

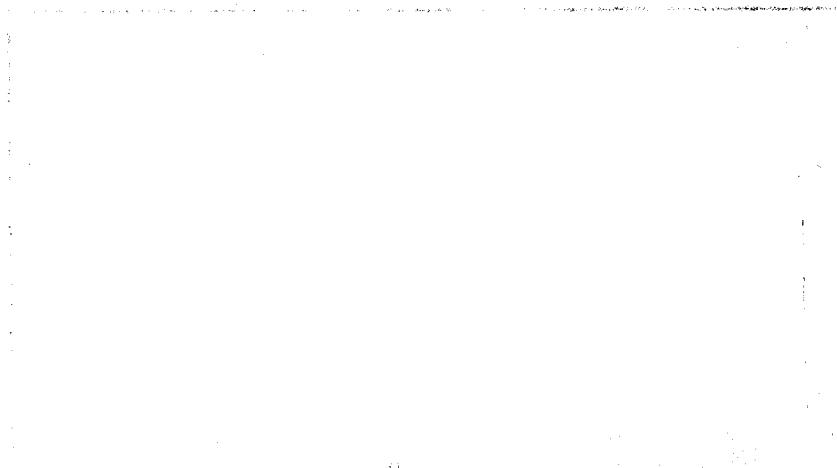
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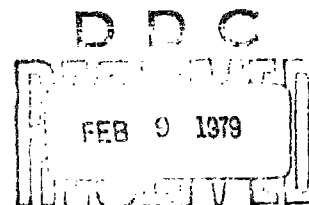
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CONTRAST SENSITIVITY OF THE HUMAN
VISUAL SYSTEM AT ONE LUMINANCE LEVEL
WHILE ADAPTED TO A STIMULUS AT
ANOTHER LUMINANCE LEVEL

THESIS

AFIT/GE/BE/78-42

Charles G. Smith
Capt USAF



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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by
Charles G. Smith, B.S.
Capt USAF
Graduate Electrical Engineering
December 1978

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Preface

The Air Force Institute of Technology (AFIT) and the Aerospace Medical Research Laboratory (AMRL) are conducting research into the operation and response of the human visual system to various visual tasks. The results obtained from investigations of this nature may provide significant contributions in defining design criteria for various visual display systems. This investigation was designed to provide an insight into how an image is processed by the human visual system.

I am indebted to Maj Joseph W. Carl whose paradigm prompted this investigation. I thank him for convincing me to undertake the thesis and for the many hours he spent explaining the underlying model.

Words cannot express my gratitude to Dr. Matthew Kab-risky for the untold hours he devoted to helping me trouble shoot, repair, modify, and calibrate the equipment, and acting as a test subject, advisor, and general supporter.

Last of all I want to thank my real supporters during these long months. To my wife, Cathy, and my daughters, Jonna and Jenny, go my loving thanks for always understanding the reasons for, and supporting me in, my pursuit of an advanced degree.

Charles G. Smith

Contents

	Page
Preface	11
List of Figures	v
List of Tables	viii
Abstract	1x
I. Introduction	1
Purpose	1
Background	2
II. Apparatus	10
Basic Equipment	10
Modification of Brightness Control	11
Modifications to Multiplex Controller	11
III. Testing Procedures	16
Laboratory Procedures	16
Experimental Structure	17
Spatial Frequency Selection	17
Data requirements	18
Experimental Procedure	19
IV. Experimental Hypothesis	24
V. Results	29
VI. Conclusion	57
VII. Recommendations	60
Bibliography	64
Appendix A: Equipment Operating Procedures	66
Appendix B: MTF Computer Program	72
Computer Program for Stimulus Control .	72
Program Operation	74
Appendix C: Contrast Calibration Data	95

Appendix D: Spatial Frequency Calibration Data	97
Test Spatial Frequencies	98
Appendix E: Equipment Configuration	100
Appendix F: Supporting Data	103
Vita	132

List of Figures

Figure	Page
1 Luminance Profile of a Sine Wave Grating	4
2 Typical MTF Plot of Contrast Sensitivity as a Function of Spatial Frequency	6
3 TV Circuit Diagram Showing the Location of Brightness Control Modification	12
4 Brightness Control Modification Circuit Diagram ..	13
5 Pattern Switching Circuit Interconnection Points .	15
6 Typical MTF Plot of Contrast Sensitivity as a Function of Spatial Frequency Indicating the One Octave Wide Frequency Specific Channels . Defining the Enveloping MTF Curve	26
7 The Effect on the Frequency Specific Adaptation Depression of the MTF Curve of Testing at a High Luminance Level When Adapted to a 6 CPD Grating	28
8 CGS, Test Bright, Adapt Bright, 0 CPD	35
9 CGS, Test Dim, Adapt Dim, 0 CPD	36
10 CGS, Test Bright, Adapt Dim, 0 CPD	37
11 CGS, Test Bright, Adapt Bright, 6 CPD	38
12 CGS, Test Bright, Adapt Dim, 6 CPD	39
13 CGS, Test Bright, Adapt Bright, 4 CPD	40
14 CGS, Test Dim, Adapt Dim, 4 CPD	41
15 CGS, Test Bright, Adapt Dim, 6 CPD (Average)	42
16 CGS, Test Bright, Adapt Bright, 8 CPD	43
17 CGS, Test Bright, Adapt Dim, 8 CPD	44
18 CGS, Test Dim, Adapt Bright, 6 CPD	45
19 MJK, Test Bright, Adapt Dim, 0 CPD	46
20 MJK, Test Bright, Adapt Dim, 6 CPD (Average)	47

21	MJK, Test Bright, Adapt Dim, 4 CPD (Average)	48
22	MJK, Test Bright, Adapt Dim, 8 CPD	49
23	CGS, Test Bright, Adapt Dim, 6 CPD (Blue)	50
24	CGS, Test Bright, Adapt Dim, 6 CPD (Average Red) .	51
25	CGS, Test Bright, Adapt Dim, 6 CPD (White)	52
26	CGS, Test Bright, Adapt Dim, 6 CPD (White, Right Eye)	53
27	CGS, Test Bright, Adapt Dim, 6 CPD (Average - Adapt Right Eye, Test Left Eye)	54
28	MJK, Test Bright, Adapt Bright, 0 CPD (20 Minutes After Adapting to 6 CPD)	55
29	MJK, Test Bright, Adapt Bright, 0 CPD (48 Hours After Adapting to 6 CPD)	56
30	MTF Program Listing	80
31	Example of Interoperative Computer Program Printout During Experiment Data Input	93
32	Diagram Showing Equipment Interconnection	102
33	CGS, Test Bright, Adapt Bright, 0 CPD	115
34	CGS, Test Bright, Adapt Bright, 6 CPD	116
35	CGS, Test Dim, Adapt Dim, 6 CPD	117
36	CGS, Test Bright, Adapt Dim, 6 CPD	118
37	CGS, Test Bright, Adapt Dim, 6 CPD	119
38	CGS, Test Bright, Adapt Dim, 6 CPD	120
39	CGS, Test Bright, Adapt Dim, 4 CPD	121
40	CGS, Test Bright, Adapt Dim, 4 CPD	122
41	MJK, Test Dim, Adapt Dim, 6 CPD	123
42	MJK, Test Bright, Adapt Dim, 6 CPD	124
43	MJK, Test Bright, Adapt Dim, 6 CPD	125

44	MJK, Test Bright, Adapt Dim, 4 CPD	126
45	MJK, Test Bright, Adapt Dim, 4 CPD	127
46	CGS, Test Bright, Adapt Dim, 6 CPD (Red)	128
47	CGS, Test Bright, Adapt Dim, 6 CPD (Red)	129
48	CGS, Test Bright, Adapt Dim, 6 CPD (White, Adapt Right Eye, Test Left Eye)	130
49	CGS, Test Bright, Adapt Dim, 6 CPD (White, Adapt Right Eye, Test Left Eye)	131

List of Tables

Table	Page
I MTF Test Plan	20
II Contrast Multiplier	77
III Spatial Frequency Calibration Data	99
IV Equipment Configuration	101
V Contrast Sensitivity Data for Graphs Appearing in Results Section	104
VI Contrast Sensitivity Data for Supporting Data ...	110

Abstract

This report documents an investigation of the hypothesis that the organization of the receptive fields in the human visual system changes to compensate for changes in the average luminance of the visual stimulus.

Foveal measurements of contrast sensitivity of sinusoidal spatial frequency were made at one luminance level while subjects were adapted to a spatial sinusoid of a different average luminance. The luminance levels used were 3.65 and 35.5 ft-lamberts.

Contrast sensitivity curves were generated for the range of spatial frequencies from 2 through 11 cycles per degree for adapting spatial frequencies of 4, 6, and 8 cycles per degree.

Adaptation and testing at the same average luminance level produced a depression in the contrast sensitivity curve centered over the adapting spatial frequency. Adapting to a low level stimulus and testing at a higher luminance level produced a shift in the adaptation depression to a lower spatial frequency. Adapting to a high luminance level and testing at a lower luminance level produced a shift to a higher spatial frequency. The shift in the adaptation depression was observed for red, green, blue, and white light stimuli and was observed for the unadapted eye of a subject whose other eye was adapted.

CONTRAST SENSITIVITY OF THE HUMAN
VISUAL SYSTEM AT ONE LUMINANCE LEVEL
WHILE ADAPTED TO A STIMULUS AT
ANOTHER LUMINANCE LEVEL

I. Introduction

Purpose

This report documents an investigation of the hypothesis that certain aspects of the functional organization of the human visual system change in response to the visual task being performed. If one accepts the hypothesis that a center-surround receptive field organization exists at various levels in the visual system, then the organization of the receptive fields can be assumed to change as a function of the visual stimulus. A visual system model based on center-surround receptive fields has been proposed which predicts that the frequency-specific adaptation depression in the contrast sensitivity curve will shift to a different spatial frequency when the average luminance of the test stimulus is higher or lower than the average luminance of the adapting stimulus (Ref 1). The specific purpose of this investigation was to determine whether this shift in the specific frequency adaptation-depression on the contrast sensitivity curve can be predicted and detected.

Background

Information is presented to the visual system as a two dimensional light distribution spread over the receptors in the eye. It can be shown that any two dimensional spatial pattern can be expressed as a sum of an appropriate set of spatial sinusoids of proper orientation, amplitude, and spatial frequency. The set of sinusoidal components which must be added together to obtain a given pattern is obtained by Fourier analysis. Each component can be identified with a point in a polar representation of a two-dimensional frequency plane. The angular dimension represents the sinusoid's orientation and the radial dimension represents its spatial frequency. The central hypothesis of the Fourier analysis model of the human visual system is that the spatial frequency components of the light pattern are abstracted or encoded by the visual system (Ref 2: 8-9).

The susceptibility of the human visual system to damage precludes interrupting neural connections or using other invasive techniques to obtain precise quantitative measurements of visual system operation. Therefore, most investigations into the operation of the human visual system are psychophysical in nature. Psychophysical testing is accomplished using very specific and controlled stimuli and observing the subjects' responses. The specific stimuli generated data can be analyzed to provide an insight into the physiological operation of the visual system.

The human visual system primarily depends on the contrast characteristics of a scene to discriminate details (Ref 3: 551). If one constructs a linear model of the human visual system, then the effect of contrast in a scene on visual resolution can be expressed in terms of the system's contrast threshold for detecting the presence of sinusoidal gratings.

The profile of a sinusoidal grating can be generated by using a sine wave input to drive the control grid of a cathode ray tube to cause variations in the intensity of the screen presentation. If the sine wave input is synchronized with the sweep rate of the cathode ray tube's raster-scan generator, an alternating pattern of light and dark bars which blend with each other at their edges is displayed on the screen. This pattern is a sinusoidal grating (see Fig. 1, p. 4).

Contrast has been defined by Michelson (Ref 4) as

$$\text{Contrast} = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}} \quad (1)$$

where $L_{\max}$ is the luminance at the centers of the bright bars and $L_{\min}$ is the luminance at the centers of the dark bars. This is illustrated in Fig. 1. This definition of contrast is used consistently in this investigation. Fig. 1 also depicts how a sinusoidally varying voltage must be

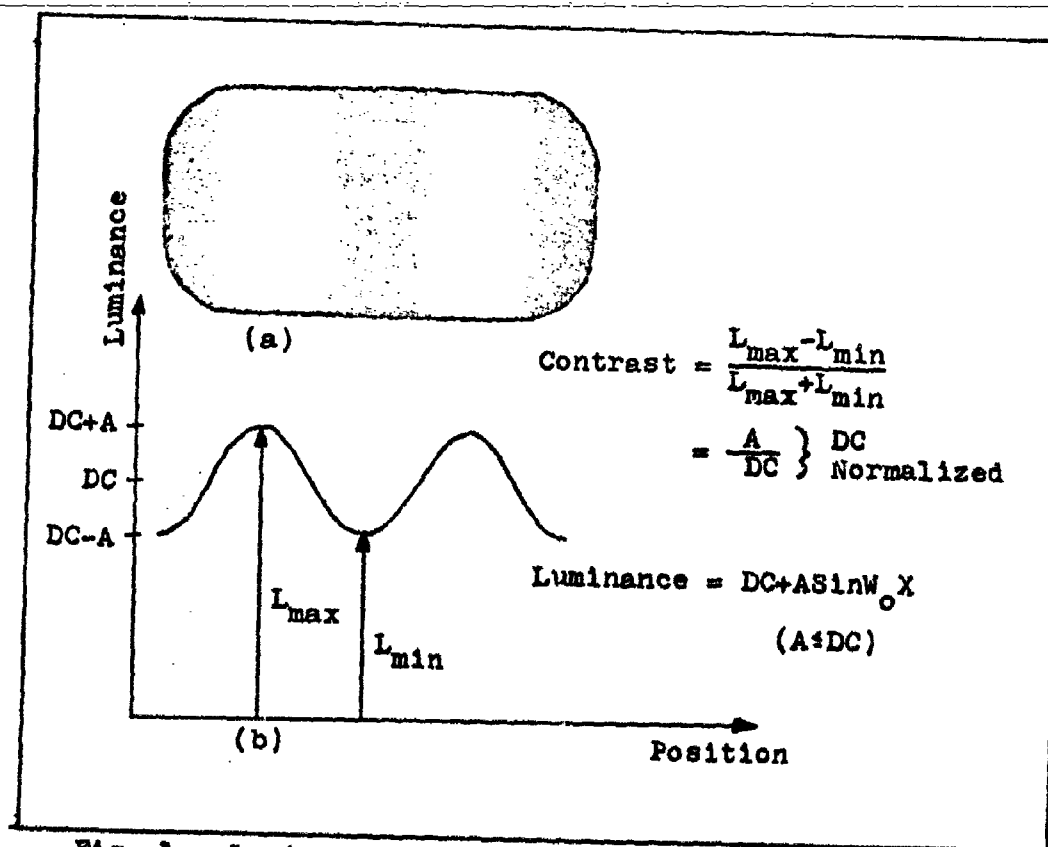


Fig. 1. Luminance Profile of a Sine Wave Grating
(a) Sinusoidal Grating, (b) Luminance
Grating (Adapted from Ref 14: 3)

superimposed on a DC (or average) level to maintain a sinusoidal luminance profile.

For the purpose of this investigation, the threshold contrast is the contrast value at which a sine wave grating for a given average luminance, $DC = (L_{max} + L_{min})/2$, is just distinguishable from a blank screen of the same average luminance. For this investigation a blank screen was defined as a presentation which is uniform in luminance.

Contrast sensitivity is the reciprocal of threshold contrast.

One can quantitatively describe some characteristics of the visual system in terms of the contrast sensitivity of the system to sinusoidal gratings of various spatial frequencies. The spatial frequency of a sine wave is measured in cycles per degree (CPD). This sinusoidal spatial frequency refers to the number of cycles in the sine wave grating per degree of visual field (Ref 5: 312-324). A sinusoidal variation from light to dark and back to light is one cycle. The contrast sensitivity of the human visual system as a function of the spatial frequency of the stimulus grating is generally referred to as the modulation transfer function (MTF) of the system.

The imaging properties of any linear system can be described in terms of the MTF of the system. In purely optical systems the MTF describes the ratio of image-to-object reductions in contrast for sinusoids of varying spatial frequencies (Ref 6: 420-421). A plot of the logarithm of contrast sensitivity against spatial frequency (as shown in Fig. 2, page 6) is called an MTF plot. The data which resulted from this investigation is displayed using this type of MTF plot.

Research has shown that certain aspects of the contrast sensitivity of the human visual system can be modeled using linear system analysis. Linear system analysis allows one

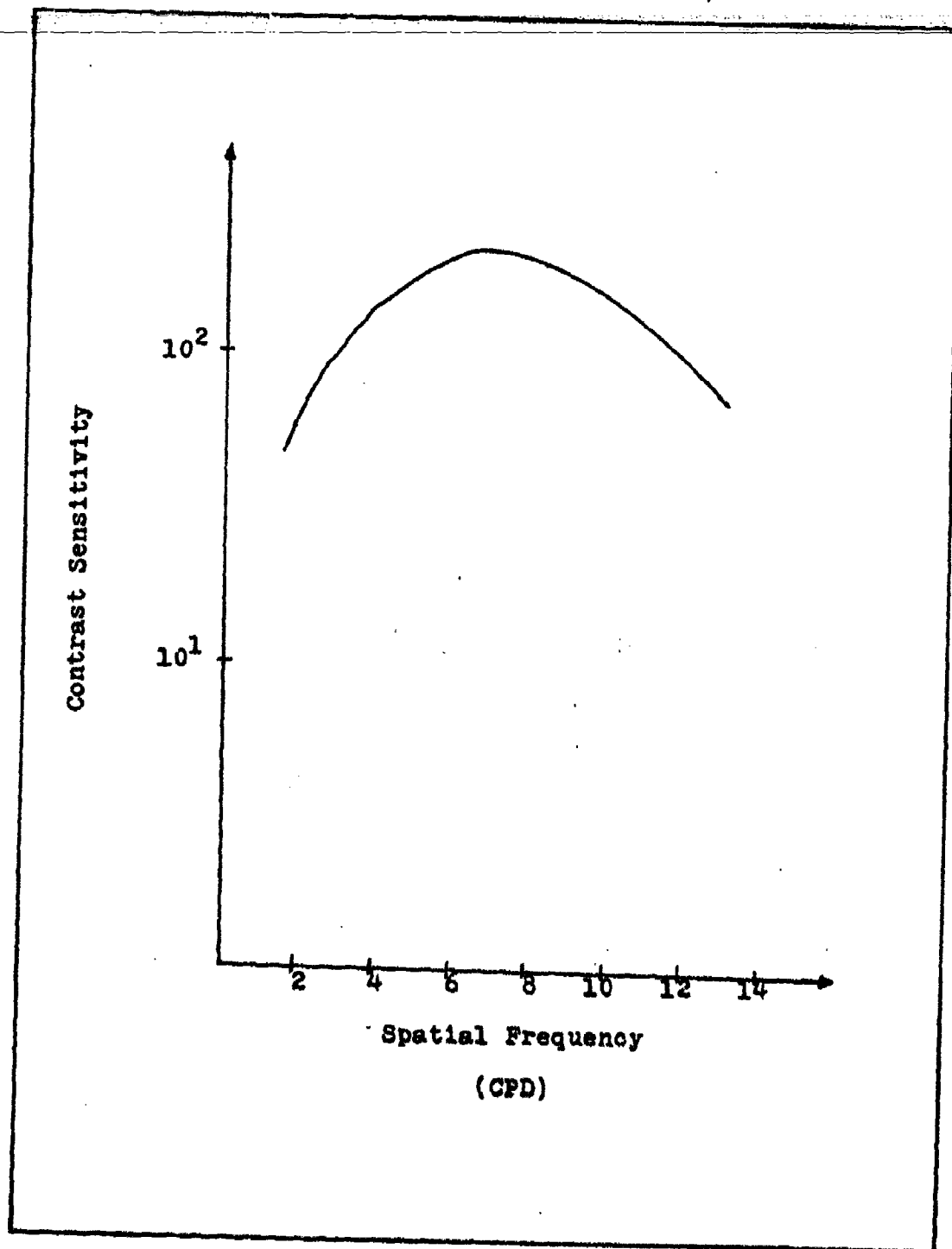


Fig. 2. Typical MTF Plot of Contrast Sensitivity as a Function of Spatial Frequency

to develop a convenient mathematical representation for the system of interest. The mathematical representation is then used to make predictions about expected system output for a given input. Once a model has been developed, it must be tested to verify its predictive capabilities.

The results of this investigation support the hypothesis that the functional organization of the human visual system changes in response to the visual task being performed. Evidence exists which suggests that one of the parameters which effects reorganization is the average luminance of the visual scene. Previous research has demonstrated that the visual system's contrast sensitivity tends to increase with an increase in average luminance. This is accompanied by a shift in peak sensitivity toward a higher spatial frequency (Ref 2: 25-26; 7: 690-691). The visual system is able to form high-contrast neural images over a broad range of light conditions because nerve cell interactions shift the response range of the system to adjust for changes in ambient light conditions (Ref 8: 71). In his investigation of the processing of visual images, Werblin found that the retinal message changed significantly after leaving the bipolar cell. He determined that neighboring receptor cells were able to communicate with the bipolar cell via the horizontal cells (Ref 8: 73) and that this communication is a major factor in the ability of the visual system to adapt quickly to changes in luminance level (Ref 8: 78). He attributes

the actual adaptation to a shift in the bipolar cell's luminance intensity response curve caused by the horizontal cell input.

Adaptation to the specific spatial frequency of the test pattern presented is another aspect of visual system response. Visual system contrast sensitivity is significantly decreased for spatial frequencies within one octave of the adapting spatial frequency of a high contrast sine wave grating (Ref 9: 1926; 2: 32). Adaptation results in a depression of the contrast sensitivity curve approximately centered over the adapting spatial frequency. The fact that the contrast sensitivity depression resulting from adaptation is limited to a narrow range of spatial frequencies suggests to some investigators that the visual system might contain a number of independent channels, each of which is selectively sensitive to a narrow range of spatial frequencies (Ref 2: 32). It has been proposed that these channels are neuron populations organized in a center-surround configuration. There is also a relationship between the size of the receptive field and the range of spatial frequencies to which the visual system is most sensitive (Ref 10: 950-951). If this relationship is coupled with the hypothesis that receptive field organization is a function of stimulus luminance, then one would expect to observe a shift in the adaptation effect to another spatial frequency when the subject is adapted at a low luminance level and tested at a

higher luminance level.

There were two main considerations in determining the contrast and luminance levels for this investigation. The adapting grating contrast had to be high enough to provide good adaptation effects. The luminance change from dim to bright had to be sufficient to produce a predicted clear shift in the MTF curve.

II. Apparatus

Basic Equipment

This investigation was conducted using equipment designed and built for the purpose of collecting MTF data by previous thesis students at the Air Force Institute of Technology. The original design, subsequent modifications, and operation of the equipment is described by Nystrom (Ref 11), Hannikel (Ref 12), Quill (Ref 13), and Scheidegg (Ref 14) in their respective theses.

The equipment consists of a digital computer and a computer program which controls the equipment, records the data and computes the results; a multiplex controller which converts the digital signals from the computer into three dc voltages; a frequency generator which converts one of the dc voltages into a sine wave; and a pattern generator which accepts the other two dc voltages and the signal from the frequency generator and supplies a signal which produces sine wave gratings at a desired contrast level on the screen of a modified 17" commercial television set (Sony model KV-1710). The leads to the red, blue, and green cathodes have been cut and pin plugs have been installed to facilitate single color illumination of the screen.

The television set was previously modified to include a dual-level brightness control (Ref 14: 8-9) so that a test subject could be adapted at one luminance level and then

tested at another luminance level under computer control.

Modification of Brightness Control

The dual brightness control increases the brightness of the television screen by instantaneously adding resistance to the brightness control circuit. Fig. 3 shows the location of the brightness control, VR 901, in a schematic of the original television circuit.

The point where the dual brightness modification was added to the circuit is indicated by an "X". Fig. 4 is a schematic diagram of the original dual brightness control and the modified dual brightness control. The modified dual brightness control is mounted on the rear television chassis adjacent to the original brightness control (VR 901) knob. Analysis of photometer measurements with the full 20K ohms of B2 in the brightness control circuit and with it switched out of the circuit indicated that an additional 20K ohms of resistance was necessary to obtain the desired luminance range of 3 to 30 foot lamberts.

The operation of the dual brightness control circuit is described by Scheidegg (Ref 14: 8-9). The basic operation of the circuit is unaffected by the increase in circuit resistance.

