interfere with the production of the grating patterns. This limitation is overcome by incorporating the fringe-producing system into a Maxwellian View apparatus. As Cavonius and Hilz, (1973) point out: "The Maxwellian view system is small, inexpensive and relative trouble free. Because a single entrance beam is used, alignment with the patient's pupil is easier. Any test pattern can be used, as long as it can be duplicated, i.e. photographed and trans-illuminated".

The method uses a small bundle of rays entering the eye, so that if a small area of the lens is free from cataract, the light can enter as if no opacities were present.

STATEMENT OF THE PROBLEM.

The ability to recognize Snellen letters subtending different visual angles of arc at a certain distance is the traditional clinical arrangement for visual acuity assessment. However, visual resolution may be determined with other test targets, which consequently can define acuity differently. The merits of these various targets which include point sources, nonius displacement, checkerboards and grating are discussed by Ogle, (1969).

The purpose of the present work is to consider the use of one such test stimulus, namely grating patterns. This type of test target is used extensively in the psychophysical examination of the human visual system. Its greater relevance today is due to the work of Hubel and Wiesel, (1962) and Campbell, Cooper and Enroth-Cugell, (1966). who have shown that cells in the occipital cortex in cats and monkeys respond best to lines and edges of specific orientation, rather than to single points and do not respond, in general, to diffuse flashes of light.

METHODS AND MATERIALS.

Contrast sensitivity of the human visual system has been measured in the presence of opacities of the ocular media with the aid of both coherent light and non-coherent light sources. To avoid the effects of ocular media opacities the latter is combined with a Maxwellian View system. The refinement of the Maxwellian View method in this apparatus gave as a result an increased ease of use in a clinical environment, and simplified calibration.

These advantages are gained by splitting the source output into two channels with a metal coated optical wedge. One channel contains the test grating while the other delivers stray light to the retinal image of the grating via a beam combiner. Contrast is determined by the reflectance-transmittance ratio of the optical wedge at a given setting, and the average luminance is constant to better than $\pm$ 5 per cent, because the flux diverted from one channel is simultaneously added to the other. Spatial frequency was controlled in this apparatus by using two counter rotating square wave gratings to produce Moire' fringes (Goldmann and Lotmar, 1970).

In addition to the conventional Maxwellian View system a variable prism was used to sweep the exit pupil horizontally across the entrance pupil of the test eye. The rate at which the stimulus was swept across the test eye was controlled by a synchronous motor and was therefore kept constant. One advantage to using a scanning system for presenting the stimulus is that small eye and head movements would have less effect on determination of the threshold. This view was supported by observations during the development of the apparatus that grating patterns that were presumably below threshold would often return to above threshold with a small eye or head movement. An additional, possible advantage to the scanning system is that the chances that the exit pupil will encounter a "window" in opacified media are increased. Thus, a scanning system that makes it possible to present the stimulus under conditions of controlled duration has the capability of reducing artefact in the data acquisition.

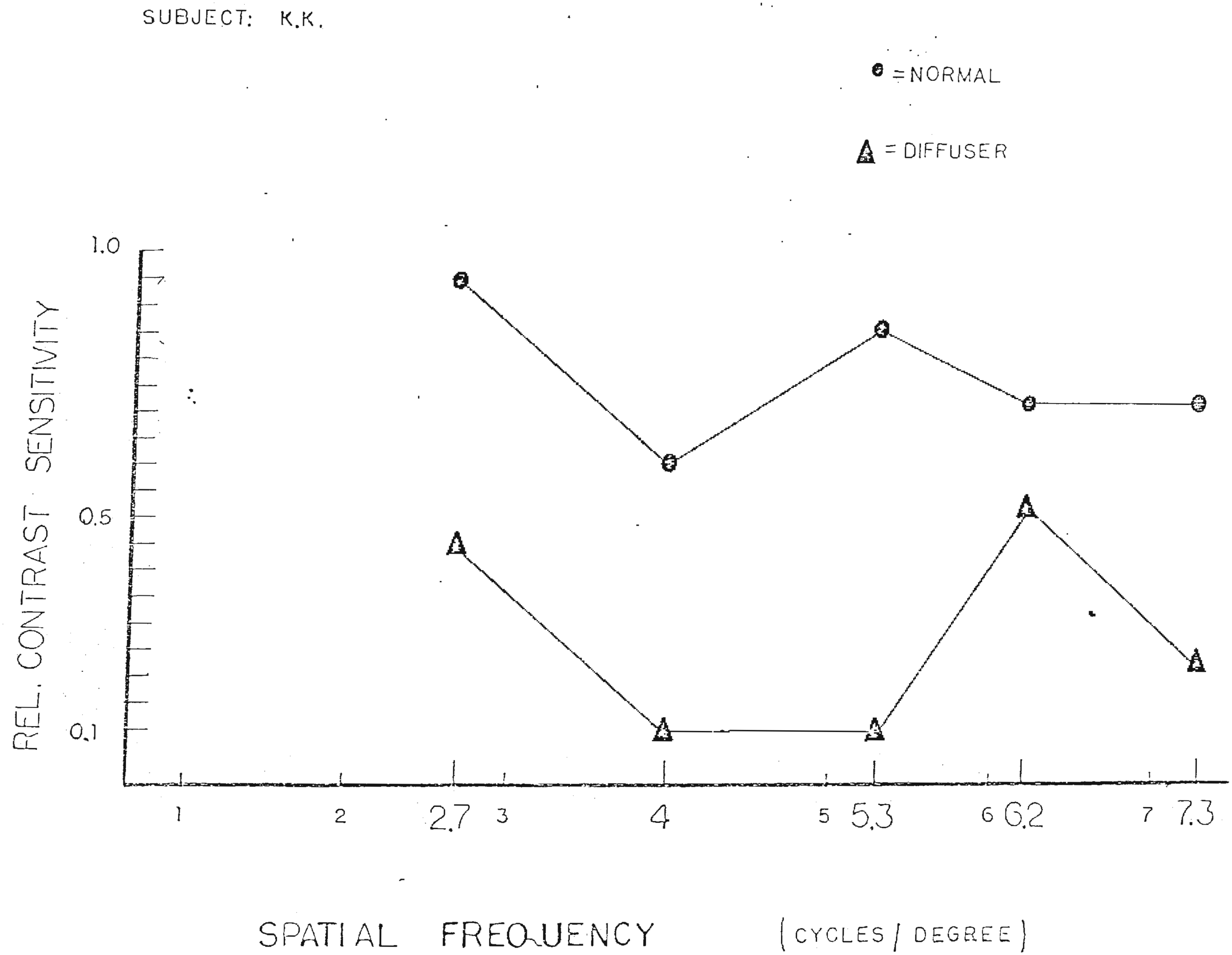
The five subjects, (4 males and 1 female), ranged in age from 24 to 31 years. None showed any evidence of pathology, ocular or otherwise. All had a visual acuity of at least 20/25 (corrected). Preliminary clinical data on these subjects was obtained as follows:

1. Best visual acuity with correction.
2. Ophthalmoscopic findings - from recent clinic records or by direct obervation.
3. Unaided visual acuity through the simulated cataract.