Modifications to Multiplex Controller

The digital to analog converters (DAC's) in the

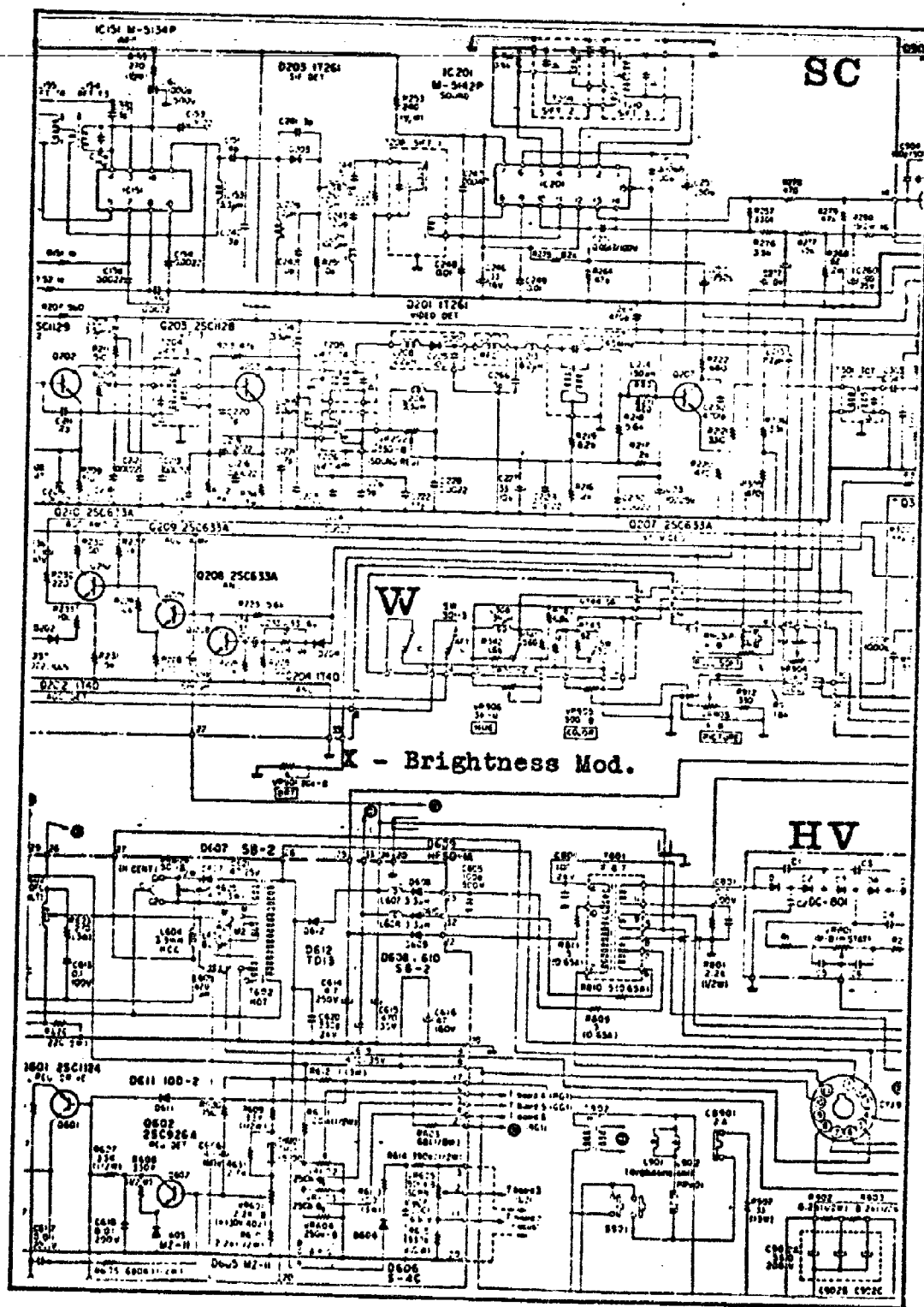


Fig. 3. Portion of TV Circuit Diagram Showing the Location of Brightness Control Modification

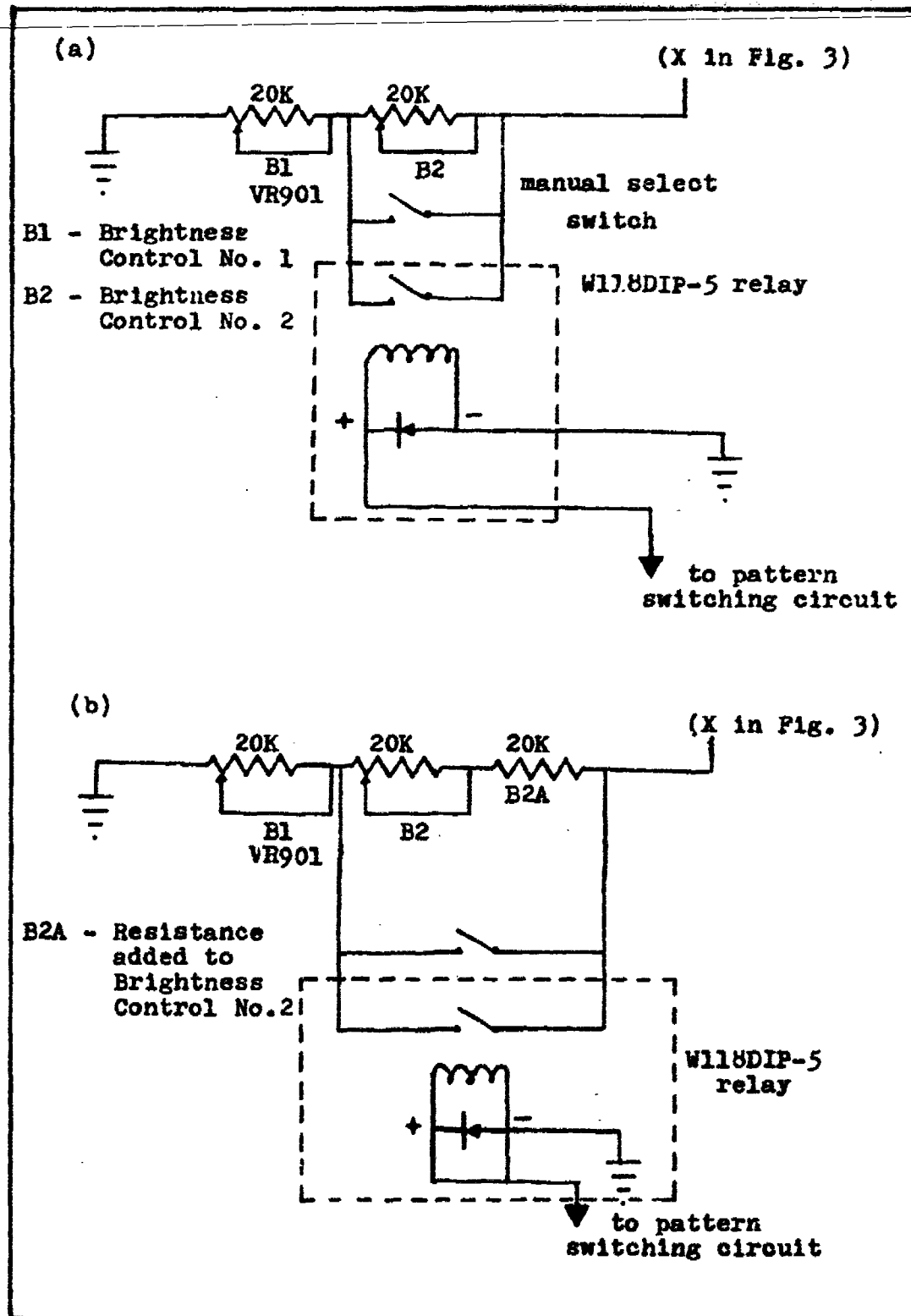


Fig. 4. Brightness Control Modification Circuit
Diagram (a) as Modified by Scheidegg (b) as
Modified by Smith

multiplex controller are designed to provide the dc control voltages, of 0-10v, for computer controlled operation of the system. (The DAC's for the analog output number 1 and 3 are not functioning properly at the present time). The DAC in position B of the type I output card in slot A0 of the multiplex controller is totally unpredictable in output. The DAC in position B of the type I output card in slot A1 has a maximum output of 2.5 volts. It provides proper analog output voltage below 2.50 volts. The DAC's in position A of both cards function properly (Ref 11: 31, 62).

The front panel wiring for the analog output of the multiplex controller was reaccomplished to work around the above equipment malfunction. This was done because the expected delay in data gathering while waiting for parts delivery would have precluded timely thesis completion.

Analog output "0" is now wired to the contrast control line of the pattern generator. Analog output "2" is wired to the pattern frequency circuitry of the pattern generator. Analog output "3" provides the brightness control voltages (0.0v dc, dim; 0.5v dc, bright) for the pattern switching circuit. The pattern switching circuit interconnection points are shown in Fig. 5.

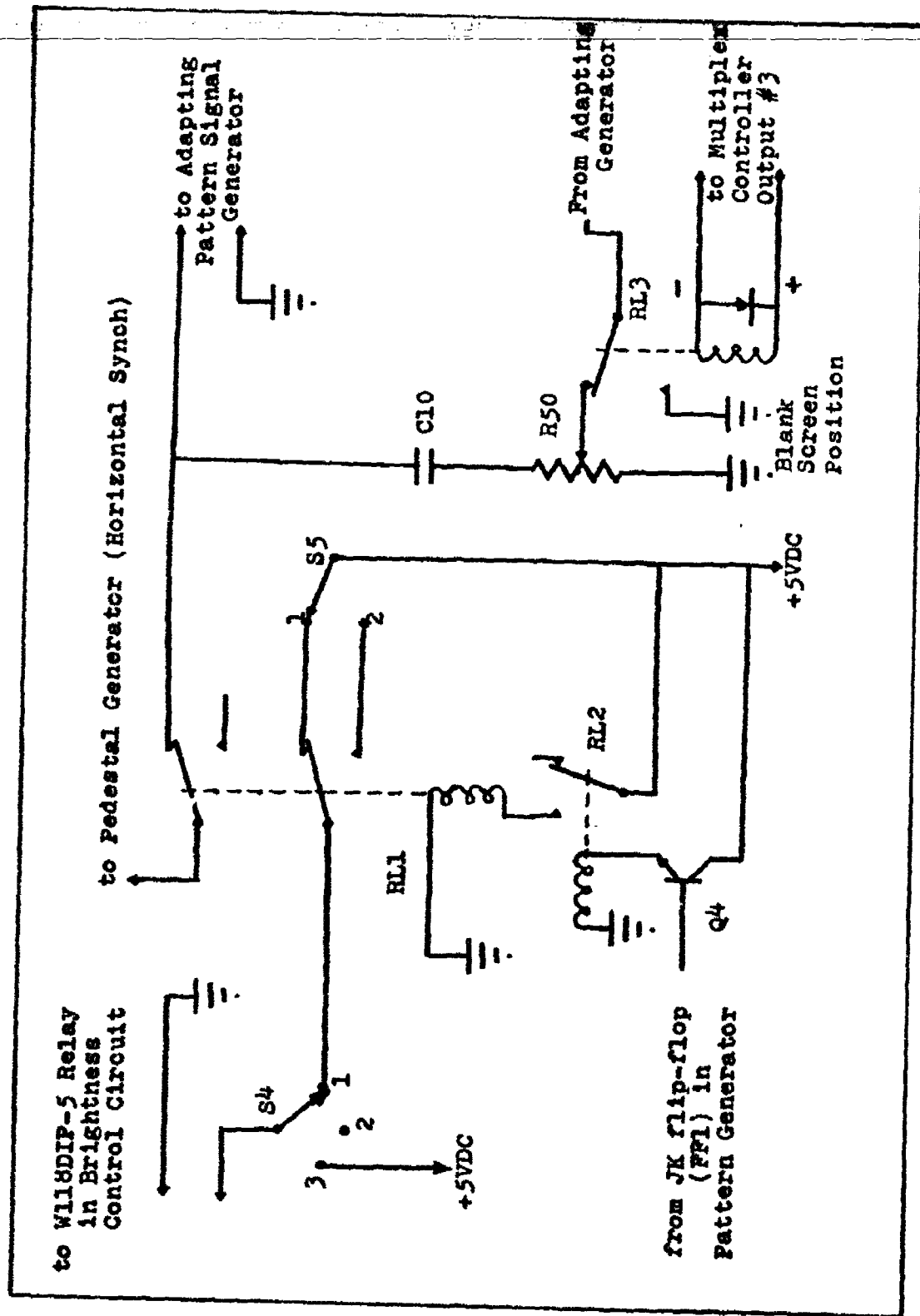


Fig. 5. Pattern Switching Circuit Interconnection Points

III. Testing Procedures

Laboratory Setting

The stimulus generating equipment is located in a windowless room. The television set has a mask over the screen in the center of which a 10" diameter hole has been cut. When viewed through the mask, the stimulus grating subtends approximately two degrees of the visual field of the subject seated in a chair 24 ft from the screen. The only source of illumination other than the television screen is one overhead fluorescent lamp, above and slightly behind the television set. This lamp adds 0.1 ft-lamberts to the average luminance of the television screen. This increased luminance was included at both the high and low luminance levels when the contrast calibration of the television display was accomplished. This low background illumination allows the subject to be aware of the test environment but not distracted by it. A small black dot ($\frac{1}{4}$ " diameter) has been affixed to the center of the television screen to aid the subject in fixating on the television screen.

A partition separates the subject from the operator and the stimulus generator control equipment. This allows the operator to monitor the equipment during the experiment without distracting the subject.

Experimental Structure

The test subject was shown an adapting grating (4, 6, or 8 CPD) or a blank screen at either of two luminance levels. Upon subject request (by manually operating a micro-switch), a test grating was displayed on the screen for 500 msec. The test grating was shown at either of two luminance levels and at varied contrast levels. The two luminance levels were 3.65 and 35.5 ft-lamberts. The contrast levels were from .007 to .631 contrast units as defined by Michelson's formula. Contrast was varied in steps of 0.05 logarithmic contrast units (40 steps from -2.15 to -.20).

Spatial Frequency Selection

The range of frequencies from 2-11 CPD generally cover the range of highest contrast sensitivity (see Fig. 2). This investigation used this range of frequencies.

The experiment was designed to determine the effect of adaptation to a stimulus grating within this range of spatial frequencies on the subject's MTF curve. The peak sensitivity for the typical MTF curve in this experimental situation appears to be around 6 CPD. It was decided to make the initial data runs at this frequency and determine whether any change could be observed in the MTF curve which could be attributable to the difference in the luminance level of the adapting and test stimuli. Two additional sets

of data runs were made at 4 CPD and 8 CPD to determine if observed changes in the MTF curve were repeatable at another frequency. If the MTF curve changes, then there should be some correlation between the changes resulting from the three different adapting spatial frequencies.

Data Requirements

It was necessary to obtain a complete set of data on at least one individual to provide a profile for relating the MTF curves generated during this investigation to the results of previous investigators. In order to verify any MTF curve changes observed in the data set for this individual, four things were necessary. First, a run with a bright blank adapting screen and a bright test pattern to establish a baseline to which all changes could be related. Second, one run with a dim blank adapting screen and a bright test pattern to establish the change in the MTF curve due solely to luminance change. Third, a set of runs with bright adapting patterns of 4, 6, and 8 CPD and testing at a high luminance level to establish the presence of a frequency specific adaptation depression in the subject's MTF curve centered at those frequencies. Finally, a set of repeated runs using a dim adapting grating at 4, 6, and 8 CPD while testing at a high luminance level to determine if a shift was observed in the adaptation depression. The test plan called for the results of tests on this individual to

be verified by testing two other individuals. Equipment and scheduling problems precluded one potential test subject from participating. The desired data sets for the two test subjects are listed in Table I.

Experimental Procedure

The procedure used to carry out this experiment had three parts; operator preparation, subject threshold testing, and data output. The operator preparation for testing, including equipment checkout and operation, is included in Appendix A, Equipment Operating Procedures. The data inputs required by the computer program and the data output are included in Appendix B, MTF Computer Program. This section will be restricted to an explanation of the procedure used to obtain an MTF plot for each subject.

The computer program for computer control of the stimulus equipment required that the operator provide the computer with digital values corresponding to the desired spatial frequencies to be tested. The digital values were determined using the procedures outlined in Appendix A. The operator also had to input test grating luminance level, adapting luminance level, and the spatial frequency of the adapting grating. After the operator provided this data, the computer controlled the experiment.

The operation of the Stimulus Request Switch and hand-held Response Box was explained to the test subject prior to

Table I
MTF Test Plan

Subject	Luminance Level		Adapting Spatial Frequency (CPD)		
	Adapting grating	Test grating			
CGS	Bright	Dim	Bright	Dim	
		X		X	0
		X	X		0
	X		X		0
		X		X	6
	X		X		6
		X	X		6
		X		X	4
	X		X		4
		X	X		4
	X		X		8
MJK		X	X		0
	X		X		6
		X	X		6
	X		X		4
		X	X		4
	X		X		8
		X	X		8

his first test. The subject was cautioned to maintain a consistent decision criteria during the course of the experiment.

The subject was seated in a comfortable chair 24 ft from and directly in front of the television set. The pre-determined adapting stimulus was on the screen before and between all test intervals. The adapting stimulus was either a blank screen or an adapting grating with an average luminance of either 3.65 or 35.5 ft-lamberts.

The exact time at which the test stimulus was presented was controlled by the subject through the hand-held Stimulus Request Switch. The luminance, contrast, and spatial frequency of the test grating were controlled by the computer. The subject's response to each test stimulus presentation was tabulated by the computer. The subject could make only one of two responses to each test stimulus presentation, either "I think a test grating is present" or "I don't think a test grating is present."

When the test subject depressed the Stimulus Request Switch, the adapting stimulus was instantaneously replaced by the test grating. The duration of the test grating presentation was 500 milliseconds. This time period was determined optimal during Scheidegg's investigation of this problem (Ref 14; 24).

The contrast of the first test grating was set high enough to ensure easy recognition by anyone who does not

have a visual deficit. This ensured that each subject's initial response was affirmative and gave the subject an opportunity to see clearly the test grating he was expected to identify during subsequent test intervals. The affirmative response caused the computer to decrease the test grating contrast by six contrast levels. It took 5 to 8 seconds for the computer to record the subject's response and to print the next set of commands for the multiplex controller. The subject continued to view the adapting grating during this interval. As soon as the teletypewriter had finished printing the commands, the subject was able to obtain the next test grating by depressing the Stimulus Request Switch.

The computer program was designed to lower the test grating contrast in increments of six contrast levels until the subject responded that he could no longer see the grating. The computer then reversed the direction of contrast change and increased the contrast by two contrast levels per response. When the subject indicated that he could again see the test grating, the contrast was incrementally lowered by one contrast level until the subject again indicated that he could not see the grating. The contrast level was then near the subject's contrast threshold. The contrast threshold was established by raising and lowering the contrast one level at a time until six reversals had been obtained.

The computer program averaged the contrast response values to determine contrast sensitivity for that spatial

frequency (Ref 18: 59). The subject's response pattern for the ten spatial frequencies was tabulated by the computer and used to generate MTF plots for each frequency. These plots were printed on the CALCOMP plotter and are included as Figs. 8 through 29 and 33 through 49.

IV. Experimental Hypothesis

The experimental paradigm was developed to investigate the hypothesis that certain aspects of the human visual system change in response to the visual task performed. Previous research has shown that the average luminance of the visual scene is one of the parameters which affects visual system reorganization. It has been demonstrated that an increase in the average luminance of the scene causes the peak sensitivity of the human visual system to shift to a higher spatial frequency. The increased luminance also causes an increase in the contrast sensitivity of the visual system at all spatial frequencies (Ref 2: 25-26, 7: 690-691).

If a center surround receptive field organization exists within the visual system, then the changes in the visual system in response to a changing visual task can be assumed to be a result of changes in the receptive fields. Several versions of the center surround receptive field theory were addressed in Section I. The specific version reflected in this model assumes that the spatial distributions of the center and surround fields are Gaussian in form, concentric, and overlap. The surround distribution has a smaller peak and a larger spread than the center (Ref 1).

The center distribution is postulated to produce an excitatory response to a visual stimulus while the surround produces an inhibitory response. These two responses are

1 summed in the retinal ganglion to provide the neural impulse pattern transmitted to the visual cortex (Ref 5: 307-310). The precise site of the summation is not known, but there is evidence indicating that it is after the receptors, foveal cones in this case, but before the ganglion cell outputs (Ref 5: 251). Schmitt, Dev, and Smith cite evidence to support a model in which this summation is accomplished by means of "reciprocal" synapses between pairs of horizontal cells and between amacrine and bipolar cells (Ref 16: 115).

The second aspect of visual system response affecting the structure of this paradigm is the affect of adaptation on the system. The adaptation phenomenon is described in Section I. For the purposes of this investigation, the salient fact is that the depression in the contrast sensitivity of the human visual system resulting from adaptation to a grating of a specific spatial frequency is limited to a narrow range of spatial frequencies centered about the adaptation frequency. This suggests that the visual system contains a number of independent channels, each of which is selectively sensitive to a narrow range of spatial frequencies (Ref 2: 32). It has been postulated that the MTF curve is an envelope of the responses of these independent channels to the visual system stimulation (See Fig. 6).

A center surround receptive field theory has been proposed which postulates that the receptive field organization is a function of stimulus luminance (Ref 1, 10: 949-951,

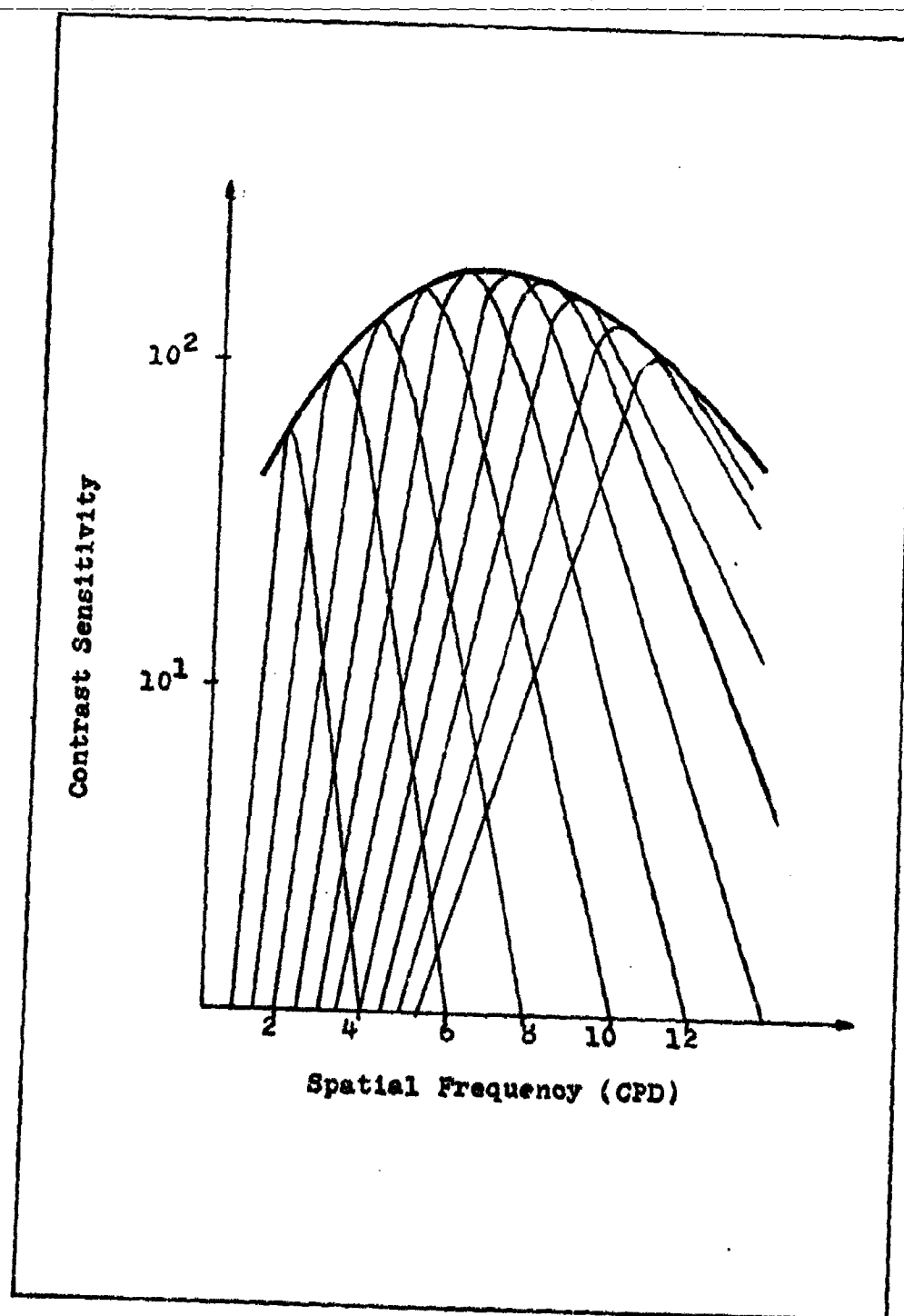


FIG. 6. Typical MTF Plot of Contrast Sensitivity as a Function of Spatial Frequency Indicating the One Octave Wide Frequency Specific Channels Defining the Enveloping MTF Curve

5: 307, 17: 75). Previous research has indicated that there is a relationship between the size of the receptive field and the range of spatial frequencies over which it is most sensitive (Ref 10: 950-951). If a relationship exists between the size of the receptive field and the average luminance of the stimulus, it could be expected to manifest itself as a change in receptive field organization of the visual system with a concomitant change in the spatial frequency sensitivities of the system.

It has been shown that adaptation at one luminance level causes desensitization of the system to the spatial frequency of the adapting stimulus. This paradigm assumes that this desensitization is a result of desensitization of the receptive fields maximally sensitive to that adapting frequency. Under this hypothesis, if a change in stimulus luminance level resulted in a change in the receptive field organization before the desensitization of particular cells wears off, then the MTF curve at the new luminance level should exhibit a frequency specific adaptation depression at a spatial frequency different from the one at which the system was adapted. Specifically, it is postulated that the frequency specific depression in the contrast sensitivity curve will shift to a higher spatial frequency if the visual system is adapted to a low luminance level grating and tested at a high luminance level. Fig. 7 illustrates this theory.

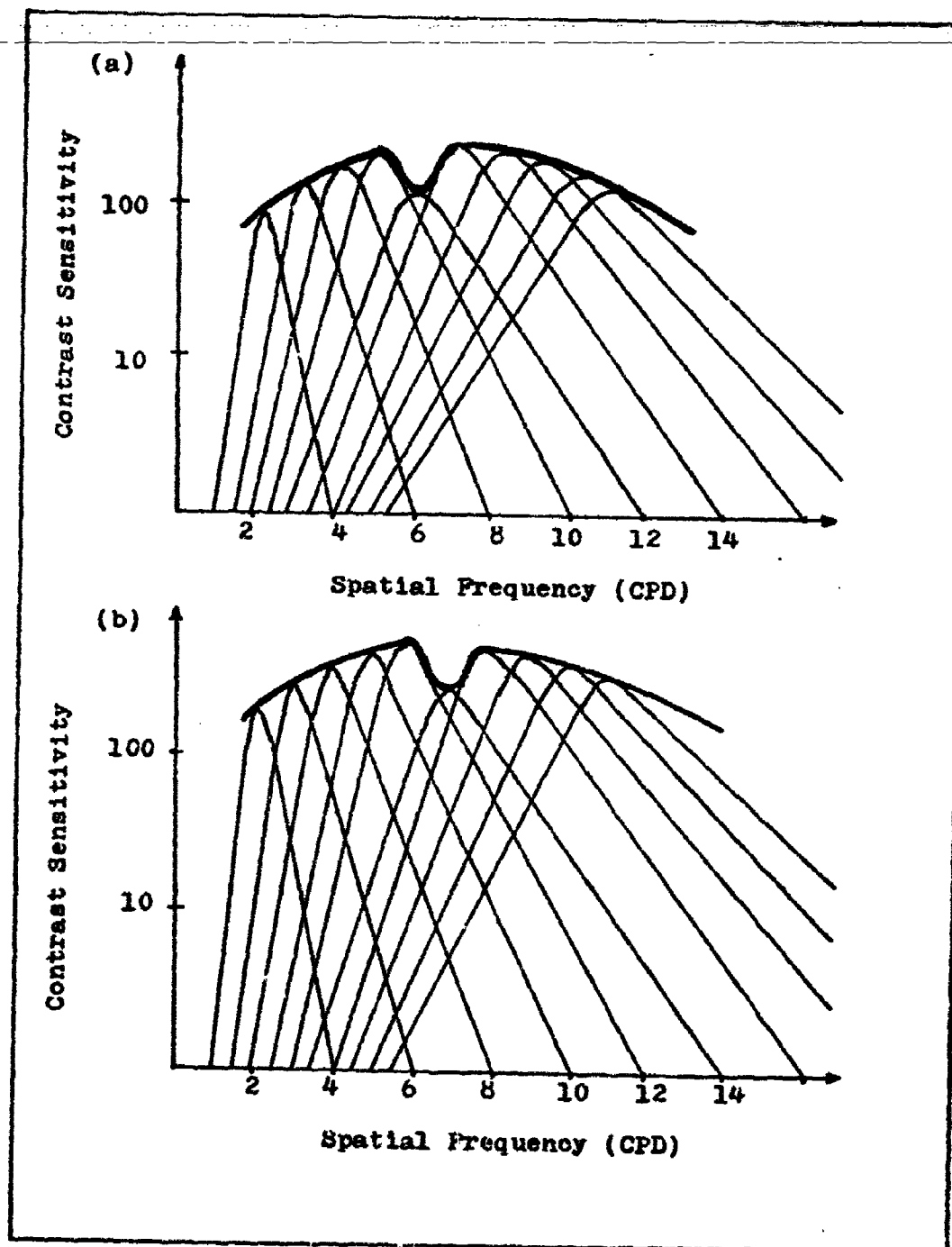


Fig. 7. The Effect on the Frequency Specific Adaptation Depression of the MTF Curve of Testing at a High Luminance Level When Adapted to a 6 CPD Grating at (a) a High Luminance Level and (b) a Low Luminance Level

V. Results

The experimental structure described in Section III was followed to obtain the data sets described herein. Both subjects were thoroughly familiar with the experimental paradigm and the test structure. They were also familiar with the results of Scheidegg's research (Ref 14). Both subjects were involved in the calibration and checkout of the equipment and had experience in the repair of the equipment. They were also familiar with the computer program used to develop the stimulus patterns and were aware of the program changes and equipment modifications.

Test subject familiarity with equipment and test procedure does not degrade these test results. A test subject would have to remember the exact order of approximately 100 responses to 12 different experimental conditions to generate biased test sequences. Both test subjects indicated that soon after the test started they lost track of where they were in the test under the stress of concentrating on the adapting and stimulus gratings.

One factor which created stress during the conduct of the experiments was the interference from the "phantom grating" when the contrast of the test grating was near contrast threshold. The phantom grating phenomenon was first reported by Scheidegg (Ref 14: 24-25) and was first investigated as a laboratory project under M. Kabrisky, Professor of

A-4
Bio-Engineering, AFIT. The results of that investigation are being prepared for publication at this time. The "phantom grating" is a persistent, low contrast, (presumably) cortically generated, high spatial frequency after-response to adaptation to sinusoidal gratings. The strength of the phenomenon varies from individual to individual and with stimulus orientation but occurs for all three color phosphors of the P-22A screen of the Sony Trinitron.

Subject MJK had greater difficulty than subject CGS with "phantom grating" interference. This may account for the greater variation in data from experiments with MJK. Some tests with MJK were totally unreliable (MJK mistook the "phantom grating" for the test grating and gave affirmative responses to grating presence when only a blank screen was displayed). The problem of interference from the "phantom grating" can be diminished by adopting a "Yes, I can see the test grating" and "I am not sure if I see the test grating" response criteria. This provides a basis for making the response decision a little above threshold and avoiding the near threshold "phantom grating" interference. As long as the response criteria of the subject is consistent for the specific test run, the test results permit comparison for the purpose of determining if a shift in the adaptation depression has occurred.

When subject CGS adapted to a bright blank screen and was tested at the high luminance level, the result was the

fairly uniform MTF curve shown in Fig. 8. This curve was used as a baseline for the test results from adapting to sinusoidal gratings of 6, 4, and 8 CPD. Adapting subject CGS to a low luminance blank screen and testing with a low luminance grating again produced a fairly uniform MTF curve but significantly decreased in magnitude (see Fig. 9). Subject CGS exhibited a peak sensitivity at 6 CPD when adapted to a low luminance blank screen and tested with a high luminance grating.

Adaptation to a high luminance 6 CPD sinusoidal grating while testing with test gratings of the same average luminance produced the expected frequency specific adaptation depression precisely at 6 CPD. Decreasing the luminance level of the adapting grating from 35.5 ft-lamberts (high) to 3.65 ft-lamberts (low) resulted in the frequency specific adaptation depression being manifested at 5 CPD. These results are presented graphically in Figs. 8-12.

Fig. 13 indicates that when subject CGS was adapted to a high luminance level 4 CPD grating and tested at the same luminance level the adaptation depression was observed, as expected, at the adapting spatial frequency. Fig. 14, even though very noisy, indicates that the adaptation dip is manifested at the adapting frequency when the test and adapting pattern luminance levels are both low. When the adapting luminance level was lower than the test stimulus luminance level, the adaptation depression shifted to a lower spatial

frequency (see Fig. 15). Figures 16 and 17 show that the same shift of the adaptation depression to a lower spatial frequency also occurs for an adapting frequency of 8 CPD.

Fig. 18 is the result of testing to see if the shift in the adaptation depression would move both ways. There is an apparent shift to a higher spatial frequency when the subject is adapted to a high luminance level stimulus grating and the MTF is tested at a lower luminance level.

Subject MJK was used to verify the test results obtained from CGS. Figure 19 shows a baseline MTF curve for MJK. It should be noted that, as mentioned earlier in this report, MJK's data are substantially noisier than that obtained from CGS due to "phantom grating" interference. Figures 20, 21, and 22 show the results of subject MJK adapting to low luminance level sinusoidal gratings of 6, 4, and 8 CPD respectively. In each case, the shift to a lower spatial frequency can be observed.

All the above tests were done using the green phosphor component of the Sony Trinitron television screen. Additional testing was done with subject CGS using the television set's red and blue components. The shift of the frequency specific adaptation depression to a lower spatial frequency was observed for blue and red as well as green.

Since the shift in the adaptation depression had been observed for all three colors, the final tests were conducted with all three cathodes (red, blue, and green) of the

Sony television set connected. This produces the subjective white color of the P22A phosphor. The first test simply verified that the shift in the adaptation depression resulting from adapting to a stimulus grating at one luminance level and performing an MTF test at a higher luminance level was also apparent when P22A white light was used for the stimulus. Fig. 25 shows the results of binocular adaptation to a P22A white light stimulus grating of 6 CPD, and Fig. 26 shows monocular adaptation to the same stimulus. These two figures were used as a baseline for evaluating the results of adapting the right eye of subject CGS to a low luminance level grating of 6 CPD and testing the MTF of the subject's left eye using high luminance level stimulus gratings. This testing was accomplished by having the subject obscure the vision of the left eye with a blank card while adapting the right eye and then simultaneously pressing the Stimulus Request Button while switching the card to uncover the left eye and obscure the right eye. Fig. 27 provides the results of this test.

Early in the test program, an adaptation persistence was noted that was not investigated until after all other tests were completed. Specifically, if a subject has been adapted to a sinusoidal grating of some frequency, he will produce MTF curves indicating a frequency specific adaptation depression at that spatial frequency for some period of time after the adapting stimulus has been removed. In

Fig. 28 MJK exhibits a strong adaptation depression in an MTF test performed 20 minutes after he was adapted to a 6 CPD stimulus grating. The subject was shown a uniform high luminance screen between test stimulus presentations. After approximately 48 hours, MJK was again tested without an adapting stimulus. Again the MTF curve indicated an adaptation depression at 6 CPD although the effect had diminished with time (Fig. 29).