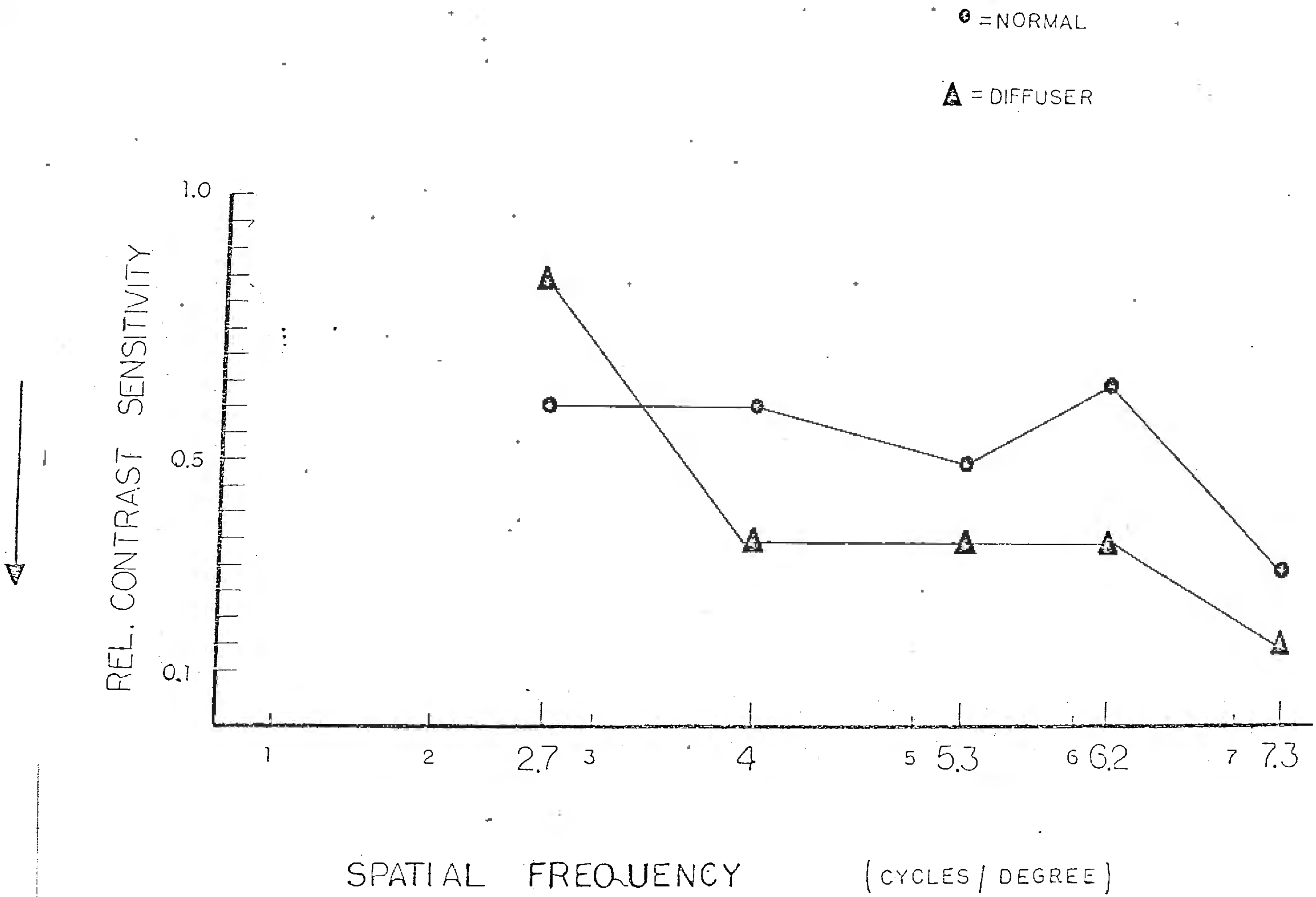
RESULTS.

Referring to the graphs, (pp. 9a - 9e), an additional impression gained from the survey of the five graphs is that the shape of the contrast sensitivity function was not significantly changed by interposing a simulated cataract between the test eye and the Maxwellian system. Also from the subject's standpoint and based on earlier observations before the scanning device was incorporated into the apparatus, determination of the threshold contrast level was much easier and more definite with the scanning device than without.

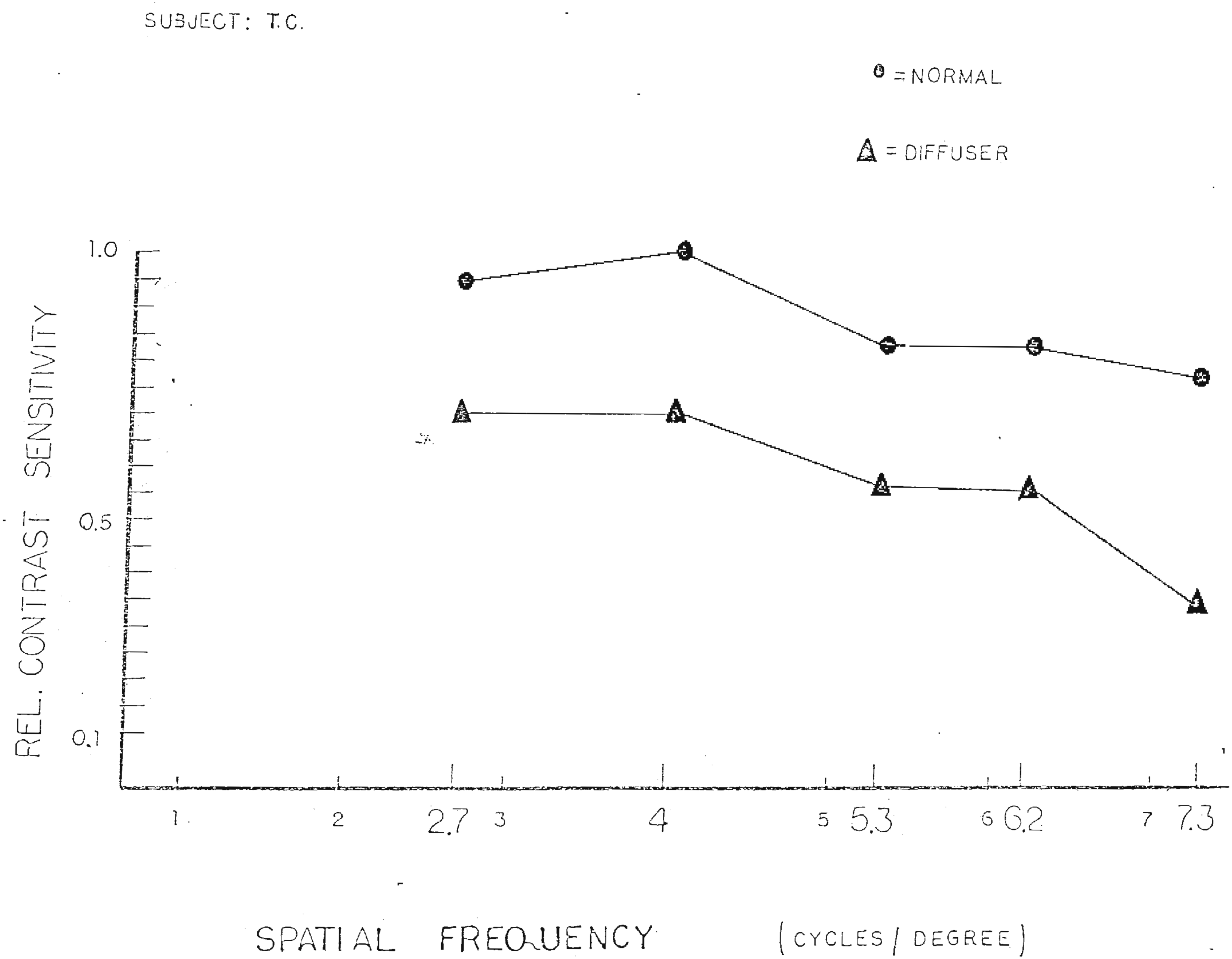
In addition to the individual graphs plotted for each subject showing contrast sensitivity with and without simulated cataract respectively, an additional graph was plotted for each subject showing the difference in contrast sensitivity between the simulated cataract condition and the no-cataract condition. These graphs are to be found in Appendix 1, pp 9f - 9j.