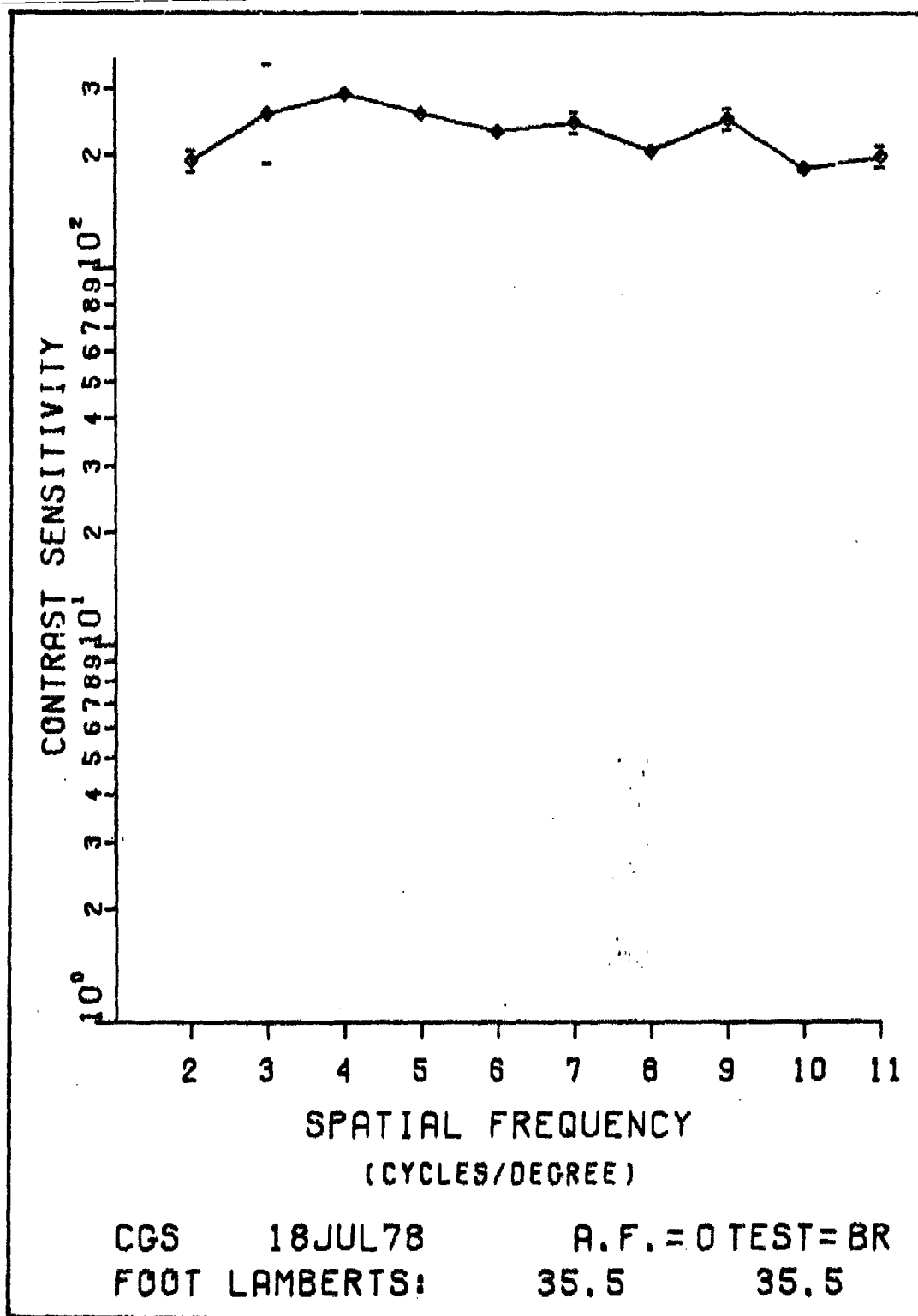


Fig. 8. CGS, Test Bright, Adapt Bright, 0 CPD

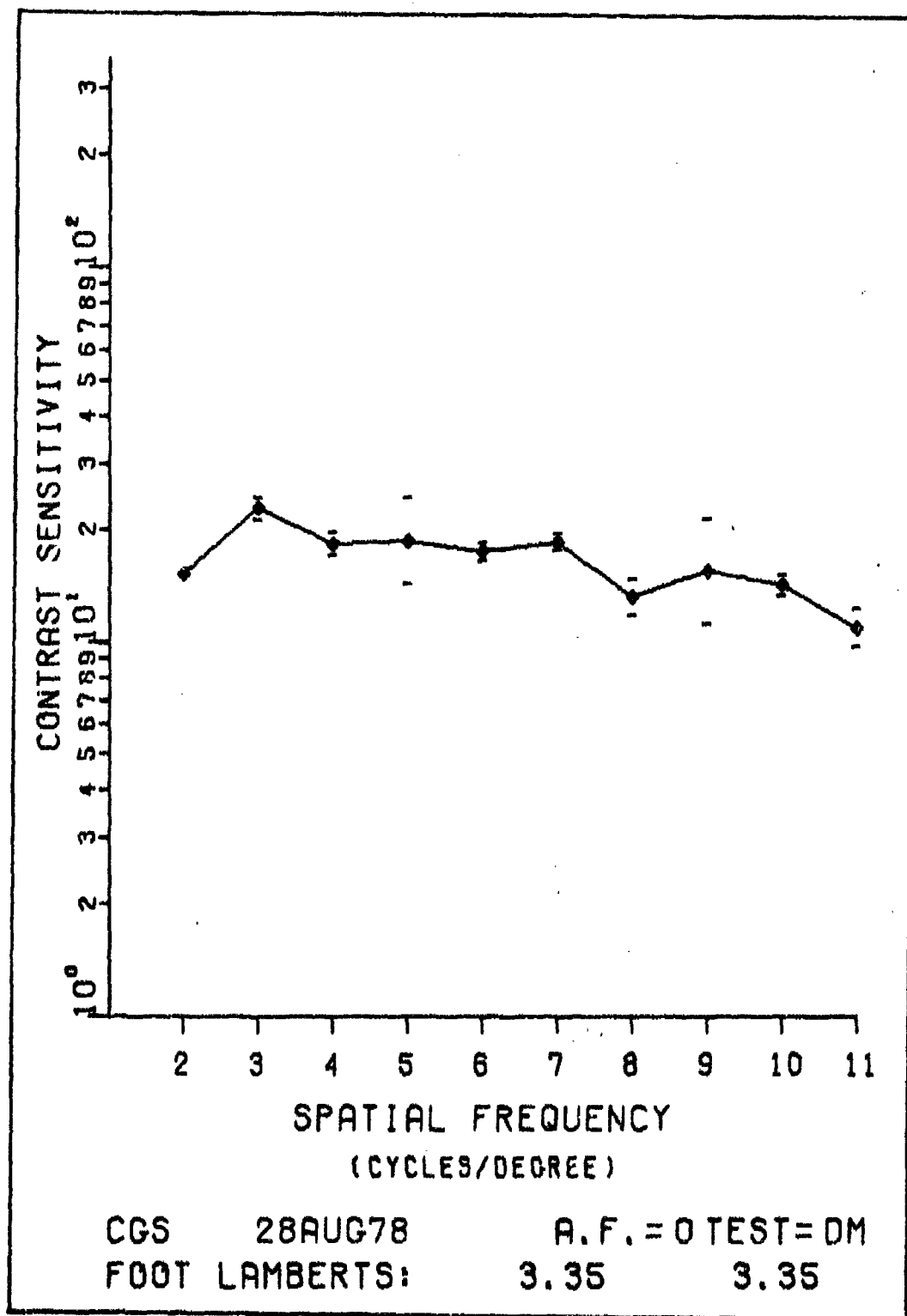


Fig. 9. CGS, Test Dim, Adapt Dim, 0 CPD

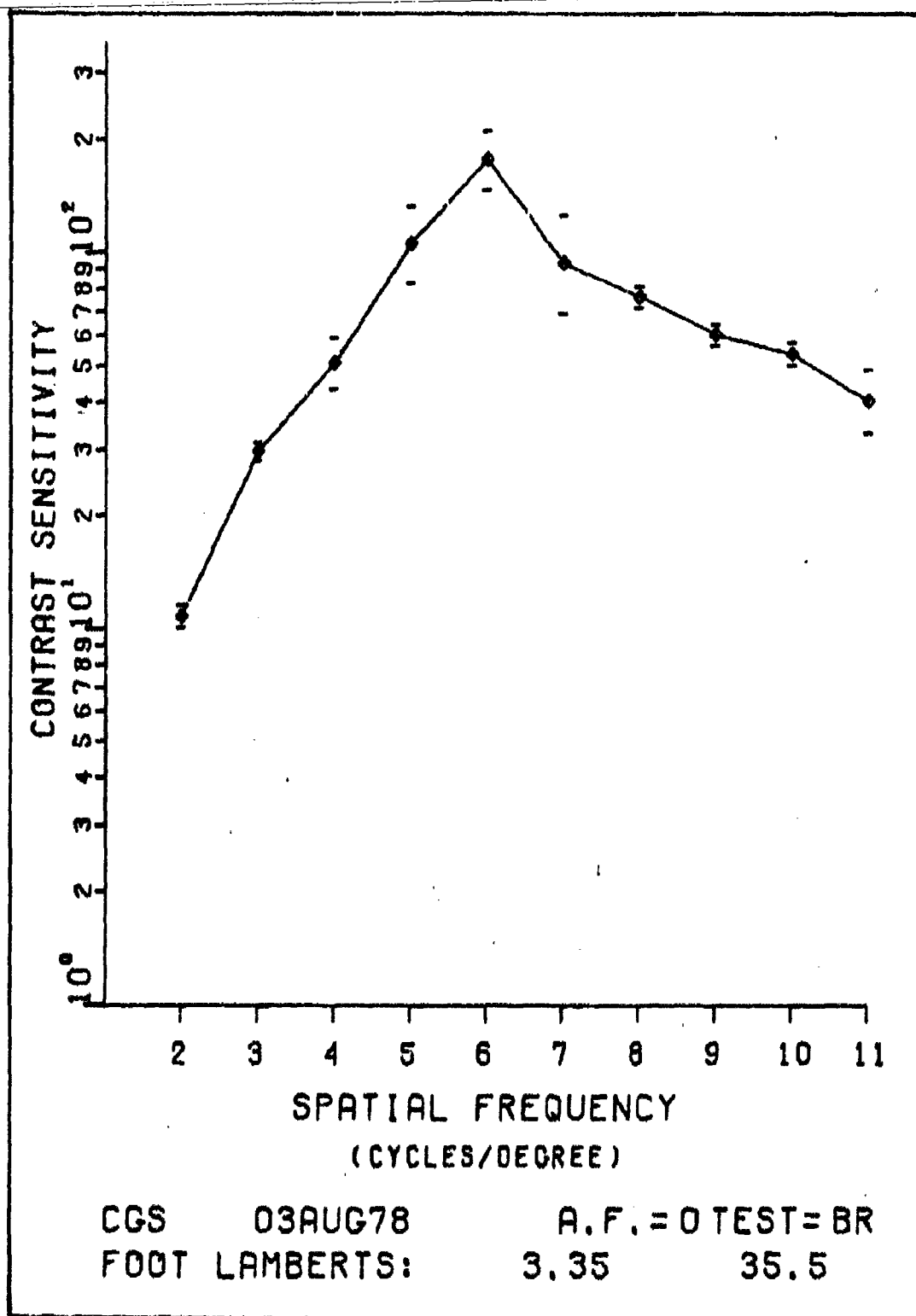


Fig. 10. CGS, Test Bright, Adapt Dim, 0 CPD

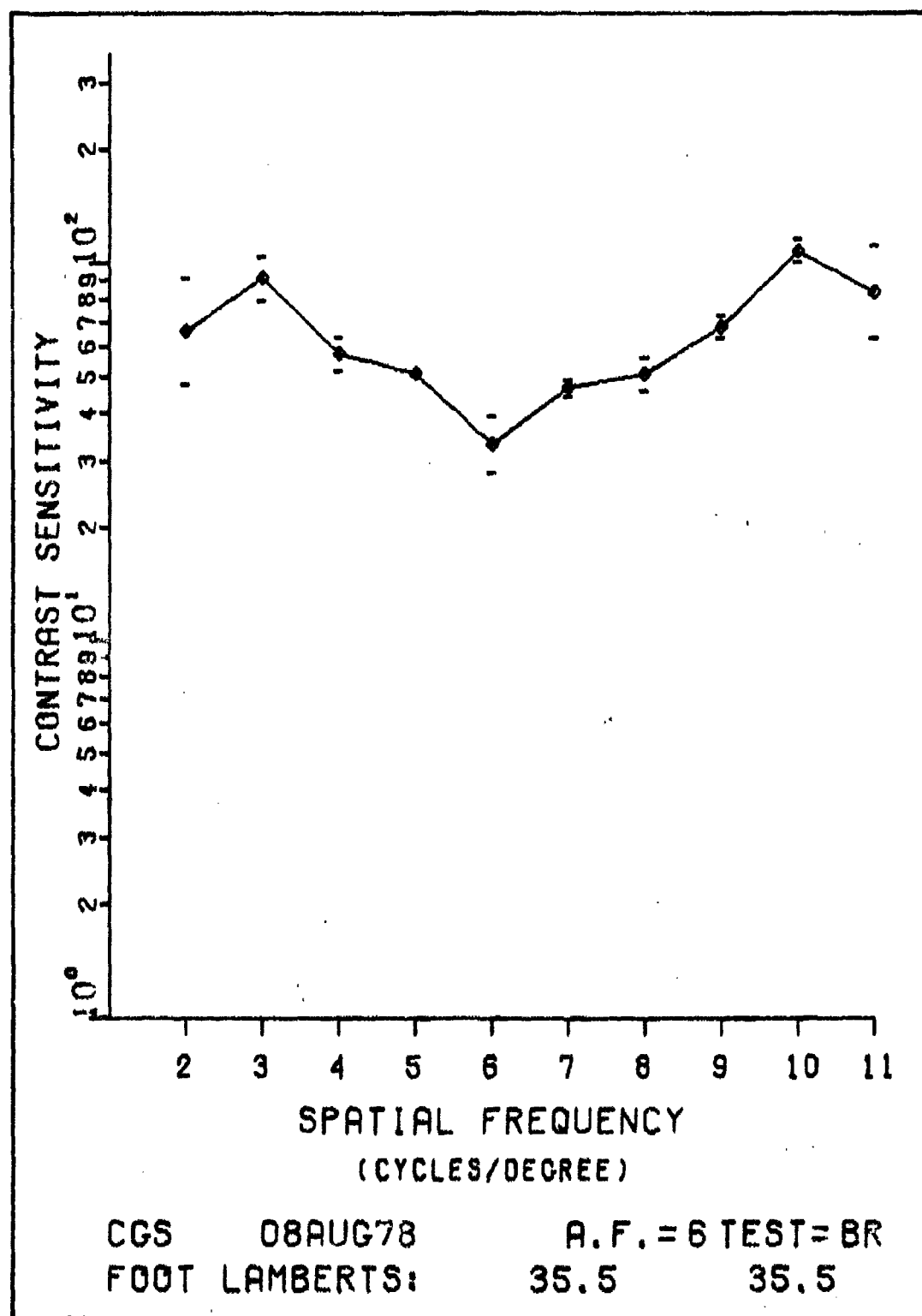


Fig. 11. CGS, Test Bright, Adapt Bright, 6 CPD

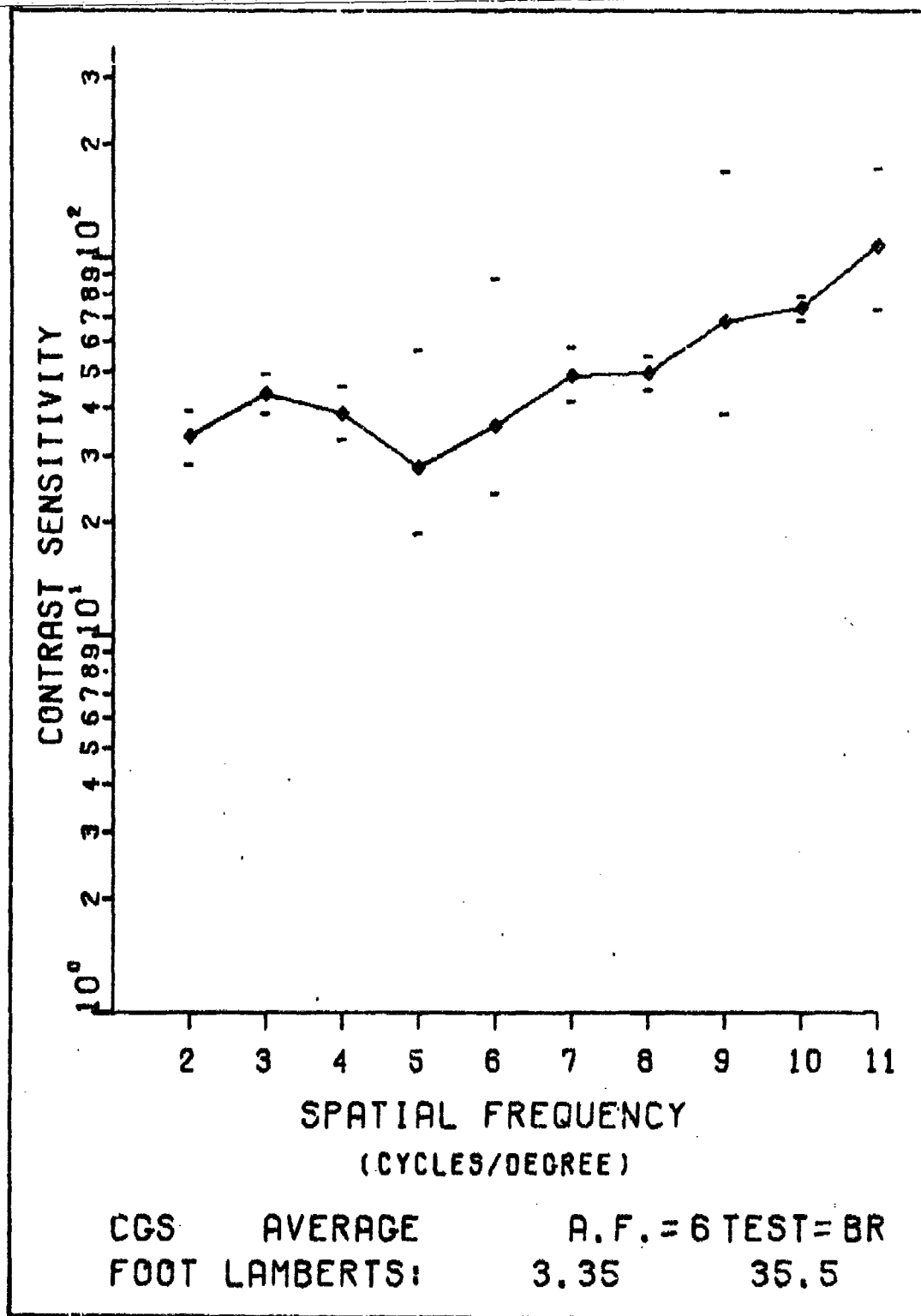
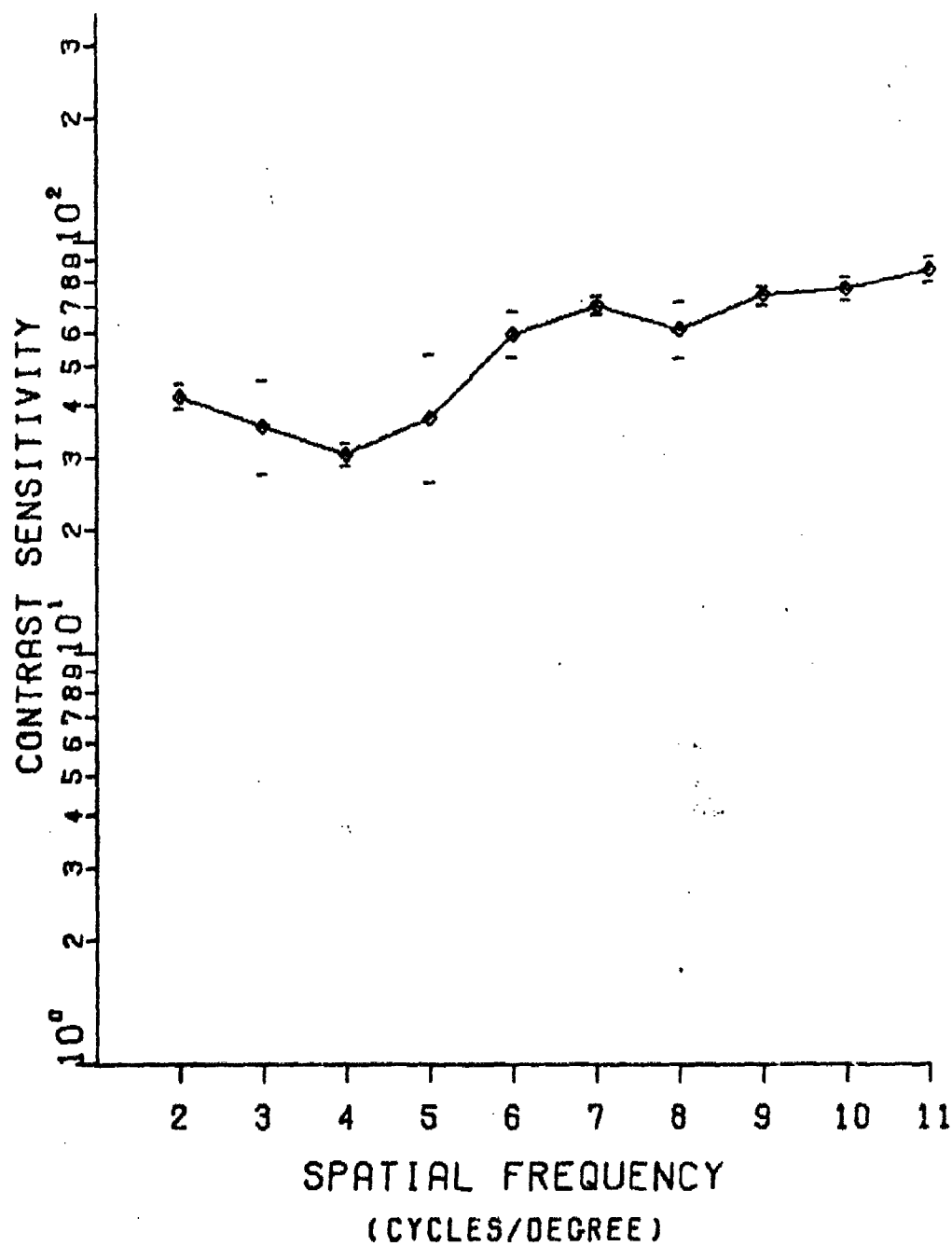


Fig. 12. CGS, Test Bright, Adapt Dim, 6 CPD



CGS 16AUG78 A.F. = 4 TEST = BR
 FOOT LAMBERTS: 35.5 35.5

Fig. 13. CGS, Test Bright, Adapt Bright, 4 CPD

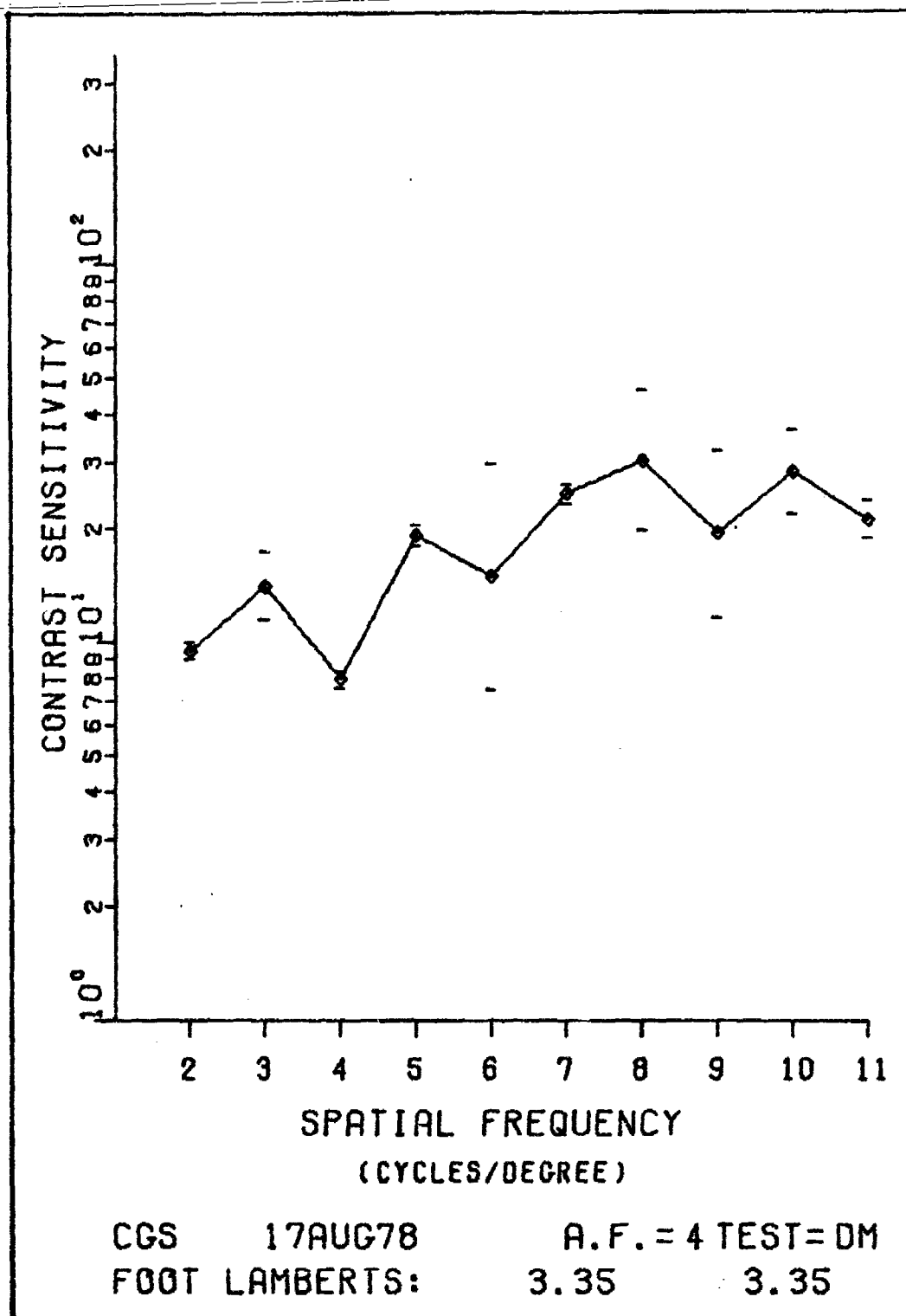


Fig. 14. CGS, Test Dim, Adapt Dim, 4 CPD

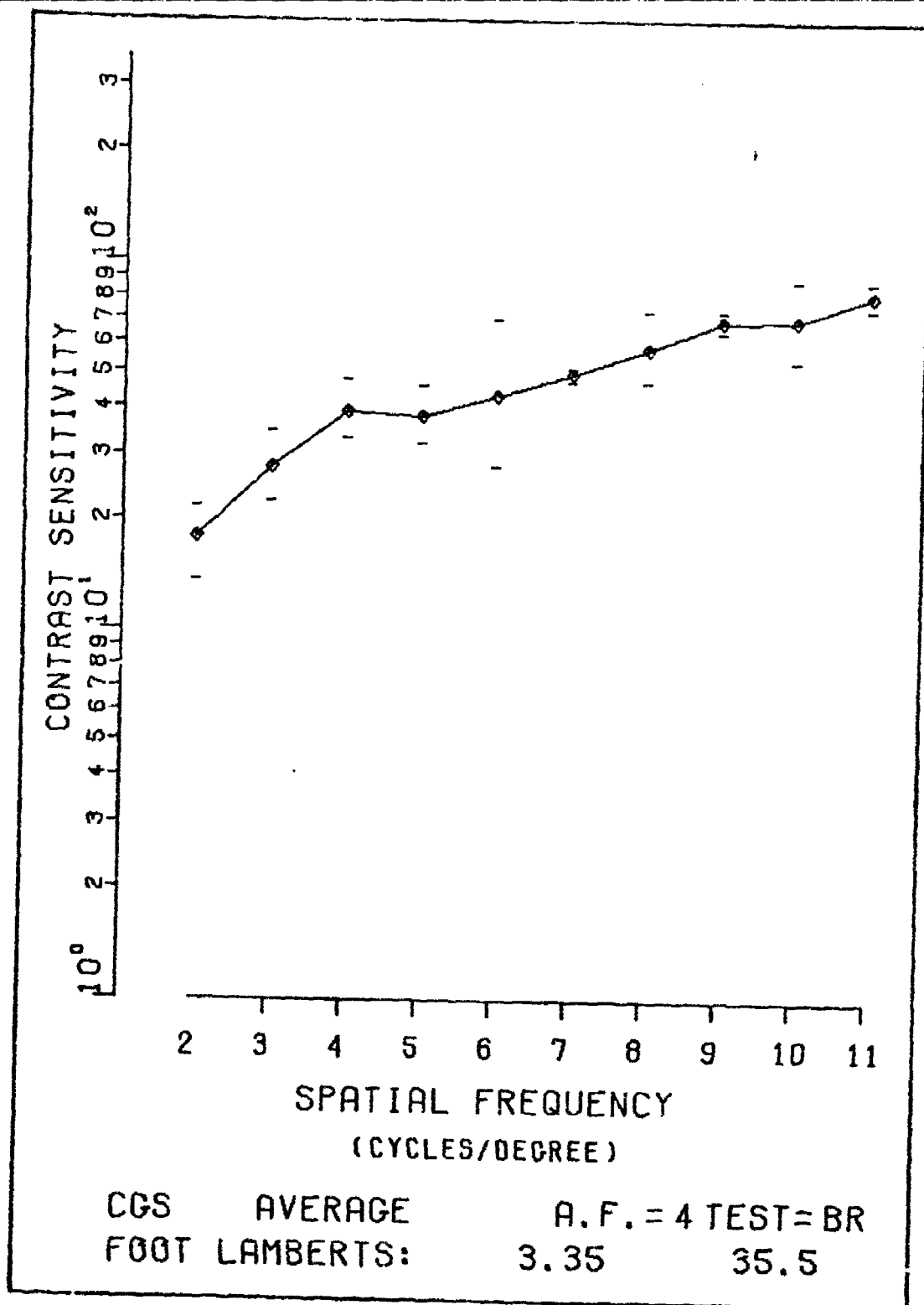


Fig. 15. CGS, Test Bright, Adapt Dim, 4 CPD (average)