SUBJECT: K.K.
= NORMAL
= DIFFUSER
1.0
0.5
0.1
REL. CONTRAST SENSITIVITY
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY (CYCLES / DEGREE)

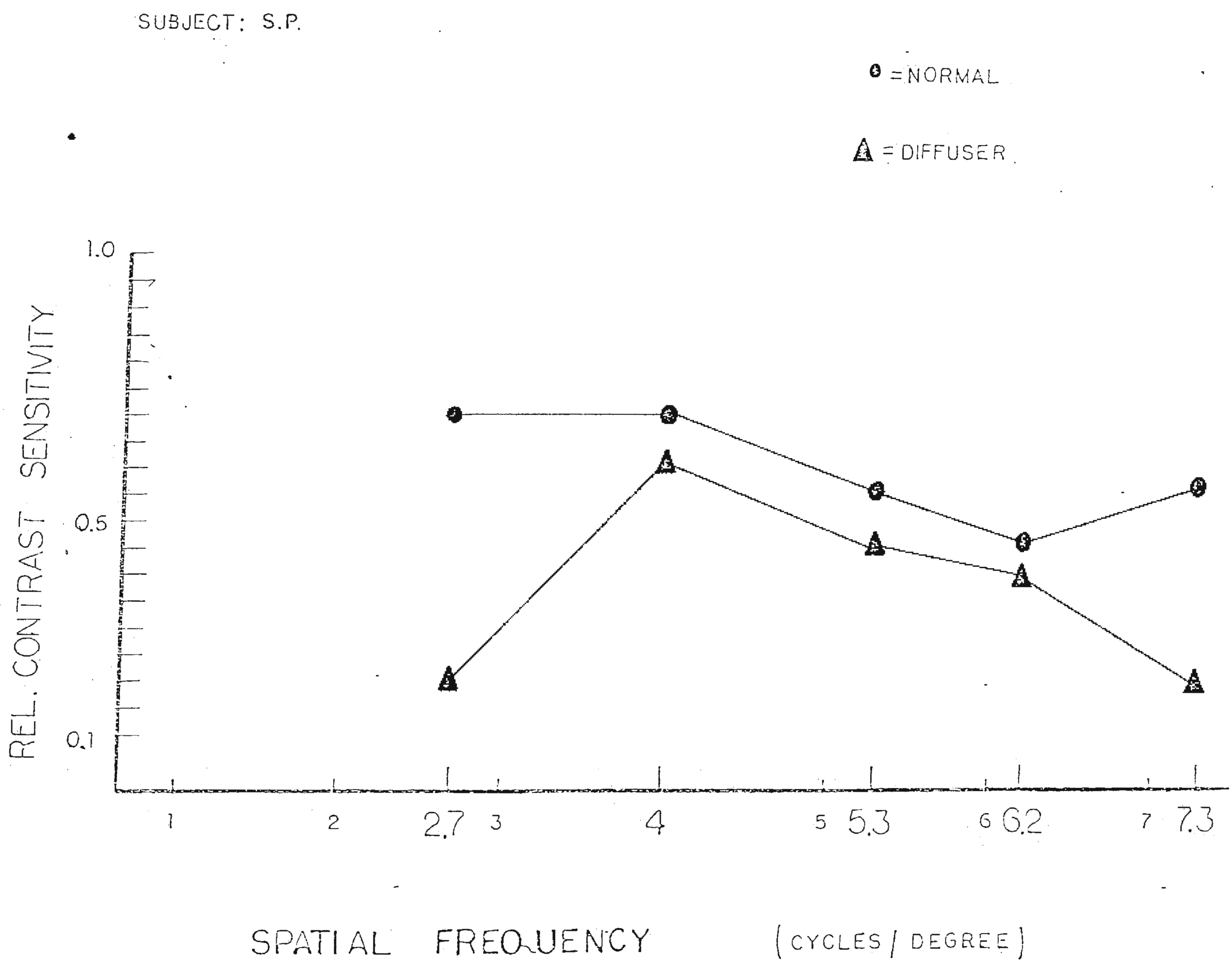
SUBJECT: D.S.



= NORMAL
= DIFFUSER
1.0
0.5
0.1
REL. CONTRAST SENSITIVITY
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY (CYCLES / DEGREE)



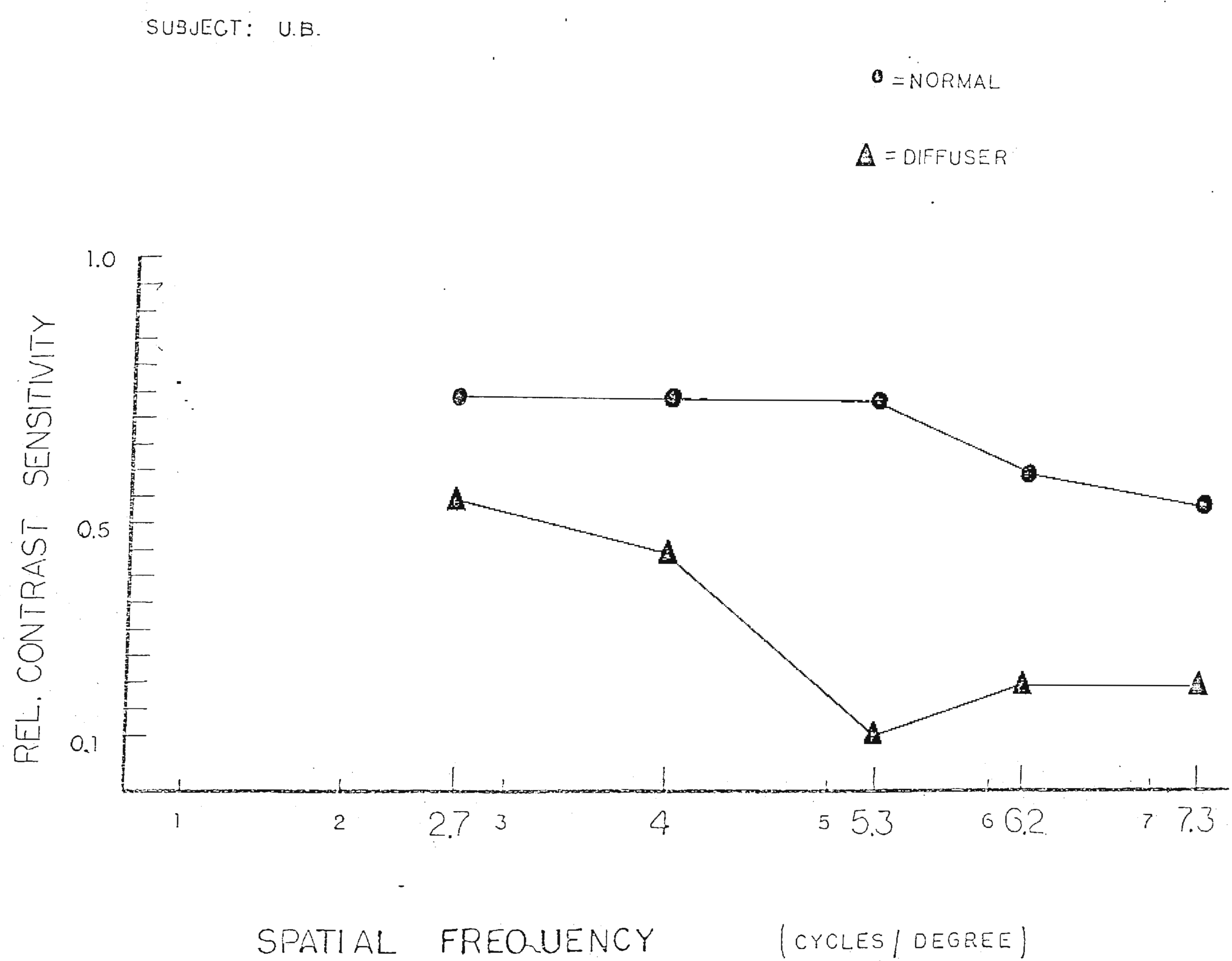
SUBJECT: T.C.
= NORMAL
= DIFFUSER
REL. CONTRAST SENSITIVITY
1.0
0.5
0.1
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY (CYCLES / DEGREE)


SUBJECT: S.P.
= NORMAL
= DIFFUSER
1.0
0.5
0.1
REL. CONTRAST SENSITIVITY
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY
(CYCLES / DEGREE)