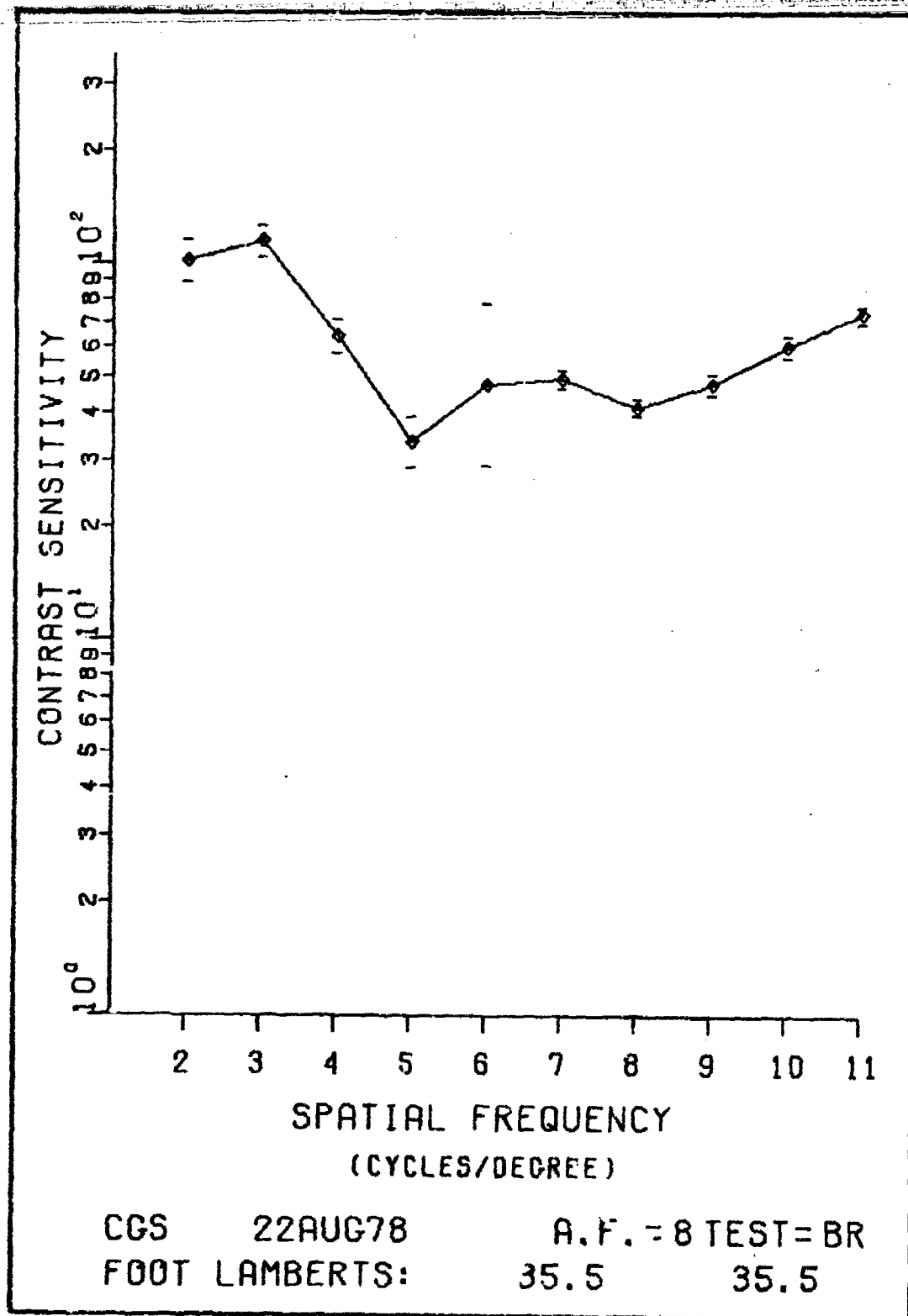


Fig. 16. CGS, Test Bright, Adapt Bright, 8 CPD

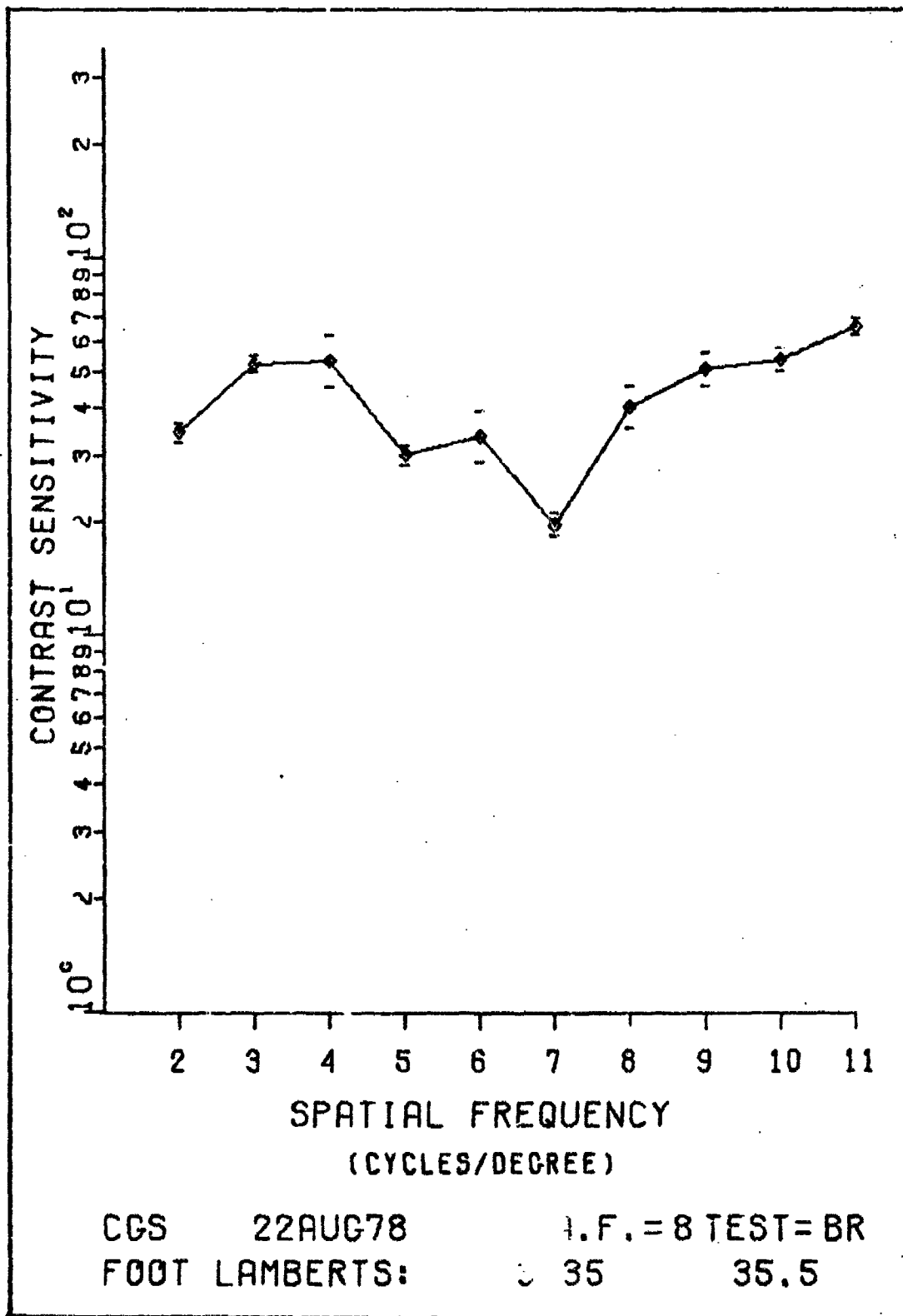


Fig. 17. CGS, Test Bright, Adapt Dim, 8 CPD

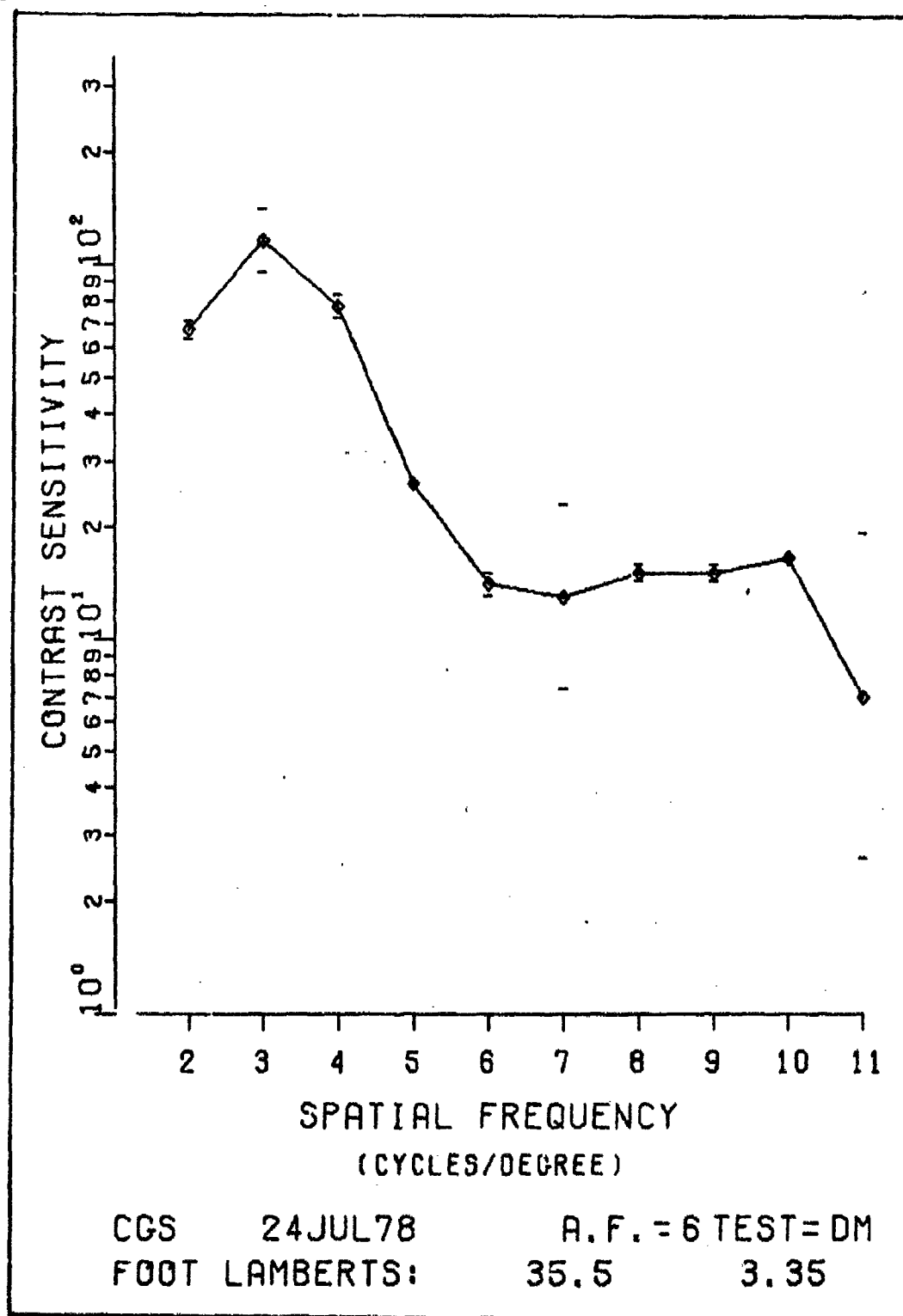


Fig. 18. CGS, Test Dim, Adapt Bright, 6 CPD

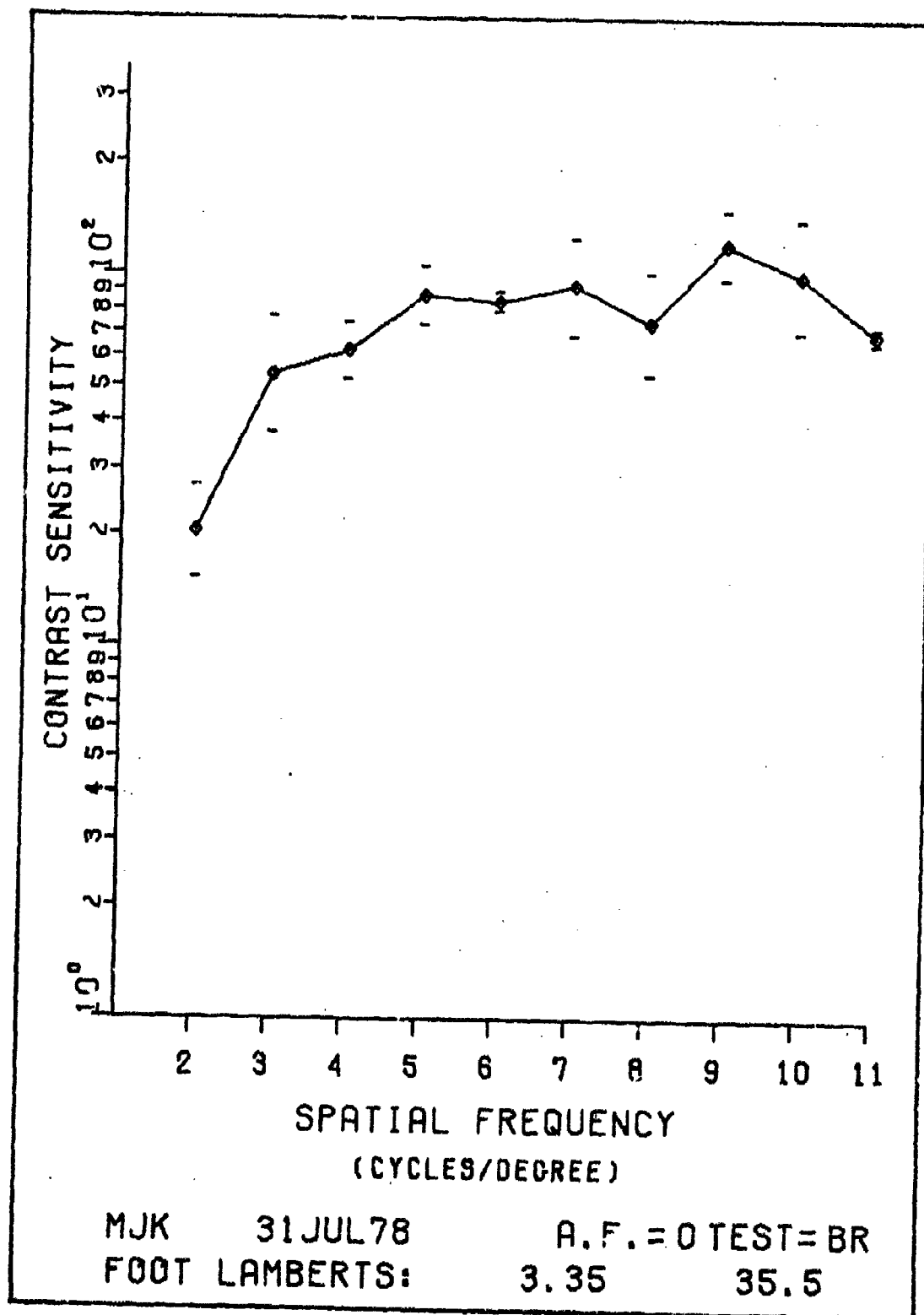


Fig. 19. MJK, Test Bright, Adapt Dim, 0 CPD

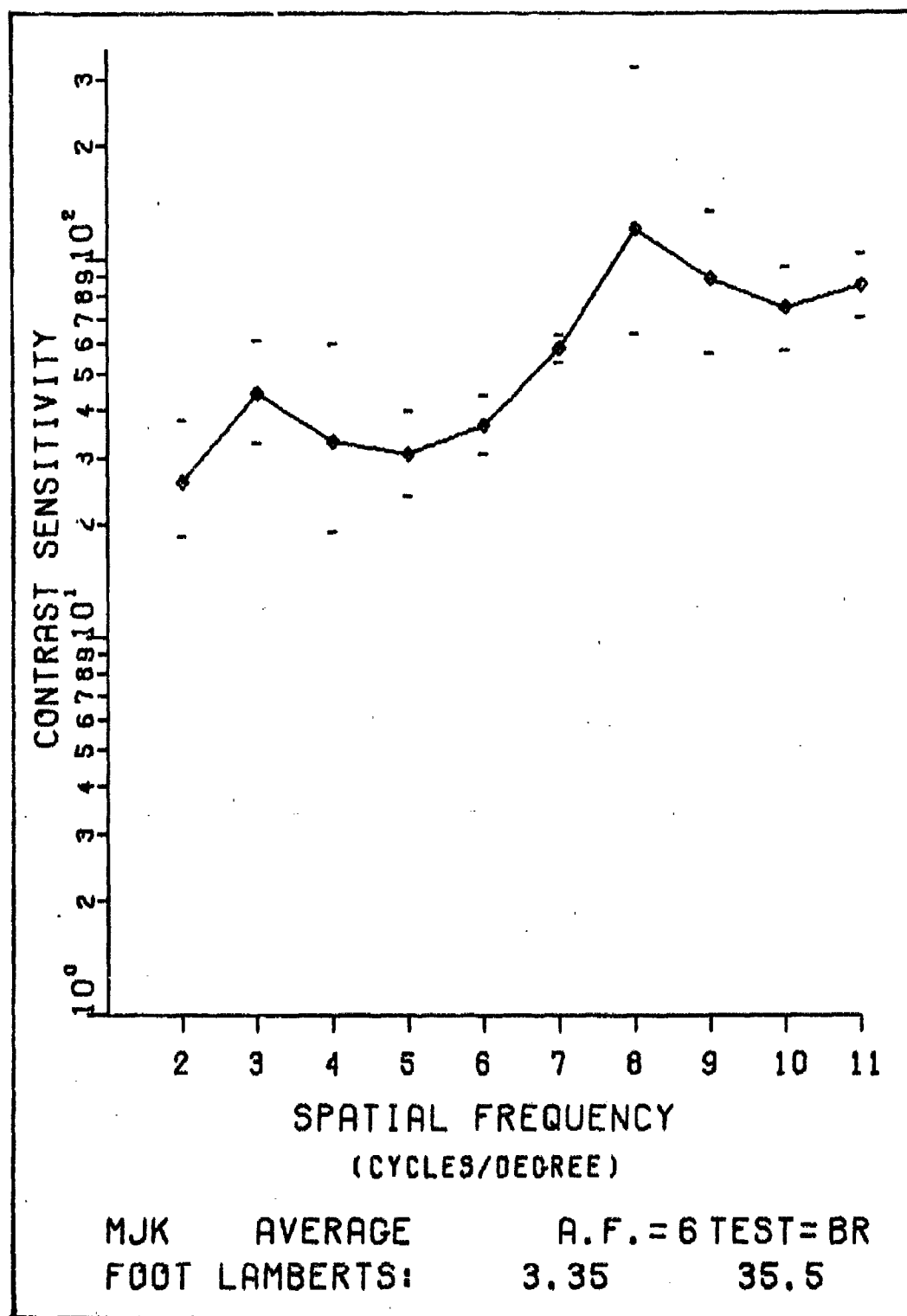


Fig. 20. MJK, Test Bright, Adapt Dim, 6 CPD (average)

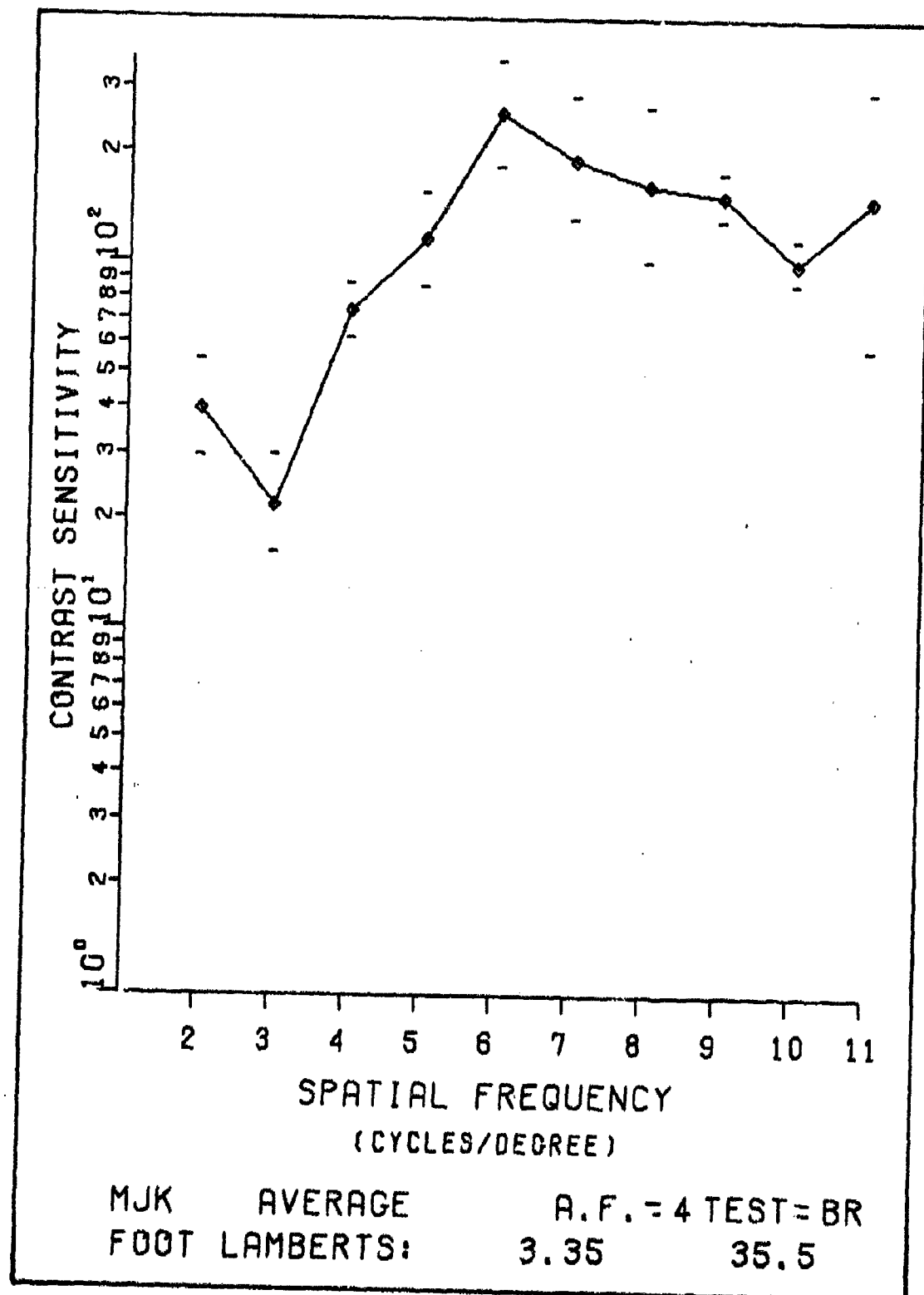


Fig. 21. MJK, Test Bright, Adapt Dim, 4 CPD (average)

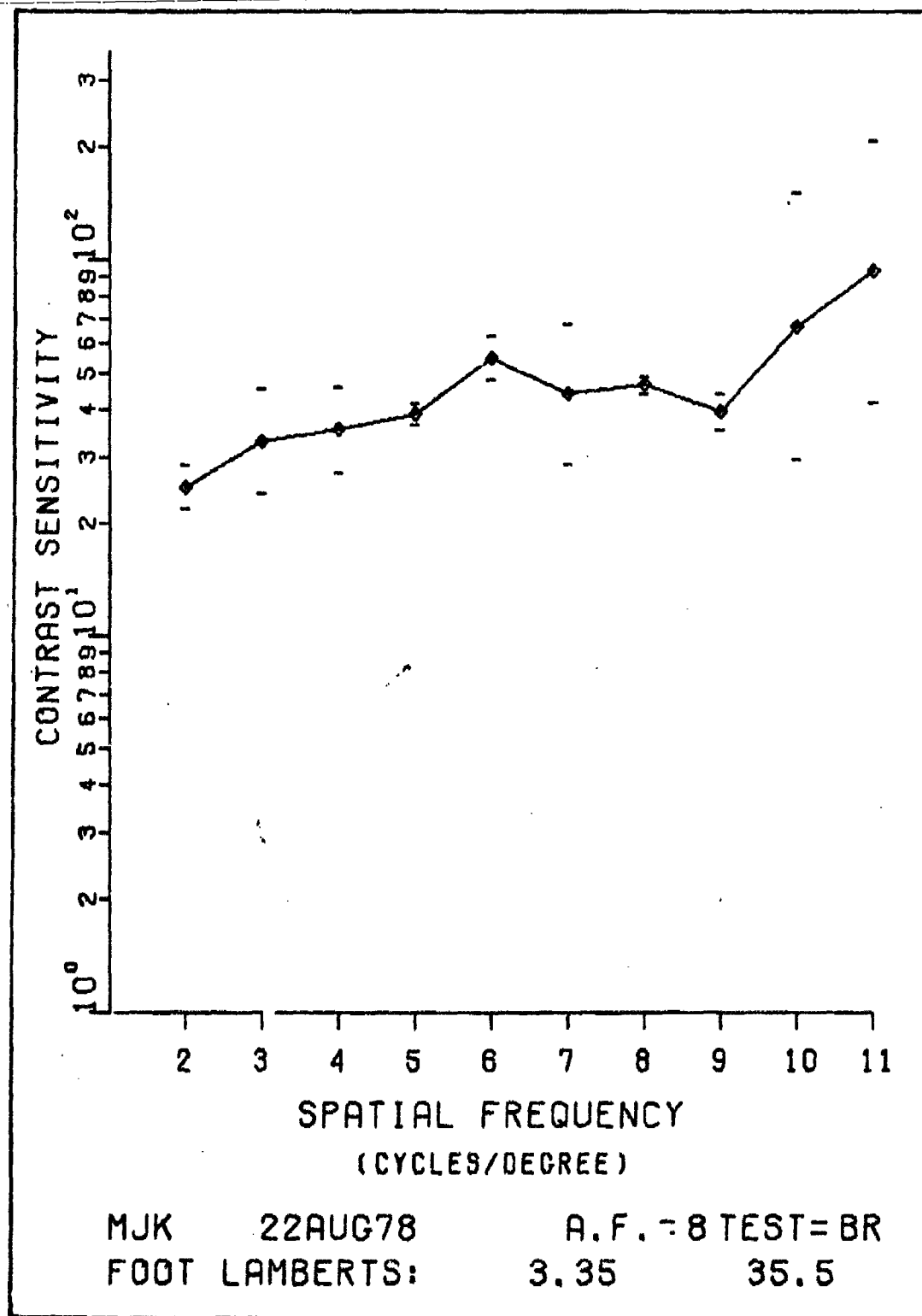


Fig. 22, MJK, Test Bright, Adapt Dim, 8 CPD

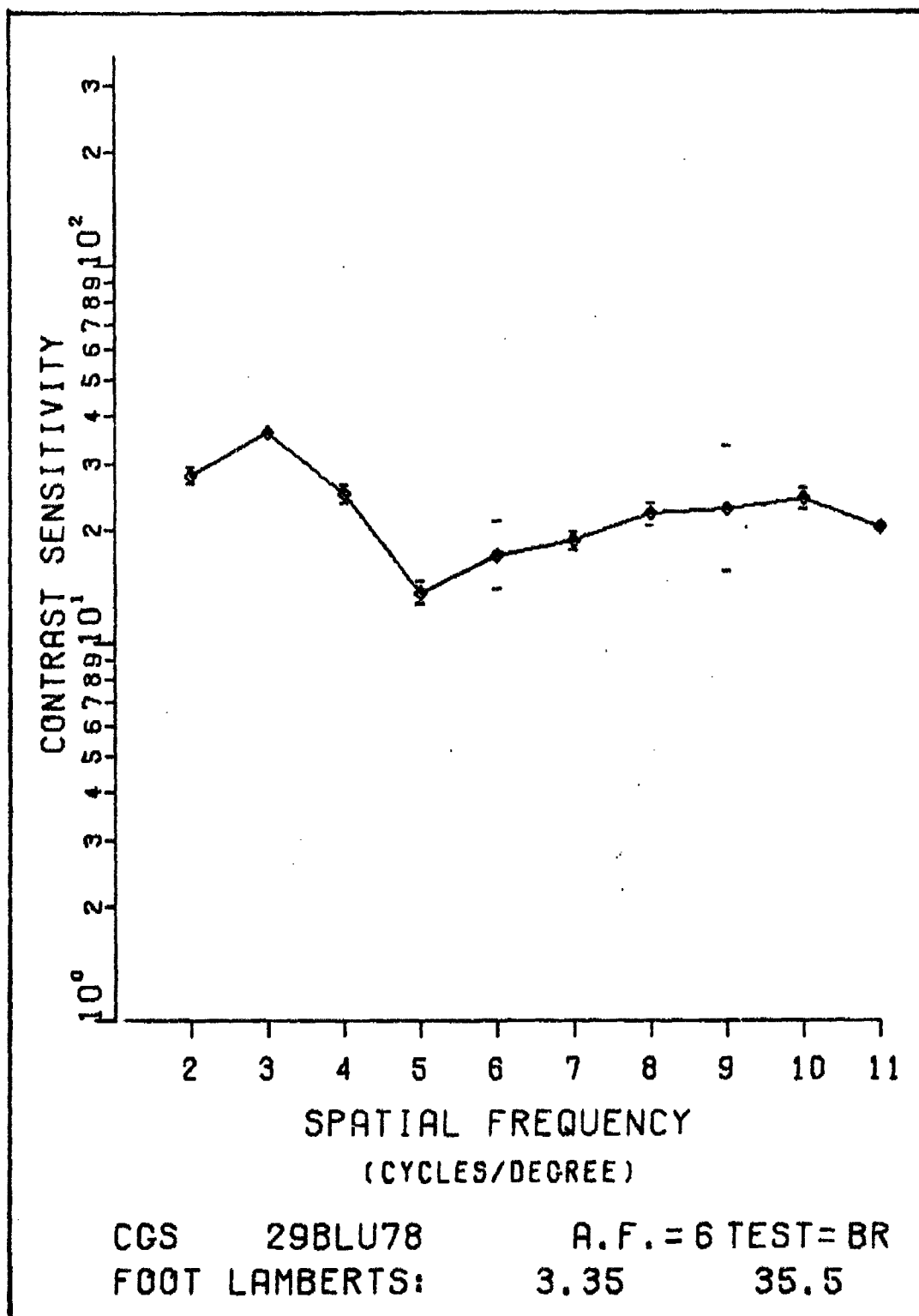


Fig. 23. CGS, Test Bright, Adapt Dim, 6 CPD Blue

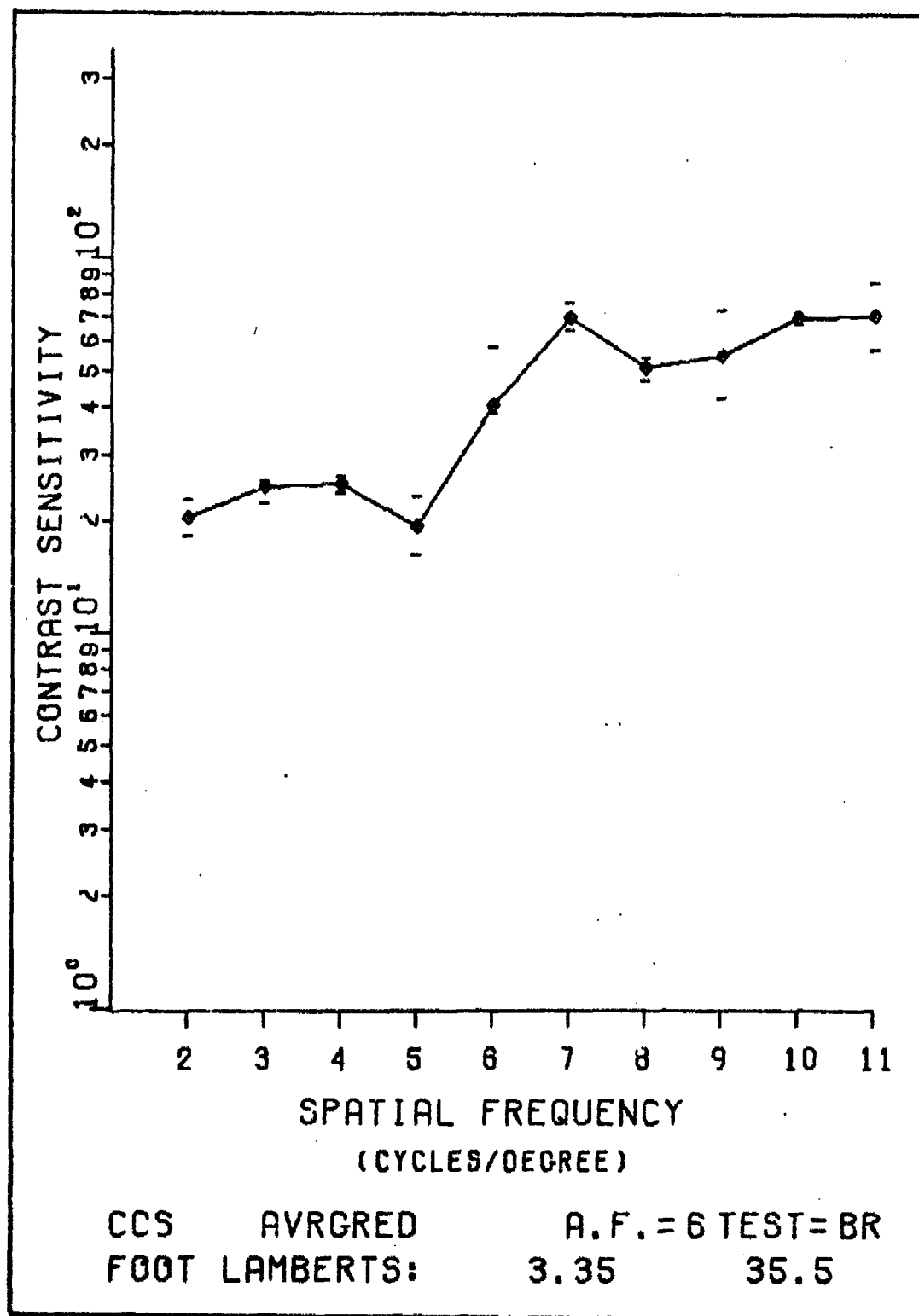


Fig. 24. CGS, Test Bright, Adapt Dim, 6 CPD
(Average Red)