D

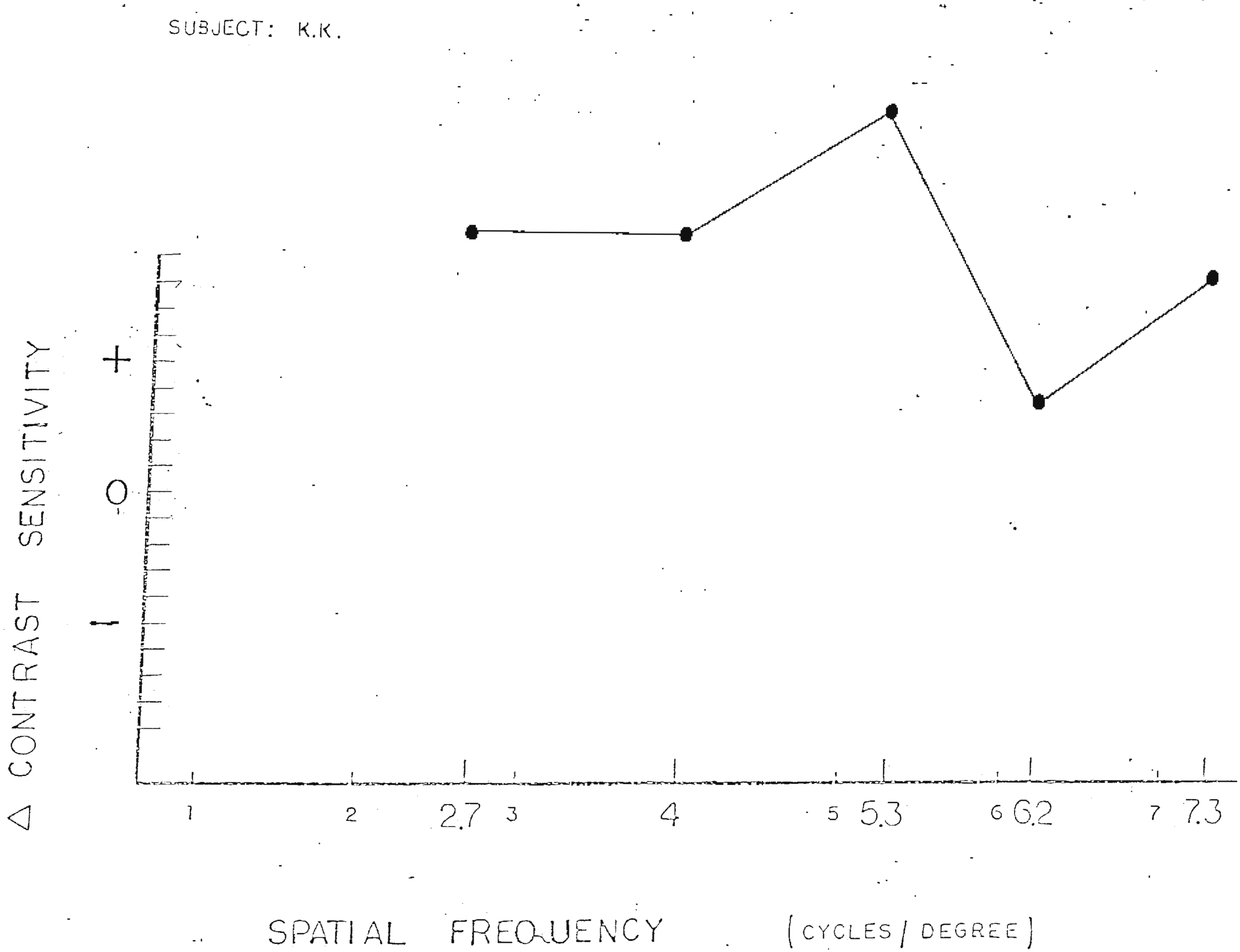
9d

E

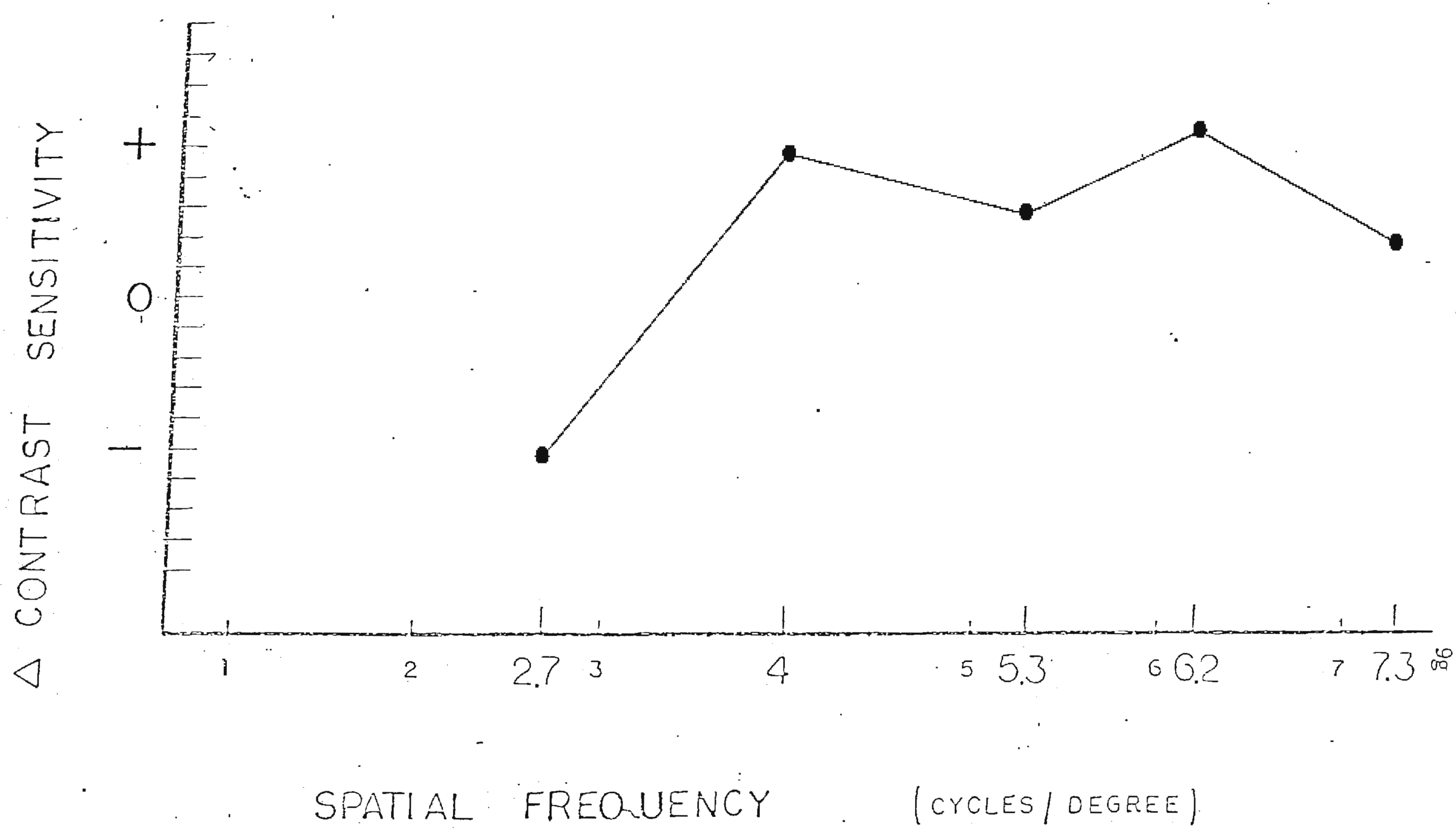

SUBJECT: U.B.
● = NORMAL
▲ = DIFFUSER
1.0
0.5
0.1
REL. CONTRAST SENSITIVITY
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY (CYCLES / DEGREE)

9e

APPENDIX 1.