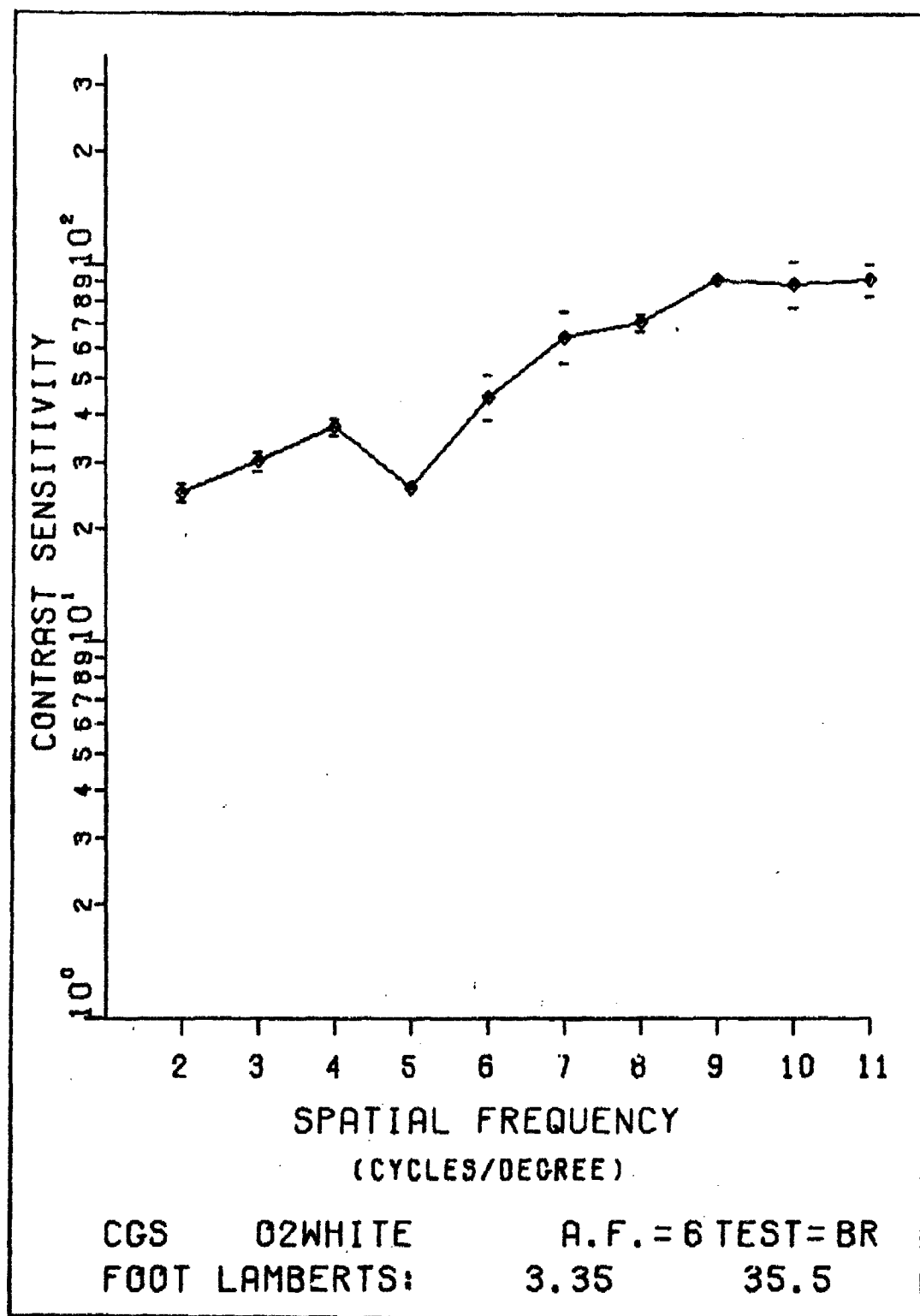


Fig. 25. CGS, Test Bright, Adapt Dim, 6 CPD White

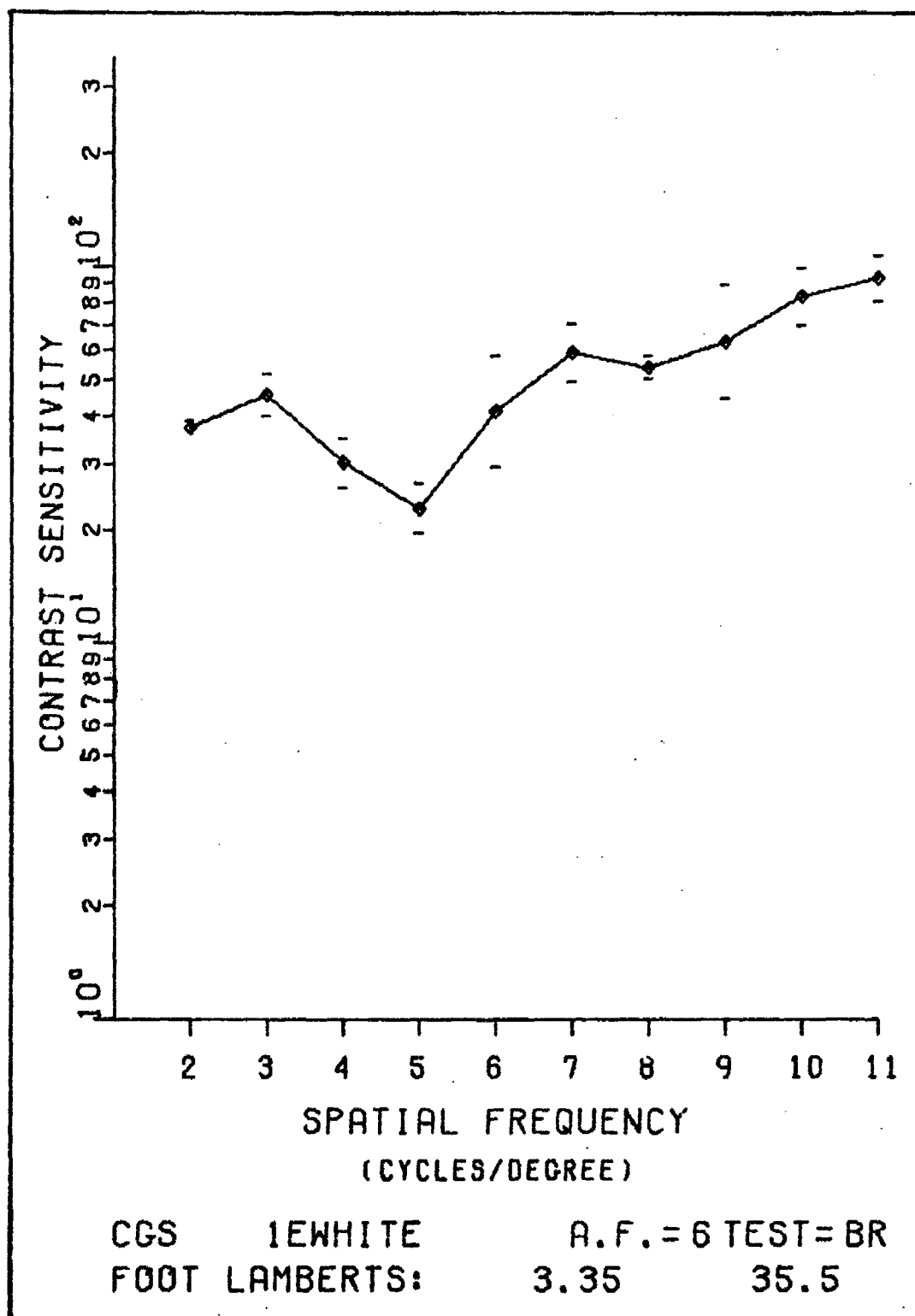


Fig. 26. CGS, Test Bright, Adapt Dim, 6 CPD White
(Right Eye)

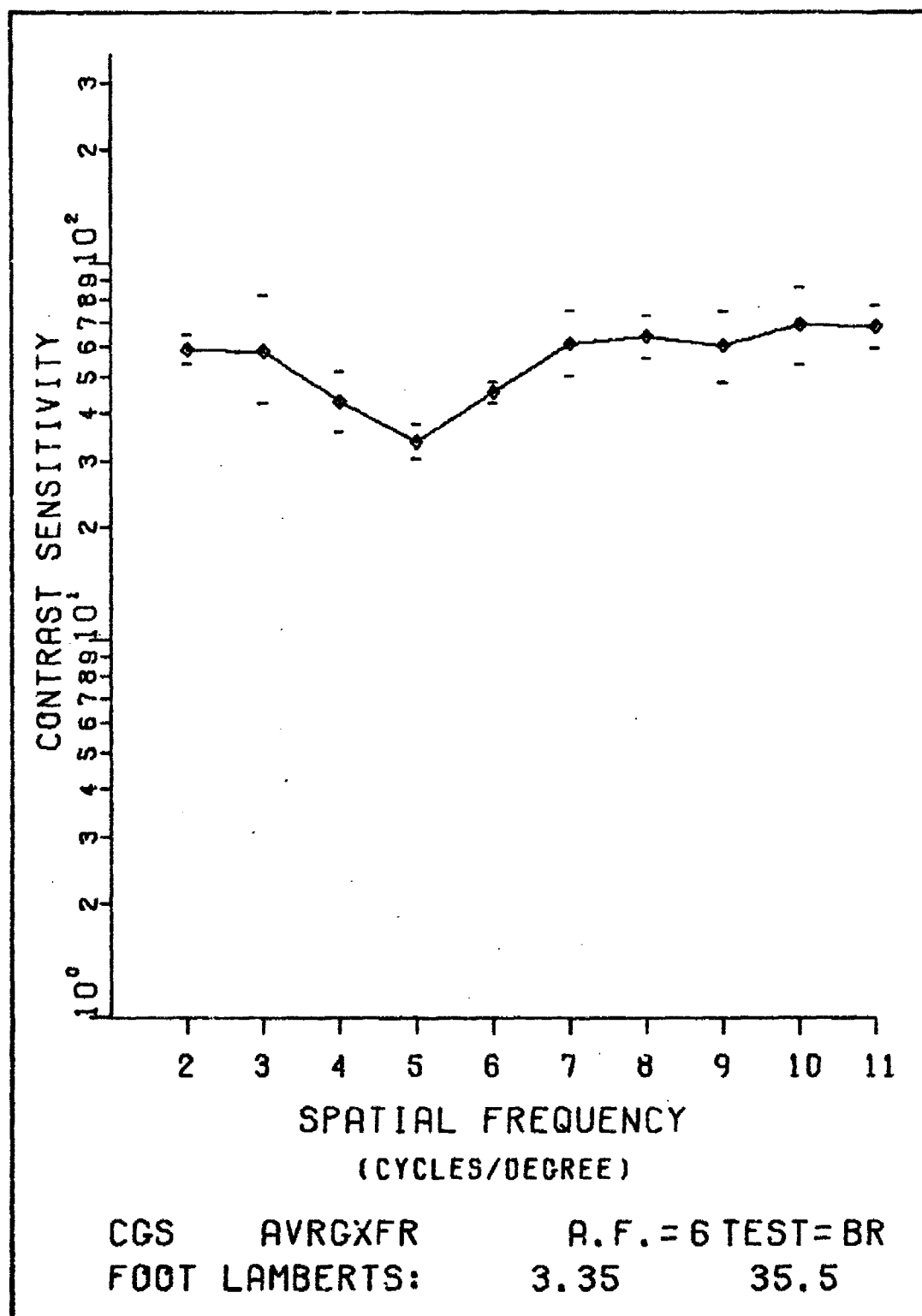


Fig. 27. CGS, Test Bright, Adapt Dim, 6 CPD (Average - Adapt Right Eye, Test Left Eye)

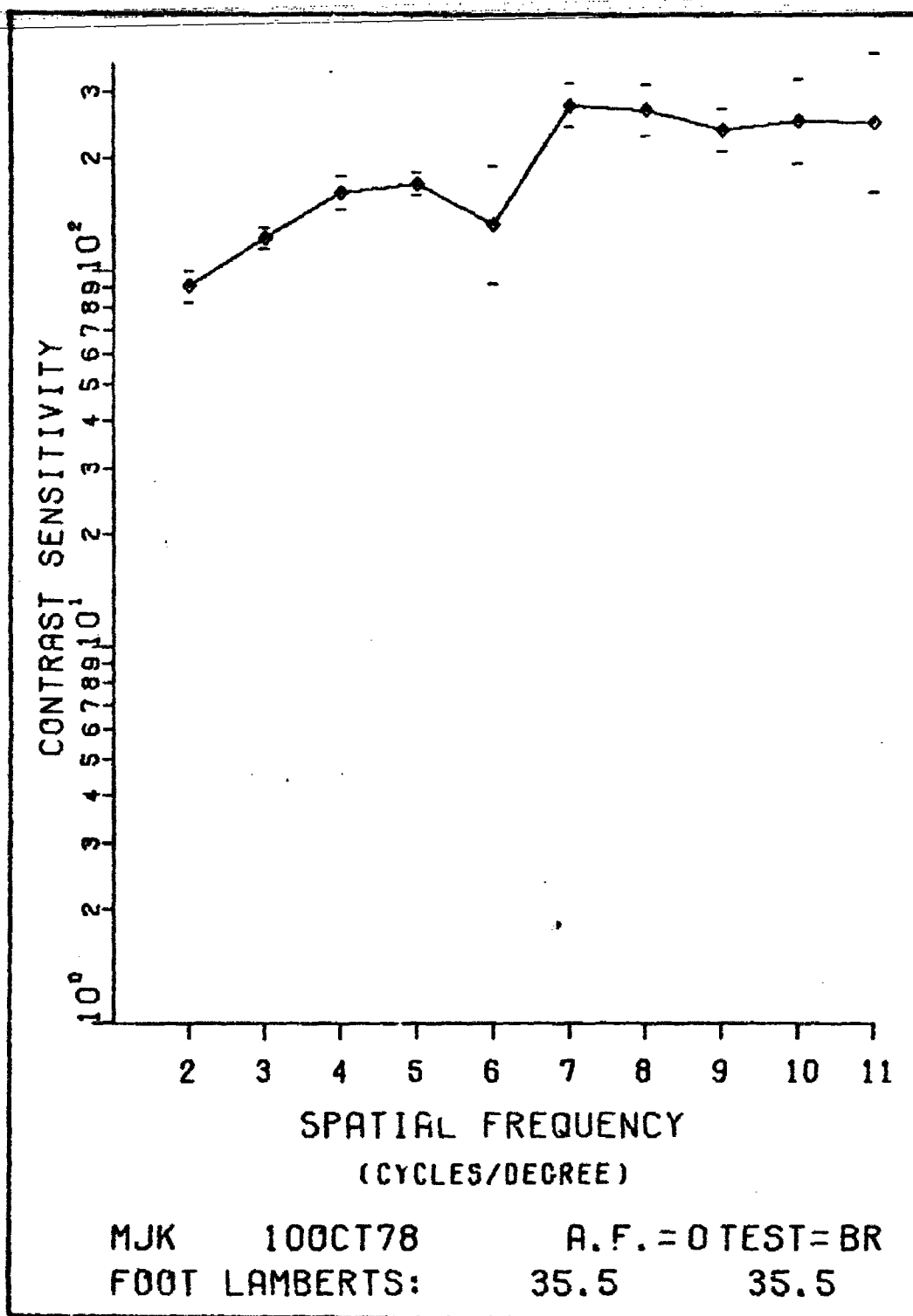


Fig. 28. MJK, Test Bright, Adapt Bright, 0 CPD
(20 Minutes After Adapting to 6 CPD Grating)

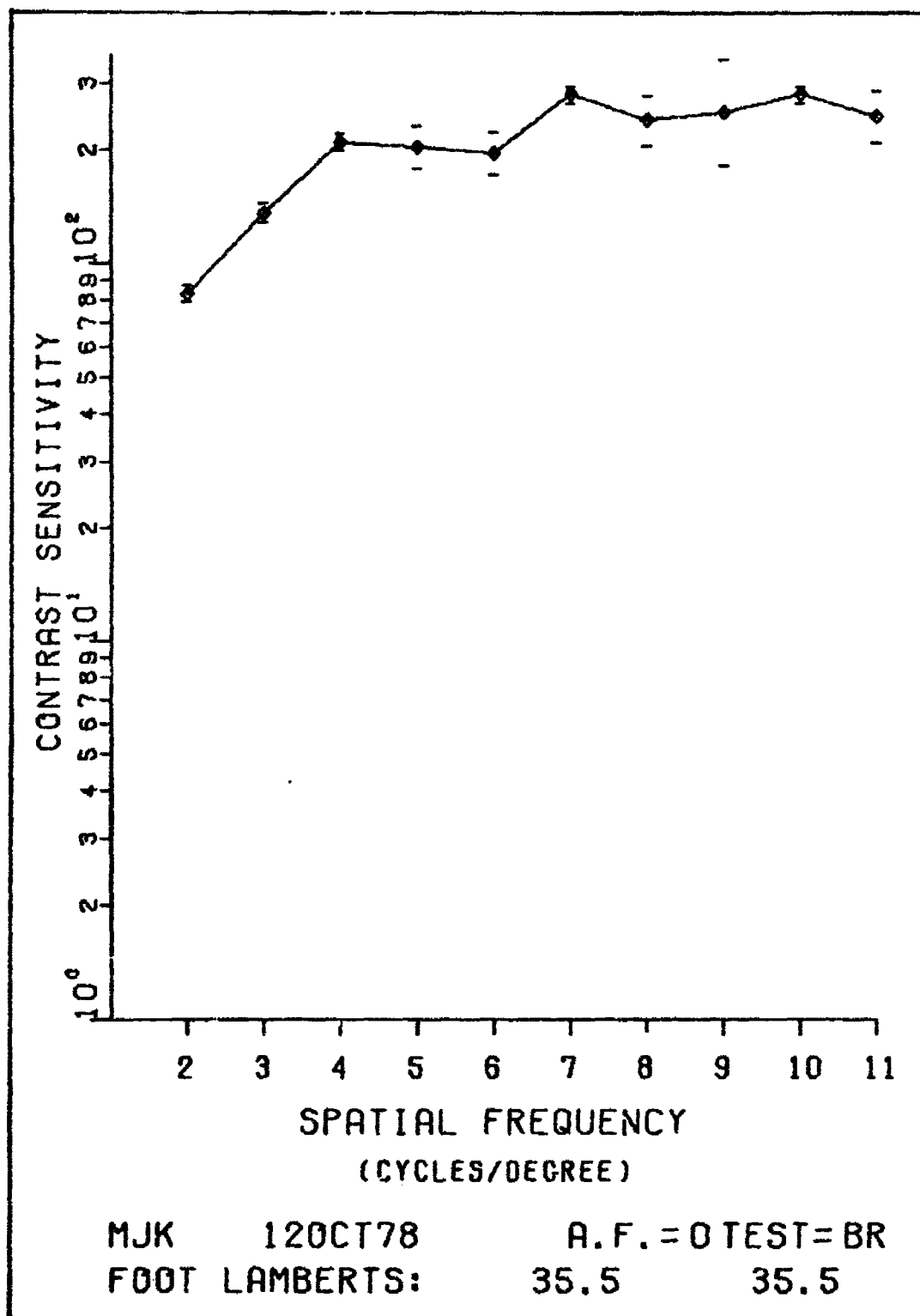


Fig. 29. MJK, Test Bright, Adapt Bright, 0 CPD
(48 Hours After Adapting to 6 CPD Grating)

VI. Conclusion

The experimental structure of this investigation sought to expose a receptive field reorganization process by desensitizing those receptive fields specifically sensitive to the adapting frequency at a certain luminance level and testing at a different luminance level to determine at which spatial frequency the desensitization would occur. This investigation has shown that a luminance change which would shift the MTF curve to higher spatial frequencies exhibits a shift in the adaptation depression to lower spatial frequencies.

The observed shift in the location of the frequency specific adaptation depression in the MTF curve as a result of adapting at one luminance level and testing at another luminance level is consistent and, therefore, predictable from one experiment to another.

These results do not, however, support the hypothesis that a change has occurred in the frequency sensitivity of the receptive fields as a result of a change in the relative size of the fields caused by a change in luminance level. The experimental hypothesis stated that the increase in luminance would result in a decrease in the size of the center distribution and an increase in the size of the surround distribution with a resultant shift in the frequency specific adaptation depression to a higher spatial frequency.

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The results of this experiment indicate that exactly the opposite of this prediction is occurring. When a subject is adapted to a low luminance stimulus and tested with a high luminance level stimulus, the adaptation depression is manifested at a lower spatial frequency than the adapting frequency. This implies that either this receptive-field description of neural organization or this simple model of adaptation, or both, are wrong. This therefore implies that more complex models of one or both processes are required.

Maffei, Fiorentini, and Bisti found a center-surround receptive field organization of neural elements in the cortex of cats (Ref 17: 1036-1037). This extension of the center-surround organization which Werblin reported for the retina appears to support the center-surround receptive field model. Maffei, et al also provide evidence to support the contention that a simple cell fatigue adaptation model is not applicable to high contrast experimentation (Ref 17: 1037).

Four important conclusions can be drawn from the results of this experiment. First, there is a predictable shift in the location of the adaptation depression when there is a sufficient change in luminance between adapting and test stimuli. Second, since the adaptation depression shift was observed in an MTF curve for an unadapted eye of a subject whose other eye was adapted, the shift phenomenon

must be taking place subsequent to the retina. The third important conclusion is that the spatial frequency desensitization induced by adapting and testing at different luminance levels is not affected by color. This implies that the elements of the visual system whose luminance sensitivity affect their spatial frequency sensitivity are functioning independently of any color sensitivity of the visual system. The final conclusion is that the spatial frequency adaptation-effect exhibits a temporal persistence similar to the persistence that Favreau and Corballis reported for the color orientation adaptation phenomenon known as the McCollough effect (Ref 19: 44-45).

VII. Recommendations

To provide a broader data base for analysis this investigation should be reaccomplished with a larger number of subjects. The observed persistence of the adaptation effect indicates that in such a re-investigation extreme care should be taken to structure the order of experiments to preclude previous adaptation from interfering with later experiments. The results of this investigation also indicate that there are four new areas for further investigation:

1. persistence of adaptation effect
2. effect of color difference between adapting and test stimuli on the frequency specific adaptation
3. maximum shift which can be caused by a difference in the luminance level of the test and adapting stimuli
4. the effect of the contrast level of the adapting stimulus on the shift in the adaptation depression.

An investigation into any of the above areas should include an experiment to determine whether the results obtained for adapting one eye are transferred to an unadapted eye. A transfer of the adaptation effect implies that the observed effect is a result of changes in the visual system which

take place subsequent to the retina.

Various investigators have shown that the persistence of the color oriented adaptation known as the McCollough effect may last for a week to ten days (Ref 20: 45). This paper reports that stimulus color did not affect the shift of the specific frequency adaptation depression to a different spatial frequency. A study of the frequency specific response in conjunction with color adaptation persistence would provide an insight into whether a common system response is responsible for both effects.

The experimental result which indicates that stimulus color does not affect the shift in the adaptation depression caused by changes in luminance does not provide all the information needed relating to color. In two separate reports, May and Matteson and Green, Corwin, and Zemon have described their experiments with colored checkerboard patterns which indicate that color is coded within the visual system with frequency specific (as opposed to feature specific) information (Ref 21: 147, 22: 147-148). A determination that this is true for sinusoidal gratings would provide significant support to the hypothesis that a model based on a Fourier-like mechanism is applicable to the human visual system. One way that an investigation based on this recommendation could be implemented would be to adapt subjects to a stimulus grating at one color and use a different color for the test grating. If the spatial frequencies and

contrast levels used in this investigation were used, then the data contained in this report could provide a baseline for determining how the visual system processes information relating to pattern color. If color information is being processed with the frequency specific information then there should be no change in the test results.

The model of the visual system which purports that the system comprises a number of independent, approximately one octave wide, channels has been the source of considerable controversy (Ref 2: 32, 21: 147-148, 22: 209, 23: 2139). An investigation to determine the maximum shift which could be induced by adapting to a stimulus grating at one luminance level and testing at a different luminance level could contribute significantly to resolving this controversy. If a multi-channel model is descriptive of the human visual system, one would expect the region over which the adaptation depression could be shifted to be a narrow range centered about the adapting spatial frequency. Such an investigation could be accomplished by using the same adapting grating contrast level (0.23) and luminance level (3.35 ft-lamberts) used for this experiment and performing MTF tests at several higher luminance levels.

Blakemore, Muncey, and Ridley attempted to expose spatial frequency selective channels in the human visual system by using a contrast reduction technique (Ref 9: 1928). They reported changes in subject perception of grating contrast

after adaptation to a grating of a different contrast. This investigation was accomplished using an adapting grating contrast of 0.23. The experiment should be accomplished at both a higher and a lower adaptation contrast level to determine the effects of contrast on the observed shift in the adaptation depression and to gain further insight into how contrast levels affect visual resolution.

Regardless of which of the above additional studies are undertaken or whether the equipment is subsequently used for other as yet undefined MTF testing the following equipment modifications would facilitate testing. 1) The switches, S4 and S5, which control adapting and test pattern luminance should be replaced by relays. The operation of the relays could be coupled to the output of the multiplex controller. 2) The continuous trigger switch and the contrast level switch on the pattern generator should be relocated to the operator's console. This would be particularly helpful to the operator during equipment calibration and modification.

Bibliography

1. Carl, Joseph W. Personal Communication.
2. Pantle, Allan. Visual Information Processing of Complex Imagery. AMRL-TR-74-43. Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory, July 1974.
3. Campbell, F. W. and J. G. Robson. "Application of Fourier Analysis to the Visibility of Gratings," Journal of Physiology, 197: 551-566 (1968).
4. Michelson, A. A. Studies in Optics. University of Chicago Press, 1927.
5. Cornsweet, T. N. Visual Perception. New York: Academic Press, 1970.
6. Hecht and Zajac. Optics. Reading, Mass.: Addison-Wesley Publishing Co., 1974.
7. Patel, A. S. "Spatial Resolution by the Human Visual System. The Effect of Mean Retinal Luminance," Journal of the Optical Society of America, 56: 689-694 (May 1966).
8. Werblin, Frank S. "The Control of Sensitivity in the Retina." Scientific American, 228 (1): 70-79 (January 1973).
9. Blakemore, C., J. P. J. Muncey, and R. M. Ridley. "Stimulus Specificity in the Human Visual System." Vision Research, 13: 1915-1931 (1973).
10. Daitch, J. M. and D. G. Green. "Contrast Sensitivity of the Human Peripheral Retina." Vision Research, 9: 947-952 (1969).
11. Nystrom, Ronald E. 16-Device x 12-Bit Multiplexer Controller 75-300 Baud. MS Thesis GE/EE/73A-20. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, December 1973.
12. Hannickel, Harold L. Design and Construction of a Computer Controllable Multi-Chromatic Stimulus for Human Visual System Testing and Modeling. MS Thesis GE/EE/74-46. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, December 1974.

13. Quill, John E. Design and Construction of a Computer Controlled System for Measuring the Anisotropic Modulation Transfer Function of the Human Visual System. MS Thesis GE/EE/75-4. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, March 1975.
14. Scheidegg, Carl P. Contrast Sensitivity of the Human Visual System at One Luminance Level While Adapted to Another Luminance Level. MS Thesis GE/EE/77D-34. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, December 1977.
15. Sakai, Jack T. A Measure of Foveal Sensitivity in an Expanded Field of Visual Attention. MS Thesis GE/EE/76-11. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, June 1976.
16. Schmitt, Francis O., Parvati Dev, and Barry H. Smith. "Electronic Processing of Information by Brain Cells." Science, 193: 114-120 (9 July 1976).
17. Maffei, L., A. Fiorentini, and S. Bisti. "Neural Correlate of Perceptual Adaptation to Gratings." Science, 182: 1036-1038 (7 December 1973).
18. Guidry, Roland D. A High Resolution Measurement of the Anisotropic Modulation Transfer Function of the Human Visual System. MS Thesis GA/EE/73-1. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, December 1974.
19. Favreau, Olga Eizner and Michael C. Corballis. "Negative Aftereffects in Visual Perception." Scientific American, 235: 42-48 (December 1976).
20. May, James G. and Halsey H. Matteson. "Spatial Frequency-Contingent Color Aftereffects." Science, 192: 145-147 (9 April 1976).
21. Green, Marc, Thomas Corwin, and Vance Zeman. "A Comparison of Fourier Analysis and Feature Analysis in Pattern-Specific Color Aftereffects." Science, 192: 147-148 (9 April 1976).
22. Sekuler, Robert. "Spatial Vision." Annual Review of Psychology, 25: 195-232 (1974).
23. Lange, Robert V., Claude Sigel, and Sidney Stecher. "Adapted and Unadapted Spatial Frequency Channels in Human Vision." Vision Research, 13: 2139-2143 (1973).