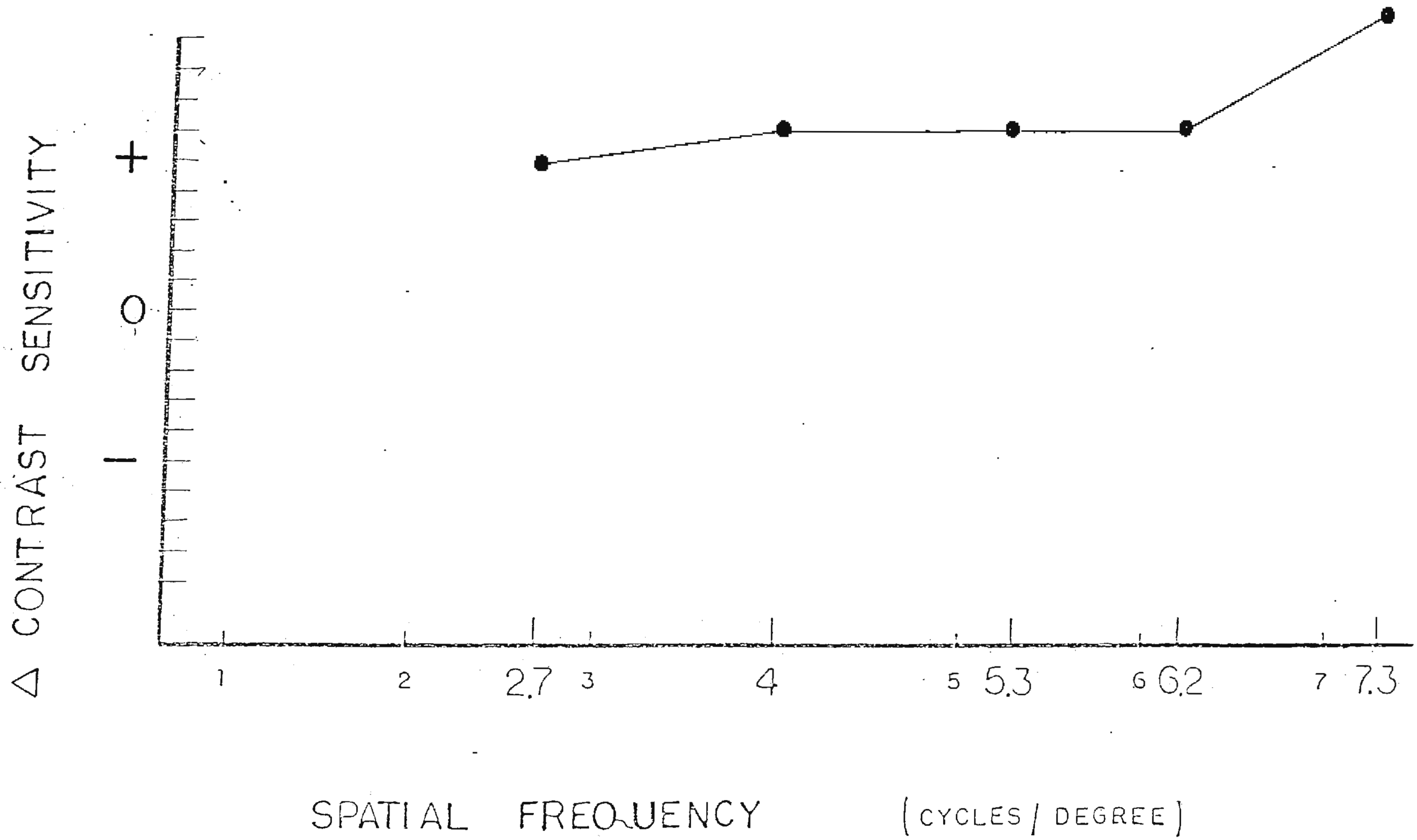

SUBJECT: K.K.
Δ CONTRAST SENSITIVITY
+
0
-
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY (CYCLES / DEGREE)

SUBJECT: D.S.

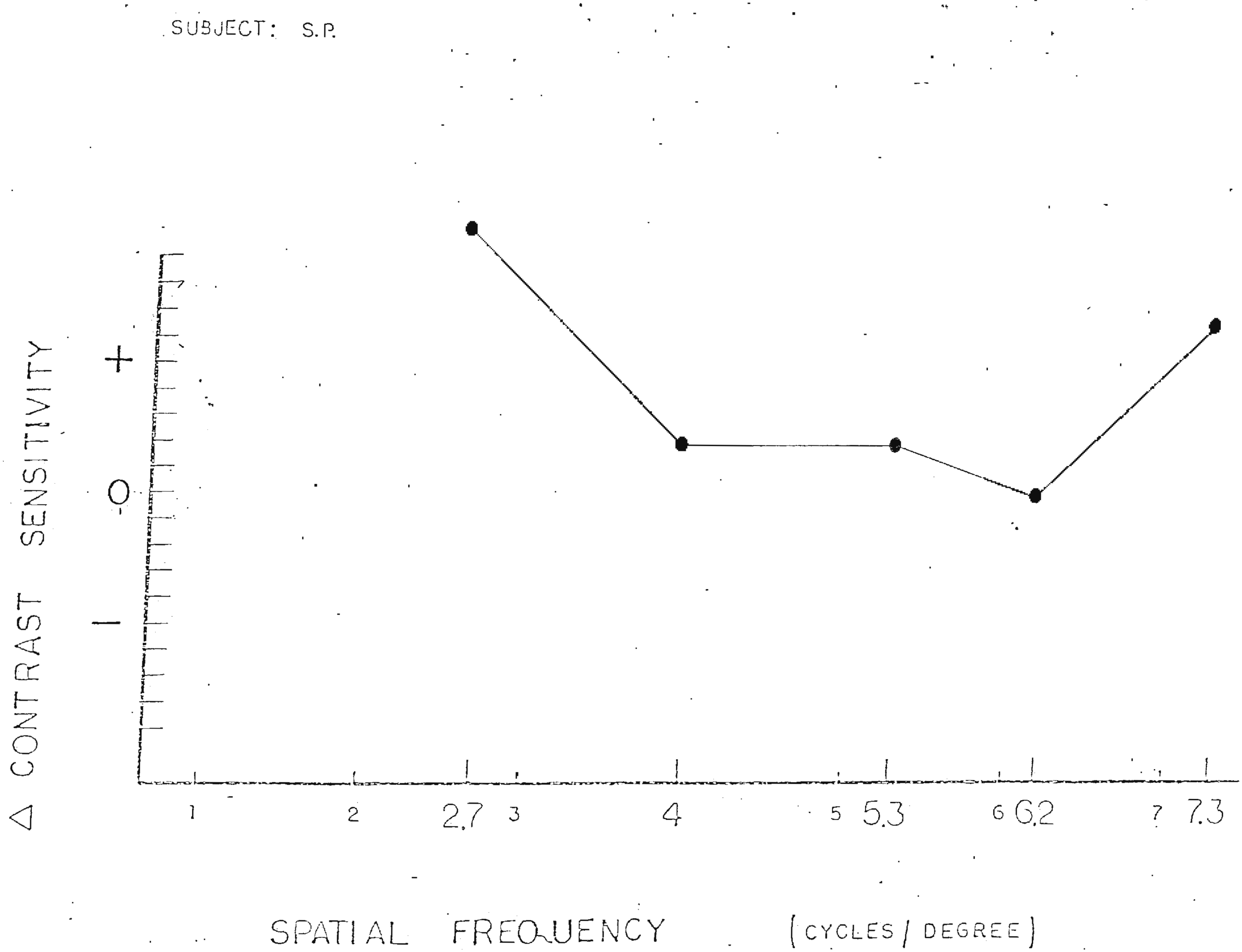


Δ CONTRAST SENSITIVITY
+
0
−
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
8
9
SPATIAL FREQUENCY (CYCLES / DEGREE)

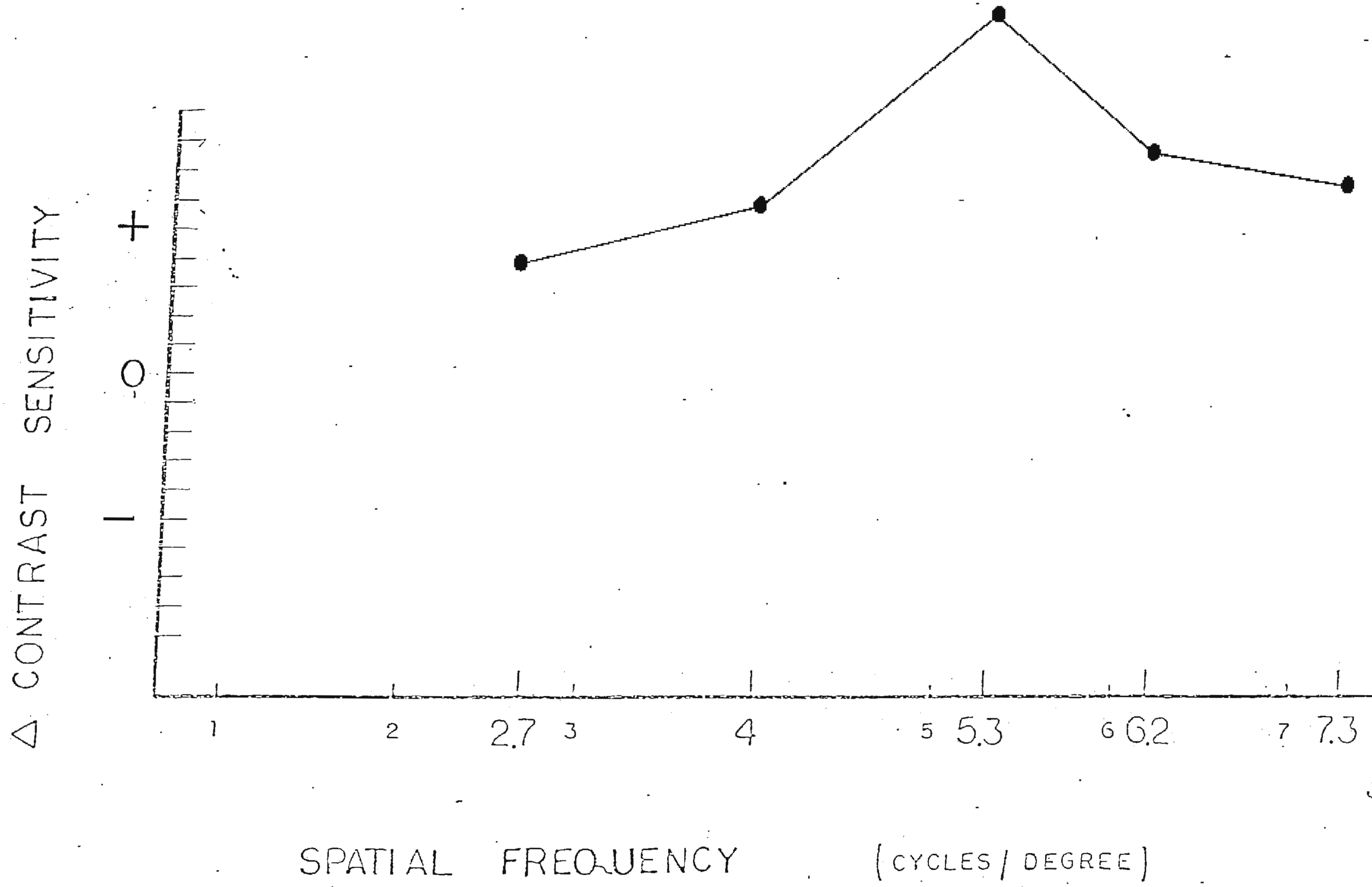
SUBJECT: T.C.



Δ CONTRAST SENSITIVITY
+
0
−
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY
(CYCLES / DEGREE)


SUBJECT: S.P.
Δ CONTRAST SENSITIVITY
+
0
-
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY (CYCLES / DEGREE)

SUBJECT: U.B.



+
0
-
Δ CONTRAST SENSITIVITY
1
2
2.7
3
4
5
5.3
6
6.2
7
7.3
SPATIAL FREQUENCY (CYCLES / DEGREE)

DISCUSSION.

In this pilot study a simple cataract analogue was constructed to study the feasibility of using the apparatus to test retinal resolution and contrast sensitivity in the presence of opacities. This was accomplished by using only normal subjects whose vision was reduced artificially by means of simulated cataracts. These same subjects acted as their own controls when trials were conducted without the simulated cataracts.

The study was rendered more significant by the inclusion of a scanning device designed to implement a testing procedure heretofore unused in this type of instrument. The possible advantages of sweeping the exit pupil across the test eye were listed earlier. (See under Methods and Materials).

In basic terms, a cataract may be thought of as an optical element containing a random distribution of scattering centers. The scattering centers are simply regions of appropriate size within the lens whose index of refraction differs from that of the surrounding matrix.

Light passing through such a medium will therefore undergo scattering, and imagery will be aberrated. Put another way, the aberrations introduced by the randomly-distributed scattering centers cause any incident light wavefront to suffer distortions so severe that only hazy large angular subtense objects (low spatial frequency) images are seen.

The major effect of the cataract on imagery is to produce phase aberrations on the optical electromagnetic wavefront propagating through the eye's cornea and lens. Since the work of Benedek (1971), it is generally accepted that light scattering alone, as distinct from absorption processes, is capable of accounting for the image characteristics of cataractous eyes. It has been shown (Benedek, 1971) that a decrease in object contrast is the result of having the components of the optical field scattered randomly by the cataract. Similarly, random scattering centers can account for glare sensitivity and decreased resolution. These considerations, and the fact that the overall intensities with and without cataracts striking the entire retina are comparable strongly suggest that the cataract introduces random phase aberrations on the optical wavefront by virtue of the fact that some portions of the cataract have a different index of refraction from that of adjacent portions. If this were not true, and a cataract was instead composed primarily of randomly-distributed, light-absorbing regions, far less light would reach the retina. Furthermore, image contrast and resolution would be higher than observed.

Readers interested in the biochemical bases for opacification of the chrystalline lens can refer to Benedek's (1971) paper.

Psychophysical aspects.

Spatial periodic stimuli (gratings) with a rectangular or sinusoidal luminance profile have proven to be very convenient for psychphysical and electrophysiological experiments in vision. Theoretically, sinusoidal gratings are the simplest light distribution. Indeed, according to Fourier theory, any light distribution in the retinal image can be expressed as the sum of its sinusoidal components.

In particular these stimuli have been employed for studying the response of neurons at various levels in the visual system as a function of the spatial frequency, i.e.

of the number of grating bars (light or dark bars) per unit of visual angle. A sinusoidal stimulus has two relevant variables beside its spatial frequency: its contrast (amplitude of the sine-wave light distribution) and its position with respect to the cell's receptive field (spatial phase).

Using microelectrodes to obtain responses of cat retinal ganglion cells to sine-wave gratings, Enroth-Cugell and Robson, (1966) have shown that the contrast sensitivity function is explainable in neurophysiological terms. Each retinal ganglion can be driven by illuminating a local area of the retina. This area is classed as the receptive field of that cell. Electrophysiologically, the organization of these receptive fields in the cat retina were originally described as consisting of two mutually antagonistic concentric areas.

Now consider an array of retinal ganglion cells which overlap extensively and are of the same size. The array's responsiveness to low frequencies is reduced by the inhibitory action of the surround mechanism, whilst at high frequencies the array's firing is reduced by the summation within the center of the field. At intermediate frequencies, the center response dominates and this responds to the maximizing of the contrast sensitivity curve.

Consequently, to change the frequency selectivity of these cells would then alter the sensitivity function. This can be achieved in low luminance conditions and in the presence of certain variations in stimulus patterns.

Great progress in understanding visual processing was made with the arrival of Campbell and Robson's (1968) paper in which they proposed that the fundamental and third harmonic of square wave grating are processed by quite separate spatial frequency channels. This suggestion, that in the human visual system there existed channels sensitive to bands of spatial frequency, was substantiated by Blakemore and Campbell, (1969) using an adaptation method. They found that, by adapting to a grating of fixed spatial frequency, there was a consequent threshold rise for a range of frequencies centered around the adapting frequency. These human neurones then, whose sensitivity are being depressed, seem therefore to be frequency selective like like those in the cat and monkey.

This study has quantitatively studied the relationship between image contrast and resolution as influenced by a simulated cataract.