Appendix A

Equipment Operating Procedures

This section will describe the operating procedures for the automated system for testing the MTF of the human visual system. The procedures depend on the computer program listed in Appendix B being on file in binary form in the CDC system.

The VCO's, television line voltage power supplies, and multiplex controller were left "on" continuously because of the long period of time required for these items to reach a stable output level after turn-on. Leaving the multiplex controller "on" also resulted in a decreased failure rate for this item. The transients and signal pulses resulting from the power surge at turn-on had resulted in several failures. Once the decision to leave these equipment items "hot" had been made, no subsequent failures of the multiplex controller were observed.

The first step in preparing the equipment for an experiment is to turn on the television set. The 3-5 minutes required for the set to warm up will elapse during the period of time required to complete the following steps.

Three controls must be set on the pattern generator. The contrast range switch should be set to position 1, 2, or 4 corresponding to contrast changes of 1:2, 1:5, and 1:10

respectively. The switch setting should be recorded for later entry as data into the computer program. The stimulus duration switch should be set for 500 msec. The trigger-continuous switch should be set to the "triggered" position. This provides a continuous presentation of the adapting grating on the television screen unless the Stimulus Request Switch is depressed.

The adapting and test pattern stimulus luminance levels are selected by setting switches S4 and S5 on the pattern switching box (Ref 14: 16).

The line voltage power supply should be set to provide $110 \pm .5$ v AC. The orientation of the television should be checked to insure that the rotation shaft pointer is aligned with the 0 degree mark on the rotation shaft caliper ring. This concludes the pre-operational checkout of the equipment items colocated with the TV set. The next items to be addressed are located at the operator's station.

The acoustic coupler must be set to "local" and the teletypewriter turned to the "on-line" position. The teletypewriter can now be used to provide digital values to drive the Digital-to-Analog converters (DAC's) in the multiplex controller. The "off, X.3, X1" control knob on both VCO's should be set to the "X1" position. The frequency multiplier control should be set to the "X100K" position and the frequency vernier should be centered with a sine wave output selected. The dual beam Oscilloscope should be

turned "on" and connected so that the test pattern VCO output is displayed on channel "A" and the output of the pattern generator is displayed on channel "B".

The coaxial cable which connects the test pattern VCO and the oscilloscope must be disconnected at the VCO output and connected to the output of the adapting pattern VCO. This displays the adapting pattern VCO output on channel "A". The VCO attenuation knob should be used to adjust the output level to 0.42v peak-to-peak. This sets the contrast level for the adapting pattern to 0.23 contrast units when the average luminance of the adapting pattern is 35.5 ft-lamberts (see eq. 1).

With the frequency dial of the adapting pattern VCO set to approximately 3.65, a sinusoidal grating of 6 CPD (12 full cycles) should be obtained within the 10" aperture of the television mask. This pattern can be fine tuned to the center of the lock-up range using the frequency vernier. To obtain 4 CPD, the frequency dial should be set to approximately 2.60 and the above procedure followed to obtain lock-up with 8 full sinusoidal gratings in the mask aperture. Once the adapting pattern spatial frequency has been obtained on the television, the coaxial cable can be reconnected to the output of the test pattern VCO.

The test pattern VCO attenuation control should be adjusted to obtain an output signal of 1v peak-to-peak. The preparation of the signal generating equipment for operation

with the multiplex controller is completed by setting the "triggered-continuous" switch on the pattern generator to the "continuous" position.

The teletypewriter is used to enter the initializing commands into the multiplex controller. Commands must be entered in the format "XXXnQQ". This command format causes the multiplexer to store the value XXX in the nth buffer upon receipt of the consecutive QQ keyword. For example, when the command "5553QQ" is entered from the teletypewriter, buffer 3 of the multiplexer will store 555 and the voltage level out of the Digital-to-Analog converter output 3 will be 5.55v dc. A more detailed explanation can be found in Nystrom's thesis (Ref 11: 19). The commands "0003QQ", "0052QQ", and "9990QQ" will set the pattern generator to produce a test pattern of 2 CPD on the television screen. The frequency control and vernier of the test pattern VCO should be used to fine tune to the center of the lock-up range.

The remaining nine test frequencies should be stepped through in ascending order using commands of the form "XXX2QQ", where "XXX" represents a three digit number from the FREQ CAL column of Table III.

The VCO to multiplex controller calibration and the computer program require that the first spatial frequency of 2 CPD be locked up by entering the "0052QQ" command into the multiplex controller using the teletypewriter. The

other nine frequency calibration values may be varied within the frequency range indicated in Table III as necessary to obtain a stable test pattern at all test spatial frequencies. The equipment is, at best, marginally stable in its overall operation and highly sensitive to temperature variations; consequently, the frequency calibration values for a stable test pattern vary but usually lie within the ranges listed.

The lock-up range for each spatial frequency is determined by stepping through the range of values which produce a sinusoidal grating on the screen. A frequency in the center of the lock-up range should be selected as the frequency calibration (FREQ CAL) value for the run. The equipment can now be placed in the configuration for operation under computer control by setting the "triggered-continuous" switch on the pattern generator to the "triggered" position.

The operation select switch on the acoustic coupler should be placed in the "half-duplex" position and a 110 baud link should be established with the ASD computer center. The baud rate is determined by the strapping of pad "H" on the clock card in the multiplex controller (Ref 11: Fig. A-10). Normal LOGIN procedures should be used to gain access to the ASD INTERCOM system. The MTF program stored in binary file should be attached as well as the CAL COMP plot routine designated CCAUX. The MTF program is described in Appendix B and listed in Fig. 30. The procedure for attaching both routines is shown in Fig. 31. An experiment

can now be run under computer control to determine the MTF
of a subject.

Appendix B

MTF Computer Program

This program controls the operation of an automated system for determining and plotting the modulation transfer function (MTF) of the human visual system. This control is exercised through the generation of control words to drive the Digital-to-Analog converters (DAC's) in the multiplex controller. The DAC outputs set the contrast and frequency and control the change of pattern of the stimulus display.

Computer Program for Stimulus Control

The original program was written by Quill (Ref 13: 34-57). Several modifications were made to it by Scheidegg to incorporate system modifications, contrast-out-of-limits flags, and data checks within the basic program (Ref 14: 76-88). Fig. 30 is a listing of the program as modified to meet the requirements of this investigation and described in the following paragraphs.

The data arrays labeled CONT contain the contrast calibration data for the 10 spatial frequencies to be tested. Each of the 40 numbers in the CONT array corresponds to the multiplex controller output voltage required to produce a given contrast level on the television screen. The 40 contrast levels cover the range from -0.20 to -2.15 logarithmic

contrast units and are $0.05 \log$ contrast units apart. The DAC voltage corresponding to each contrast level was originally determined by Quill using the procedure described in his thesis (Ref 13: 22-25, 74-79). The calibration results for the equipment configuration used in this investigation and the verification of the applicability of the contrast level calibration data determined by Quill are presented in Appendix C.

The program requires the operator to provide the computer with frequency, test parameters, and subject identification. This information is necessary for computer control of the experiment and for proper labeling and identification of the computer generated data plots and tables relating to the test. A data verification routine has been added to provide the operator with the capability to edit this control information before entering the run.

During the main run the computer controls the test stimulus frequency, contrast, and luminance levels. For a given spatial frequency, a change in luminance level results in a change in contrast. The constant DELTA was added to the computation phase to compensate for this difference when the test procedures required contrast computations at the lower luminance level. The technique for determining the value of DELTA is described in Appendix C.

Program Operation

The computer program is interoperative, requiring initially that the operator provide the parameters necessary to control the test and gather the data. During the main portion of the program, the subject is required to respond to the test stimulus generated. The program begins by setting the DAC's to provide the first contrast level and test stimulus spatial frequency. The program requests 10 frequency values for the FREQCAL array. The values are predetermined using the procedures in Appendix A. These values are entered at the teletype in the format: blank, I3, blank, I3, etc., until all 10 values are entered. The program then prints the values on the teletype and requests verification. Typing a zero causes the program to return to "request 10 values for FREQCAL array". Typing a "1" causes the program to progress to subject identification.

After the FREQCAL array has been verified, the program requests subject identification. This information is entered on the teletype in the format indicated by the program (subject, date, step size).

The program then requests that the luminance level of the test and adapting stimuli and the frequency of the adapting stimulus be entered from the teletypewriter. The program also requests that the contrast range switch setting be entered. This information is used by the program to control the experiment and to develop the plot routine and data

tables for the program output.

The original MTF program developed by Quill (Ref 13: 43) addressed the two stimulus contrast levels associated with the high-low contrast range switch on the pattern generator designed and built by Hannikel (Ref 12: 40). The data from Quill's low contrast level calibration was used by Sakai as a starting point in developing the contrast calibration data for his modification to the pattern generator. Sakai replaced the two position contrast level switch with a five position selector switch to obtain more contrast range levels. Each position on the selector switch corresponds to a different resistive network which can be selected to attenuate stimulus contrast (Ref 15: 19). Sakai determined experimentally that the voltage output of the pattern generator was a linear function of the input voltage and that an increase in resistance at the pattern generator output only served to divide the contrast level of the pattern by a constant.

The two luminance levels used by Scheidegg to perform his MTF experiments permitted all data to be taken with the contrast range switch of the pattern generator in position 4 (contrast level divided by 10). In order to normalize the results of his experiments to the calibration levels determined by Sakai and Quill, Scheidegg modified the specific equation in the MTF program which determines the starting point for calculating logarithmic contrast.

The one logarithmic unit difference in the two luminance levels used in this investigation precluded taking all data at the same contrast range switch setting. Furthermore, there is no basis for assuming that future experimentation with this equipment would use the same switch setting. A routine was needed to incorporate into the computer program a means of relating the contrast level at which the subject was tested to the calibrated contrast levels. Using Scheidegg's normalized logarithmic contrast equation as a basis for relating contrast levels, and the fact that contrast is a linear function as determined by Sakai, a function for interrelating the various contrast levels (CONRNG) was determined (See Table II).

The average divisor factor for each contrast level was determined from Appendix B, Table V of Sakai's thesis. The ratio of the average divisor for each contrast level to contrast level 3 (contrast range switch position 4) was calculated and a routine for operator input of this data was incorporated into the MTF program. This routine requires that the operator specify the contrast range switch setting. The MTF program then changes the contrast divisor accordingly. The subsequent computer generated data tables and graphs require no mathematical interpretation (i.e. they present the data just as if the contrast divisor were 1).

The program requests verification of all experiment parameters before entering the main program. If any errors

Table II

Contrast Range Switch Setting	Contrast Multiplier		CONRNG Factor
	Computed Average Max Volt*/Contrast Volt		
1	1.95		4.73
2	4.25		2.17
3	1.00		0.11
4	9.23		1.00
5	16.6		0.56

*From the pattern voltage taken at Pin 7, A3 to ground (Ref 12; 19, 41)

were made during data input, typing a zero (0) on the teletypewriter will return the program to the first program step requesting parameter input. Typing a one (1) causes the program to proceed to the main run.

The experiment is carried out using a staircase procedure to establish the contrast threshold of the subject. The staircase is initiated at the highest possible contrast level. This allows the subject a clear observation of the test grating that will be used and insures that the first response is always affirmative ("I see it"). This response is entered from the Hand Held Response Box (HRB). An affirmative response causes the program to decrease the contrast level by 6 logarithmic (log) contrast units. The contrast level is further decreased 6 log contrast units for each subsequent affirmative response. When the subject enters a negative response (?), the program increases the contrast level by 2 log contrast units. This 2 log contrast unit increase per response is continued until the subject indicates that he can see the grating. The point at which the subject makes this affirmative response provides an estimate of the subject's contrast threshold. The program then decreases the contrast level by 1 log contrast unit until a negative response is given. This constitutes the first reversal. The contrast level is then increased by 1 log contrast level at a time until another reversal is obtained. It is then decreased by 1 log contrast unit until

the next reversal is obtained. This alternate increase and decrease of the contrast level will continue until 6 reversals have been obtained. This staircase technique for determining the subject's contrast threshold is performed for the ten (10) sinusoidal gratings (2-11 CPD) in ascending order.

The responses for the staircase testing are stored in two data arrays; one for affirmative and one for negative responses. For each spatial frequency, the program uses the table with the fewest entries to determine the value of the average contrast sensitivity and to calculate 1 standard deviation (SIGMA) from that value. The results of this computation are printed on the teletypewriter upon completion of the run. The equipment operator can choose to continue with another run or to stop at this point. If the operator chooses to run another experiment, the data from the first experiment are held in memory until after the final experiment has been completed. When the operator indicates he is finished testing (by typing a "?" in response to the program query), he will route the data files to the appropriate output devices in the computer facility in the AFIT School of Engineering building. (Note: The heading of the file to be routed also indicates the device to which it is to be routed. Example: PUNCH - to card punch, etc.).

```

*****
PROGRAM VIF(INPUT,OUTPUT,TAPF1,BUNCH,PRINT,TAOS2=PRINT)
*****
* THIS PROGRAM CONTROLS THE OPERATION OF THE AUTOMATED
* SYSTEM FOR DETERMINING THE ANISOTROPIC MODULATION
* TRANSFER FUNCTION OF THE HUMAN VISUAL SYSTEM.
* THE PROGRAM GENERATES THE CONTROL WORDS NECESSARY
* TO DRIVE THE MULTIPLEX CONTROLLER TO SET THE CONTRAST OF
* THE VIDEO SIGNAL AND CONTROL THE FREQUENCY OF THE DISPLAY.
*****
INTEGER CONT(46,10),FLG(10),DIP(10),NUM(40),AYF,1
INTEGER YFS(40,10),REV(10),STP,SUM,DATF,PR=OCAL(10),REFSP
DIMENSION M(10),RO(40,10),LRSP(10),SIG1A(40),TRSHL7(10)
DIMENSION CONSEN(12),SPAFMED(12),SCRATCH(1024),HI(12),TABLE(10,40)
REAL LO(12)
DATA(DIP=10*1),(M=10*1),(YFS=40*0),(NO=40*0)
DATA(LRSP=10*0),(REV=10*0),(DELTA=.732)
DATA(FLG=10*1),(ADAPT=1M0),(TABLE=40*14-)
CALL PLOTS(SCRATCH,1024,1)
*****
* THESE STATEMENTS CONTAIN THE CALIBRATION DATA FOR THE
* CONTRAST LEVELS FOR EACH SPATIAL FREQUENCY.
*****
DATA(CONT(1,1),I=1,40)=3*(999),891,856,929,804,780,750,739,
X719,702,689,676,665,655,641,635,626,619,612,607,600,592,584,
Y577,572,566,561,556,553,550,542,533,529,521,517,513,504,
*****
DATA(CONT(1,2),I=1,40)=3*(999),977,899,849,813,786,757,737,719,
X709,690,677,666,656,647,637,629,621,614,608,607,596,585,
Y581,574,568,562,559,555,551,544,539,529,520,515,510,
*****
DATA(CONT(1,3),I=1,40)=3*(999),944,879,831,804,775,752,732,711,
X700,685,674,663,654,644,635,626,618,611,606,600,591,585,
Y579,573,567,563,559,555,551,543,537,531,526,519,513,
*****

```

Fig. 30. MTF Program Listing (page 1 of 13)

Fig. 30. MTF Program Listing (page 2 of 13)

```

* INITIALIZE ALL DAC'S.
*****
105 PRINT 110
110 FORMAT(" 999000 005200 000700 CHECK FREQUENCY LOOKUP OK."/)
*****
* ENTER THE CALIBRATION DATA FOR EACH FREQUENCY.
*****
112 PRINT 113
113 FORMAT(1X,"ENTER 10 VALUES FOR FREQ.,CAL. ( I3 I3 F10.) :"/)
    READ 115,(FREQCAL(I),I=1,10)
115 FORMAT(10I4)
    PRINT 117,(FREQCAL(I),I=1,10)
117 FORMAT(1X,"(FREQCAL(I),I=1,10)=" ,10I5//1X,"FRECCAL OK ?   YES=1
    X10=0 : ")
    READ 118,CNS
118 FORMAT(I1)
    IF(C.EQ.0NS) GO TO 112
*****
* THE ID, DATE, AND STEP SIZE SHOULD BE ENTERED
* IN THE FOLLOWING FORMAT: A3,A7,I1.
* ALSO NOTE BRIGHT OR DIM TEST PATTERN: (A2).
*****
120 PRINT 130
130 FORMAT(1X,"ENTER ID(A3), DATE(A7), STEP SIZE(I1): ")
    READ 135,ID,DATE,STEP
135 FORMAT(A3,A7,I1)
    PRINT 140
140 FORMAT(1X,"BRIGHT TEST PATTERN - - TYPE 'BR'"/
    X1X,"DIM TEST PATTERN - - TYPE 'DM'      : ")
    READ 142,TEST
142 FORMAT(A2)
    IF(2*CON.EQ.TEST) GO TO 143
    LUMIN=LUM75.5
    GO TO 144
143 LUMIN=LUM75.75

```

Fig. 30. MTF Program Listing (page 3 of 13)

```

*****
* ADAPTING PATTERN - RIGHT OF DIM2
*****
144 PRINT 145
145 FORMAT(1X,"BRIGHT ADAPT PATTERN - TYPE 'BR'"/
X1X,"DIM ADAPT PATTERN - TYPE 'DM' : ")
      READ 146,AL
146 FORMAT(A2)
      IF(2400,50,AL) GO TO 147
      IF(2404,50,AL) GO TO 148
      GO TO 149
147 ADJUM=4HZ5.5
      GO TO 149
148 ADJUM=403.75
*****
*SET CONTRAST RANGE
*****
149 PRINT 150
150 FORMAT(1X,"RECORD CONTRAST RANGE SWITCH SETTING (A1) : ")
151 READ 152,SWITCH
152 FORMAT (A1)
      IF (SWITCH,50,2) GO TO 153
      IF (SWITCH,50,5) GO TO 154
      IF (SWITCH,50,4) GO TO 155
153 CONTR=2.17
      GO TO 155
154 CONTR=0.55
      GO TO 155
155 CONTR=1
156 CONTINUE
*****
* ADAPTING PATTERN CO BLANK SCREEN BETWEEN TEST STIMULI
*****
      PRINT 157
157 FORMAT(1X,"ADAPTING PATTERN - TYPE AN 'A'"/
X1X,"BLANK SCREEN - TYPE 'B' : ")

```

Fig. 30. MTF Program Listing (page 4 of 13)


```

*****
* OUTPUT CONTROL WORD FOR SETTING CONTRAST.
*****
001850
001860
001870
001880
001890
001900
001910
001920
001930
001940
001950
001960
001970
001980
001990
002000
002010
002020
002030
002040
002050
002060
002070
002080
002090
002100
002110
002120
002130
002140
002150
002160
002170
002180
*****

* REQUEST RESPONSE:
*****
* A "DON'T KNOW" INPUT SIGNALS THAT THE APPROXIMATE
* CONTRAST THRESHOLD HAS BEEN REACHED.
*****
      PRINT 210
      210 FORMAT(1X,"840700 ")
      READ 230,RESP
      230 FORMAT (A1)
      I=I+1
      IF(14*50,RESP) GO TO 270
      M(I)=M(I)+1
      TABLE(I,1)=144
*****
* IF THE TABLE LENGTH IS EXCEEDED, ASSIGN PRESET CONTRAST
* AND CONTINUE STAIRCASE.
*****
      IF(M(I).GE.40) GO TO 260
      GO TO 180
*****
* ERROR ROUTINE TO CORRECT FOR CONTRAST LEVELS GREATER
* THAN 40 DURING ORIENTATION PHASE.
*****
      260 M(I)=40
      GO TO 310
      270 M(I)=M(I)+2
      TABLE(I,1)=144
      IF(M(I).GE.40) GO TO 280
*****

```

Fig. 30. MTF Program Listing (page 6 of 13)


```

002190 * BEGIN MAIN RUN.
002200 *****
002210 * THIS PORTION OF THE PROGRAM CONDUCTS 10 INDEPENDENT STATISTICS:
002220 * ALL RESPONSES ARE SCORED AND THE APPROPRIATE TABLES MAINTAINED.
002230 * AFTER ALL 10 STATISTICS COMPLETE 6 REVERSALS, THE PROGRAM
002240 * BEGINS COMPUTATIONS.
002250 *****
002260 * CHECK THE FREQUENCY FLAG TO SEE IF FREQUENCY TABLE
002270 * IS FULL.
002280 *****
002290 310 IF (FLG(I).EQ.0) GO TO 410
002300 *****
002310 * CHECK THE DIRECTION FLAG AND INCREMENT/DECREMENT THE
002320 * CONTRAST LEVEL.
002330 *****
002340 330 IF (DIR(I).EQ.1) GO TO 340
002350 * M(I)=M(I)+STP
002360 * GO TO 360
002370 *****
002380 340 M(I)=M(I)-STP
002390 *****
002400 * TEST TO SEE IF THE CONTRAST LEVEL IS OUT OF RANGE: IF
002410 * 50, CORRECT LEVEL AND CONTINUE.
002420 *****
002430 350 IF (M(I).LT.1) GO TO 355
002440 * GO TO 350
002450 *****
002460 * ERROR ROUTINE TO CORRECT FOR CONTRAST LEVELS LESS THAN J.
002470 *****
002480 * ERROR ROUTINE TO CORRECT FOR CONTRAST LEVELS GREATER THAN 40.
002490 *****
002500 355 M(I)=1
002510 PRINT 355
002520 356 FORMAT(" 002700 ERROR- HIGH CONTRAST LIMIT EXCEEDED")
002530 * GO TO 350
002540 360 IF (M(I).LE.40) GO TO 360

```

Fig. 30. MTP Program Listing (page 7 of 13)

```

002550
002560
002570
002580
002590
002600
002610
002620
002630
002640
002650
002660
002670
002680
002690
002700
002710
002720
002730
002740
002750
002760
002770
002780
002790
002800
002810
002820
002830
002840
002850
002860
002870
002880
002890
002900

PRINT 365
365 FORMAT(" 002700 ERROR - LOW CONTRAST LIMIT EXCEEDED")
M(I)=40
GO TO 360
369 CONTINUE
*****
* OUTPUT CONTRAST, REQUEST RESPONSE.
*****
PRINT 370,CONT(M(I),I)
370 FORMAT(1X,I3,"000",2X,"4LC700 ")
READ 390,RESP
390 FORMAT(A1)
T=T+1
IF(1R?.EQ.RESP) GO TO 390
RESP=1
YES(M(I),I)=YES(M(I),I)+1
TABLE(I,T)=1MY
GO TO 400
390 NO(M(I),I)=NO(M(I),I)+1
RESP=0
TABLE(I,T)=1HN
*****
* CHECK FOR REVERSAL.
*****
400 IF(RESP.EQ.LRESP(I)) GO TO 330
IF(DIR(I).EQ.0) GO TO 410
DIR(I)=0
GO TO 420
410 DIR(I)=1
420 REV(I)=REV(I)+1
*****
* IF REVERSAL HAS OCCURRED, UPDATE THE TABLES. IF 6
* REVERSALS HAVE OCCURRED, SET FLAG TO 0.
*****
IF(REV(I).LI.6) GO TO 440
FLAG(I)=0

```

Fig. 30. MTF Program Listing (page 8 of 13)

```

002910 440 LRESP(I)=RESP
002920     GO TO 310
002930 *****
002940 * TEST TO SEE IF ALL STATISTICS ARE FILLED. IF THEY ARE
002950 * FILLED, GO ON TO COMPUTATION PHASE.
002960 *****
002970 450 SUM=0
002980     DO 460 J=1,10
002990     SUM=SUM+FLG(J)
003000 460 CONTINUE
003010     IF (SUM.EQ.0) GO TO 420
003020 470 CONTINUE
003030 480 PRINT 490
003040 490 FORMAT(1X,"200700")
003050 *****
003060 * BEGIN COMPUTATION.
003070 *****
003080 * TALLY THE TOTAL NUMBER OF POSITIVE AND NEGATIVE
003090 * RESPONSES AND USE THE RESPONSE TABLE WITH THE LEAST
003100 * NUMBER OF OCCURRENCES.
003110 *****
003120 500 DO 520 L=1,10
003130     MAY=AVE=0
003140     DO 510 I=1,40
003150     AVE=AVE+YES(I,L)
003160     MAY=MAY+NO(I,L)
003170 510 CONTINUE
003180     IF (MAY.LT.AVE) GO TO 530
003190     DO 520 I=1,40
003200     NUM(I)=YES(I,L)
003210 520 CONTINUE
003220     Z=-1.
003230     GO TO 550
003240 530 DO 540 I=1,40
003250     NUM(I)=NO(I,L)
003260 540 CONTINUE