Finally, from the obtained data the contrast at which a given size object can be seen was determined as a function of the cataract present.

The study shows how the full assessment of visual quality requires the test of contrast discrimination as well as resolution. Furthermore, it has been seen that such tests, when made in the presence of pathological conditions leading to image degradation, might be used to quantitatively assess the degree of that pathological state. Thus, in the standard test situation, the addition of variable contrast targets would offer the possibility of a more complete description of the patient's visual quality.

Finally, the utilization of this procedure would enable data collection in the presence of image-degrading pathology.

Conclusion.

The ideal retinal resolution tester for cataractous eyes would have the capability of completely bypassing the opacity in order to indicate what the retinal resolution is. On the other hand, an instrument of this kind that was less than ideal would demonstrate a noticable distortion of the contrast sensitivity function compared with the normal.

The results of this preliminary study, with five subjects, wherein simulated cataracts were used have shown no significant distortions in the contrast sensitivity curves between normal and cataractous. It seems therefore likely that the present apparatus would be an ideal resolution tester of the retina in the presence of opacities. Further work, however, is needed with more subjects and a more refined apparatus before this statement can be fully substantiated.

SUMMARY.

The nature and use of spatial periodic stimuli (gratings) have been discussed. Without doubt they are a powerful analytical tool in the hand of the researcher, who attempts to evaluate the processing of normal and abnormal visual systems. The clinical application in optometric practice and orthoptics may appear to be remote, but there is no doubt that in conjunction with other techniques (e.g. visually evoked responses), their subsequent exploitation should soon offer a new diagnostic aid in routine optometric investigations.

BIBLIOGRAPHY.

BENEDEK, G.B. (1971). The theory of transparency of the eye. Appl. Optics 10: 459.

BYRAM, G.M. (1944). The physical and photochemical basis of visual resolving power. 11. Visual acuity and the photochemistry of vision. J.opt.Soc.Am. 34: 718.

CAIN, C.P. & WELCH, A.J. (1974). Measured and predicted laser-induced temperature rises in the rabbit fundus. Invest. Ophthal. 13: 60.

CAMPBELL, F.W. & ROBSON, J.G. (1968). Application of Fourier analysis to the visibility of gratings. J.Physiol. 197: 551.

CAMPBELL, F.W. & KULIKOWSKI, J.J. (1966). Orientational selectivity of the human visual system. J.Physiol. 187: 437, Nov.

CAMPBELL, F.W., KULIKOWSKI, J.J. & LEVINSON, J. (1966). The effect of orientation on the visual resolution of gratings. J.Physiol. 187: 423.

CAMPBELL, F.W. & GREEN, D.G. (1965). Optical and retinal factors affecting visual resolution. J.Physiol. 181: 576.

CAMPBELL, F.W. & GUBISCH, R.W. (1966). Optical quality of the human eye. J.Physiol. 186: 558.

CAVONIUS, C.R. & HILZ, R. (1973). Invariance of visual receptive field size and visual acuity with viewing distance. J.opt.Soc.Am. 63: 929.

CAVONIUS, C.R. & HILZ, R. (1973). A technique for testing visual function in the presence of opacities. Invest. Ophthal. 12: 933.

DAITCH, J.M. & GREEN, D.G. (1969). Contrast sensitivity of the human peripheral retina. Vis.Res. 9: 947.

DUKE-ELDER, S. (1969). System of Ophthalmology, vol. Xl. Diseases of the lens and vitreous. Kimpton.

ENROTH-CUGELL, C. & ROBSON, J.G. (1966). The contrast sensitivity of retinal ganglion cells of the cat. J.Physiol. 187: 517.

GITTER, K.A. (1970). Pediatric diagnostic ultrasonography. J.Pediat.Ophthal. 7: 7.

GOLDMANN, H. (1972). Examination of the function of the cataractous eye. Am.J.Ophthal. 73: 309.

GOLDMANN, H. & LOTMAR, W. (1970). Retinale Sehscharfenbestimmung bei Katarakt. Ophthmologica, 161: 175.

GREEN, D.G. (1970). Regional variations in the visual acuity for interference fringes on the retina. J.Physiol. 207: 351.

GREEN, D.G. (1967). Visual resolution when the light enters the eye through different parts of the pupil. J.Physiol. 190: 583.

GREEN, D.G. & COHEN, M.M. (1971). Laser interferometry in the evaluation of potential macular function in the presence of opacities in the ocular media. Trans.Am.Acad.Ophthal.Otol. 75: 629.

GSTALDER, R.J. & GREEN, D.G. (1971). Laser interferometric acuity in amblyopia. J.Pediat.Ophthal. 8: 251.

GUILD, J. (1956). The interference systems of crossed diffraction gratings - theory of Moire' fringes. Oxford Univ. Press.

HUBEL, D.H. & WIESEL, T.N. (1962). Receptive fields, binocular interaction and functional archtecture in the cat's visual cortex. J.Physiol. 106: 160.

KULIKOWSKI, J.J.(1971). Effect of eye movements in the contrast sensitivity of spatio-temporal patterns. Vis.Res. 11: 261.

KULIKOWSKI, J.J., ABADI, R.V. & KING-SMITH, P.E. (1973). Oriental selectivity of grating and line detectors in human vision. Vis.Res. 13: 1479.

KULIKOWSKI, J.J. & KING-SMITH, P.E. (1973). Spatial arrangement for line, edge and grating detectors revealed by subthreshold summation. Vis.Res. 13: 1455.

MAFFEI, L. & FIORENTINI, A. (1973). The visual cortex as a spatial frequency analyzer. Vis.Res. 13: 1255.

MIRIKAWA, T. & TAMURA, O. (1970). Relation between ERG and postoperative vision in cataract. Jap.J.Clin.Ophthal. 24: 43.

MOVSHON, J.A., CHAMBERS, B.E.I. & BLAKEMORE, C. (1972). Interocular transfer in normal humans, and those who lack stereopsis. Perception, 1: 483.

NES van, F.L. & BAUMAN, M.A. (1967). Spatial modulation transfer in the human eye. J.opt.Soc.Am. 57: 401.

OGLE, K.N. (1969). Visual acuity, in The Retina. Univ. of Cal. Press, Berkely and Los Angeles, p. 443.

SCHADE, O.H. (1956). Optical and photoelectric analogue of the eye. J.opt.Soc.Am. 46: 721.

SPAETH, E.B., FRALIK, F.B. & HUGHES, W.F., Jr. (1955).
Estimation of loss of visual efficiency.
Arch.Ophthal. 54: 462, Sept.

WESTHEIMER, G. (1966). The Maxwellian View. Vis.Res. 6: 669.

ZUCKERMAN, J.L., MILLER, D. & DYES, W. et al. (1973).
Degradation of vision through a simulated cataract.
Invest.Ophthal. 12: 213.

Le GRAND, Y. (1935). Sur la mesure de l'acuite' oculaire au moyen de franges d'interfe'rence. C.R. Acad.Sci. Paris, 200: 490.