```

Fig. 30. MTF Program Listing (page 9 of 13)

```

7=1,
550 SUM1=0
    SUM2N=0
    NSUM=0
*****
* EVALUATE CONTRAST SENSITIVITY, THRESHOLD CONTRAST, AND
* STANDARD DEVIATION FOR EACH FREQUENCY.
*****
    DO 560 I=1,40
        CONTR=(-.87-(I-1)*.05)
        IF (TEST.EQ.2HRT) GO TO 555
        CONTR=CONTR+DELTA
555 SUM1=SUM1+CONTR*NUM(I)
    SUM2N=SUM2N+CONTR**2*NUM(I)
    NSUM=NSUM+NUM(I)
560 CONTINUE
    D=0.05*STD
    VAR=(SUM2N-SUM1**2/NSUM)/(NSUM-1)
    SIGMA(L)=1.62*0*(VAR/D)**2+.029
    TWLOG=SUM1/NSUM+2*(D/2)
    TRSHLD(L)=10.*THLOG
    CONSEN(L)=(1./TRSHLD(L))/CONFRG
    LO(L)=CONSEN(L)/10.*SIGMA(L)
    HI(L)=CONSEN(L)*10.*SIGMA(L)
590 CONTINUE
*****
* END OF COMPUTATION PHASE, OUTPUT FINISHED DATA.
*****
500 PRINT 610, ID, STD, DATE, ADAPT, TEST, AL, (TRSHLD(L), L=1, 10), (CONSEN(I),
    XI=1, 10), (SIGMA(N), N=1, 10), (HI(J), J=1, 10), (LO(K), K=1, 10)
610 FORMAT(1X, "SUBJECT:", 1X, A3, 5X, "STEP SIZE:", 1X, I1, 5X, "DATE:", 1X, A7, 003570
    5X, "ADAPT. FREQ.:", 1X, A1//1X, "TEST:", 1X, A2, 5X, "ADAPT:", 1X, A2//1X,
    "TRSHLD. CON.:", 10F6.3//1X, "CON. SEN.:", 1X, 10F5.1//1X, "SIGMA:",
    25X, 10F5.3//1X, "HI:", 1X, 10F5.1//1X, "LO:", 1X, 10F5.1//1X)
    PUNCH 620, ID, DATE, STD, ADAPT, AL, TEST
620 FORMAT(A3, 2X, A7, 2X, I1, 2X, A1, A2, 2X, A2)

```

Fig. 30. MTF Program Listing (page 10 of 13)

```

PUNCH 570, (CCSEN(I), I=1, 10)
630 FORMAT(10F6.1)
PUNCH 630, (HI(I), I=1, 10)
PUNCH 630, (LO(I), I=1, 10)
WRITE(2, 550) ID, DATE, ADAPT, AL, TEST
650 FORMAT(1H1, 2X, "YES", 2X, "NO", 50X, A3, 3X, A7, 2X, A1, A2, 1X, A2)
DO 570 I=1, 40
WRITE(2, 550) I, (YES(I, J), J=1, 10), I, (NO(I, K), K=1, 10)
650 FORMAT(2X, I2, 3X, 10I4, 10X, I2, 3X, 10I4)
570 CONTINUE
DO 690 I=1, 10
WRITE(2, 580) I, (TABLE(I, J), J=1, 40)
680 FORMAT(2X, I2, 6X, 40A2)
690 CONTINUE
** GENERATE DATA FOR PLOT ROUTINE.
*****
CONSEN(11)=HI(11)=LO(11)=1.
CONSEN(12)=HI(12)=LO(12)=.4.
*****
** PLOT AND LABEL THE Y-AXIS.
*****
CALL PLOT(2.5, -12., -3)
CALL PLOT(0., 3.25, -3)
X=.5
730 DO 750 J=1, 10
CALL PLOT(X-.5, 0., 3)
CALL PLOT(X, 0., 2)
CALL PLOT(X, -.1, 2)
IF(J.GE.5) GO TO 740
CALL NUMBER(X-.047, -.375, .125, SPARENO(J), 0., -1)
GO TO 745

```

Fig. 30. MTF Program Listing (page 11 of 13)

```

740 CALL NUMBER(X=.079,-.375,.125,SPAFREQ(J),0.,-1)
745 X=X+.5
750 CONTINUE
    CALL SYMBOL(1.25,-.75,.15,17HSPATIAL FREQUENCY,0.,17)
    CALL SYMBOL(1.625,-1.00,.12,15H(CYCLES/DEGREE),0.,15)
    *****
    * PLOT AND LABEL THE Y-AXIS AND PLOT CONTRAST SENSITIVITY.
    *****
    CALL LGAXIS(0.,0.,20HCONTRAST SENSITIVITY,20,6.36,90.,1.,.4)
    CALL LGLINE(SPAREF,CONSEN,13,1,5,1)
    SPAREF(11)=1.75
    CALL LGLINE(SPAREF,PI,10,-1.80,1)
    CALL LGLINE(SPAREF,LO,10,-1.80,1)
    *****
    * LABEL IO, DATE, ADAPTING FREQUENCY, AND TEST BRIGHTNESS:
    * ENCLOSE PLOT IN BOX.
    *****
    CALL SYMBOL(0.,-1.5,.15,10,0.,3)
    CALL SYMBOL(1.,-1.5,.15,DATE,0.,7)
    CALL SYMBOL(2.625,-1.5,.15,5HAF.=,0.,5)
    CALL SYMBOL(3.625,-1.5,.15,ADAPT,0.,1)
    CALL SYMBOL(4.,-1.5,.15,HTEST=,0.,2)
    CALL SYMBOL(4.8,-1.5,.15,TEST,0.,2)
    CALL SYMBOL(0.,-1.3,.15,14HFOOT LAMPHOTS,0.,14)
    CALL SYMBOL(2.75,-1.6,.15,ADLUM,0.,4)
    CALL SYMBOL(4.13,-1.6,.15,LUMIN,0.,4)
    CALL RECT(-.75,-2.,6.75,6.25,0.,3)
    CALL PLOT(0.,0.,-3)
    *****
    * TO RETURN TO ORIENTATION PHASE, ENTER 1.
    * TO STOP, ENTER "CONT KNOWN".
    *****
    GOINT 910
810 FORMAT(" 220700      1=60      2=STOP      ")

```

Fig. 30. MTF Program Listing (page 12 of 13)

```

      READ 320,INTENT
      820 FORMAT(41)
      IF (INTENT.EQ.142) GO TO 900
      *****
      * INITIALIZE TABLES AND RETURN.
      *****
      DO 850 I=1,10
      CIP(I)=1
      W(I)=FLC(I)=1
      REV(I)=0
      LRESP(I)=0
      DO 850 J=1,40
      YES(J,I)=NO(J,I)=0
      TABLE(I,J)=14-
      850 CONTINUE
      SP45678(11)=1.
      ADJUST=140
      GO TO 105
      *****
      * STOP PROGRAM.
      *****
      900 PRINT 950
      950 FORMAT(" 001700 005200 999500 000300 ROUTE PLOT, PUNCH, & PRINT 004520
      XT FILES TO 4F17")
      CALL PLOT(1)
      STOP
      END

```

FIG. 30. MTF Program Listing (page 13 of 13)

COMMAND- ATTACH,CCAUX,CCAUX,CY=999,IE=LIEFAY,SN=ASL,ST=CSF
COMMAND- LIEFAY,CCAUX
COMMAND- ATTACH,MTF,EYETEST,CY=1
COMMAND- MTF
999000 005200 000700 CHECK FREQUENCY LOCKUP WA.
ENTER 10 VALUES FOR FREQ. CAL. (13 13 ETC.):
005 034 065 102 125 155 192 230 260 291
(FREQCAL(1),I=1,10)= 5 34 65 102 125 155 192 230 260 291
FREQCAL WA ? YES=1 NO=0 : 1
ENTER ID(A3), DATE(A7), STEP SIZE(11): KJKNENQ781
EIGHT TEST PATTERN - - TYPE 'EF'
LIE TEST PATTERN - - TYPE 'EM' : EM
EIGHT ADAPT PATTERN - - TYPE 'EF'
LIE ADAPT PATTERN - - TYPE 'EM' : EM
FREQD CONTRAST RANGE SWITCH SETTING (A1) : 4
ADAPTING PATTERN - - TYPE AN 'A'
ELANK SCREEN - - TYPE A 'E' : A
000000 - SET ADAPTING PATTERN SIGNAL GENERATOR
FREQD ADAPTING PATTERN FREQUENCY (A1) : 6

Fig. 31. Example of Interoperative Computer Program Printout
During Experiment Data Input (page 1 Of 2)


```

DATA CHECK
SUBJECT : NJK
DATE : 15NOV78
STEP SIZE : 1
ADAPTING PATTERN LUMINANCE : DN
ADAPTING FREQUENCY : 6
TEST PATTERN LUMINANCE : DN
CONTRAST RANGE SWITCH POS. : 4
DATA CHECK OK? YES=1 NO=0 : 1

5200 610700

*****
* MAIN RUN
*****

220700 1=GO ?=STOP : ?
001700 005200 999000 000300 ROUTE PLOT, PUNCH, & PRINT FILES TO AFIT

STOP
2.689 CP SECONDS EXECUTION TIME
COMMAND- ROUTE,PLOT,DC=PT,TID=EE,FID=VIS,ST=CSE
COMMAND- ROUTE,PUNCH,DC=PU,TID=EE,FID=VIS,ST=CSE
COMMAND- ROUTE,PPINT,DC=PP,TID=EE,LFID=VIS,ST=CSE

```

Fig. 31. Example of Interoperative Computer Program Printout
During Experiment Data Input (page 2 of 2)

Appendix C

Contrast Calibration Data

Contrast calibration was accomplished after completion of the brightness control modification described in Section II. The maximum and minimum luminance levels of the sinusoidal gratings were measured using a Pritchard photometer, model 1980A-CD with a 1980A-PL optical head.

The line voltage to the Sony television was set to 110.0 ± 0.5 volts ac. The controls on the television were positioned in accordance with the instructions given by Quill (Ref 13: 22-25, 75-77). The pattern generator contrast level switch was set to position 2 during calibration.

Photometer measurements were made for various spatial frequencies with the dual brightness control set to bright (35.5 ft-lamberts) using DAC drive voltages from column 4 of Quill's calibration tables as the multiplex controller input. In each case a high and a low contrast drive voltage was input and the corresponding contrast was calculated using Michelson's formula (see page 3). The contrast levels did not vary from those determined by Quill by more than the calibration limits of the photometer. As a result, the contrast calibration tables developed by Quill were used for this investigation.

Contrast measurements with the dual brightness control

in the dim position (3.65 ft-lamberts) indicated that the contrast level for dim differed from the contrast level for bright by a constant ratio for each spatial frequency. The constant DELTA was added to the contrast in the computational section of the computer program to account for the contrast change when a dim luminance sine wave was selected. DELTA is defined as the ratio of the average contrast at the dim luminance level to the average contrast at the high luminance level.

Appendix D

Spatial Frequency Calibration Data

The results of this investigation were directly dependent upon the ability to accurately produce adapting and test sinusoidal gratings at specific spatial frequencies. The adapting and test spatial frequencies were produced by two Wavetek voltage controlled oscillators (VCO) operated as standard signal generators. The VCO outputs have a tendency to drift with changes in ambient temperature. The drift in the VCO output is greater than the tolerance of the raster-synch generator. (The Sony horizontal synch circuits are much more tolerant). Because of this instability, the specific frequency desired must be locked up and verified before each run.

The procedures for setting and locking up the adapting spatial frequency in the VCO are detailed in Appendix A, Equipment Operating Procedures. A change in the spatial frequency of the adapting pattern of even a part of one degree changes the nature and location of the frequency specific adaptation depression. This significantly degrades the investigator's capability to interpret the effects of the adaptation on the MTF regardless of how well he has defined and calibrated the test spatial frequencies.

Test Spatial Frequencies

The procedures for obtaining frequency lock-up at each spatial frequency and for fine tuning the test pattern VCO to the center of the lock-up range are included in detail in Appendix A, Equipment Operating Procedures. The susceptibility of the equipment to temperature variations require that the mid-range frequency of the voltage lock-up range corresponding to each spatial frequency be determined before each experiment and entered as data in the computer program FREQCAL array. The spatial frequencies of interest and their corresponding range of VCO inputs are listed in Table III.

Table III

Spatial Frequency Calibration Data		
Spatial Frequency (cycles/degree)	Multiplex Controller Output (volts)	Teletype Input FREQCAL
2	.037 - .040	005
3	.310 - .350	032 - 035
4	.62 - .66	065 - 068
5	1.01 - 1.03	102 - 105
6	1.23 - 1.26	126 - 128
7	1.62 - 1.67	165 - 167
8	1.95 - 1.98	196 - 198
9	2.26 - 2.28	227 - 229
10	2.57 - 2.60	257 - 260
11	2.88 - 2.91	289 - 291

Appendix E

Equipment Configuration

This thesis was accomplished using equipment designed, built, modified, and remodified by previous AFIT thesis students. This appendix is included as a guide for subsequent investigators. Table IV is a guide to source information on the equipment. Fig. 32 is a schematic illustrating how the equipment is interconnected and where the pattern signals are generated and sampled.

Table IV

Equipment Configuration

Nomenclature	Design Description	Description of Modification	Description of Latest Configuration	Schematic
Multiplex Controller	R. E. Nystrom Thesis		C. G. Smith Pg 11	Nystrom Figs. A-3 thru A-24
Hand Held Response Box	R. E. Nystrom Thesis	J. E. Quill Thesis	J. E. Quill Appendix 13	Quill Fig. B-1
Pattern Generator	H. L. Hannikel Thesis	J. T. Sakai C. P. Scheidegg	C. P. Scheidegg Pg 6-12	Scheidegg Fig. 6
Dual Brightness Control	Scheidegg, et al Lab project	C. G. Smith	C. G. Smith Pg 11	Smith Fig. 3
Rotator	J. Carl H. L. Hannikel		H. L. Hannikel Pg 10-29	Hannikel Fig. 2-3
Status Box	J. E. Quill		J. E. Quill Appendix C	Quill Fig. C-1

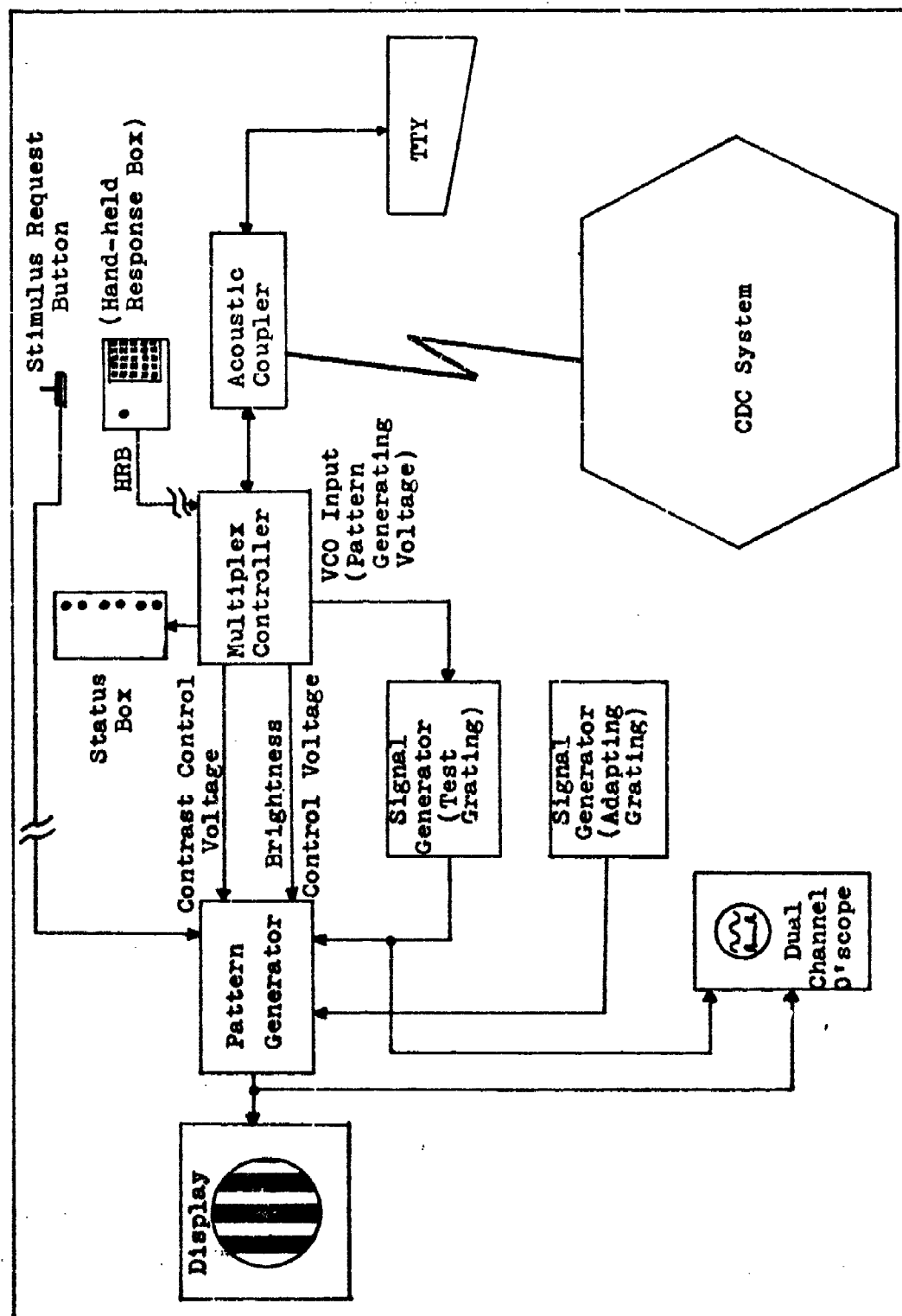


Fig. 32 Diagram Showing Equipment Interconnection

Appendix F

Supporting Data

This appendix provides a listing of the data results from which the graphs appearing in the Results Section were derived. Table V provides this data.

Also listed in this appendix is the supporting data and individual graphs from which the average MTF curves shown in Figs. 12, 15, 20, 21, 24, and 27 were developed. The remainder of the graphs and data collected during this investigation are listed in Table VI and shown in Figs. 33-49.

Table V

Contrast Sensitivity Data for Graphs Appearing in Results Section

A: Spatial Frequency in CPD
 B: Contrast Sensitivity
 C: High Contrast Response
 D: Low Contrast Response

Data for Fig. 8. CGS, Test Bright, Adapt Dim, 0 CPD

A	2	3	4	5	6	7	8	9	10	11
B:	192.1	256.2	287.4	256.2	228.3	241.8	203.5	246.5	181.4	195.8
C:	205.5	347.1	289.0	257.6	229.5	258.8	204.6	263.8	182.4	209.5
D:	179.5	189.1	285.9	254.8	227.1	226.0	202.4	230.4	180.4	183.0

Data for Fig. 9. CGS, Test Dim, Adapt Dim, 0 CPD

A	2	3	4	5	6	7	8	9	10	11
B:	15.1	22.6	18.2	18.6	17.4	18.4	13.2	15.4	14.2	10.9
C:	15.2	24.1	19.5	24.1	18.3	19.4	14.7	21.3	15.2	12.2
D:	15.0	21.1	17.1	14.3	16.5	17.5	11.8	11.2	13.3	9.7

Data for Fig. 10. CGS, Test Bright, Adapt Dim, 0 CPD

A	2	3	4	5	6	7	8	9	10	11
B:	10.8	29.6	51.1	105.4	176.2	93.5	76.5	60.7	54.1	40.6
C:	11.6	31.2	59.7	133.5	210.2	126.4	81.8	65.0	57.9	49.2
D:	10.1	28.1	43.8	83.2	147.7	69.3	71.5	56.8	50.6	33.5

Data for Fig. 11. CGS, Test Bright, Adapt Bright, 6CPD

A	2	3	4	5	6	7	8	9	10	11
B:	65.9	90.9	57.4	51.1	33.2	46.9	51.1	68.2	108.0	84.2
C:	90.9	103.5	63.3	51.4	39.6	49.4	56.4	72.9	115.6	111.2
D:	47.7	79.8	52.0	50.8	27.8	44.5	46.3	63.7	101.0	63.7

Table V (continued)

Data for Fig. 12. CGS, Test Bright, Adapt Dim, (Average) 6 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	33.7	43.7	38.7	27.7	36.0	48.9	49.7	68.1	73.5	107.5
C:	39.4	49.0	45.7	57.1	87.7	58.0	55.1	169.7	79.3	171.5
D:	28.3	38.9	33.2	18.6	23.8	41.7	45.0	38.7	68.6	73.2

Data for Fig. 13. CGS, Test Bright, Adapt Bright, 4 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	42.2	35.5	30.5	37.4	59.6	70.1	61.5	74.3	77.4	85.8
C:	45.2	46.0	32.6	53.6	67.8	73.9	71.7	78.3	82.3	91.8
D:	39.4	27.4	28.5	26.1	52.4	66.6	52.6	70.6	72.8	80.2

Data for Fig. 14. CGS, Test Dim, Adapt Dim, 4 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	9.5	14.1	8.0	19.3	15.0	24.8	30.6	19.5	28.6	21.3
C:	10.0	17.3	8.4	20.5	30.0	26.2	47.2	32.4	37.1	23.9
D:	9.0	11.5	7.6	18.1	7.5	23.3	19.9	11.7	22.1	19.1

Data for Fig. 15. CGS, Test Bright, Adapt Dim, (Average) 4 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	17.9	27.8	39.4	38.3	43.7	50.0	58.7	69.7	70.6	82.6
C:	21.6	34.9	48.2	46.4	70.6	51.9	74.6	74.3	90.6	89.7
D:	13.7	22.4	33.3	32.6	28.0	48.0	47.7	65.4	55.2	76.1

Table V (continued)

Data for Fig. 16. CGS, Test Bright, Adapt Bright, 8 CPD

	2	3	4	5	6	7	8	9	10	11
A:	102.0	114.4	64.3	33.8	47.8	49.7	41.8	48.2	60.7	74.3
B:	116.1	126.3	71.0	39.4	78.4	52.3	44.0	51.3	65.0	78.3
C:	89.6	103.7	58.3	28.9	29.2	47.1	39.7	45.4	56.8	70.6

Data for Fig. 17. CGS, Test Bright, Adapt Dim, 8 CPD

	2	3	4	5	6	7	8	9	10	11
A:	34.6	52.6	53.5	30.5	33.8	19.6	40.6	51.1	54.1	66.2
B:	36.7	55.4	62.5	32.0	39.4	21.0	46.2	56.4	57.9	69.8
C:	32.5	50.0	45.9	28.3	28.9	18.3	35.7	46.3	50.6	62.9

Data for Fig. 18. CGS, Test Dim, Adapt Bright, 6 CPD

	2	3	4	5	6	7	8	9	10	11
A:	67.2	116.1	77.6	26.0	14.1	13.0	15.0	15.0	16.4	7.0
B:	70.8	140.7	83.0	26.1	15.0	22.9	15.8	15.8	16.5	19.2
C:	63.8	95.8	72.5	25.8	13.1	7.4	14.3	14.3	16.3	2.6

Data for Fig. 19. MJK, Test Bright, Adapt Dim, 0 CPD

	2	3	4	5	6	7	8	9	10	11
A:	20.4	54.1	62.5	88.3	84.8	93.5	74.3	121.2	100.3	70.1
B:	27.1	77.6	74.4	105.3	90.2	126.4	101.5	149.6	141.3	73.9
C:	15.3	37.8	52.4	74.1	79.8	69.3	54.4	98.2	71.2	66.6

Table V (continued)

Data for Fig. 20. MJK, Test Bright, Adapt Dim, (Average) 6 CPD

	2	3	4	5	6	7	8	9	10	11
A:	25.9	44.6	33.0	30.9	36.7	58.7	121.0	89.3	75.1	86.1
B:	37.7	61.5	60.5	40.2	43.9	63.6	324.7	135.2	96.8	105.1
D:	18.6	32.9	19.1	23.8	30.8	54.2	64.5	57.0	58.3	71.1

Data for Fig. 21. MJK, Test Bright, Adapt Dim, (Average) 4 CPD

	2	3	4	5	6	7	8	9	10	11
A:	39.9	21.6	73.8	116.0	255.4	189.9	162.4	152.3	100.3	149.6
B:	54.7	29.8	88.1	156.2	356.3	285.7	267.1	176.4	117.2	296.1
D:	29.7	16.2	62.3	86.2	183.1	133.6	101.6	131.6	88.6	59.2

Data for Fig. 22. MJK, Test Bright, Adapt Dim, 8 CPD

	2	3	4	5	6	7	8	9	10	11
A:	25.0	33.0	35.5	39.1	55.2	44.3	46.9	39.8	66.9	93.5
B:	28.7	45.6	46.0	41.8	62.9	67.7	49.4	44.5	150.9	207.8
D:	21.8	23.9	27.4	36.5	48.5	28.9	44.5	35.6	29.6	42.1

Data for Fig. 23. CGS, Test Bright, Adapt Dim, 6 CPD Blue

	2	3	4	5	6	7	8	9	10	11
A:	27.9	36.2	24.9	13.6	17.1	18.7	22.0	22.8	24.2	20.3
B:	29.4	36.4	26.2	14.6	21.2	19.7	23.5	33.3	25.9	20.5
D:	26.5	36.0	23.6	12.7	13.9	17.7	20.5	15.6	22.6	20.2

Table V (continued)

Data for Fig. 24. CCS, Test Bright, Adapt Dim, 6 CPD (Average Red)

	2	3	4	5	6	7	8	9	10	11
A:	20.3	24.7	25.1	19.4	40.9	69.9	51.3	55.3	69.6	70.2
B:	22.6	25.6	26.4	23.3	58.4	76.4	54.9	73.1	72.1	86.4
C:	18.2	22.3	23.8	16.3	39.1	64.8	47.9	42.7	67.2	57.4

Data for Fig. 25. CCS, Test Bright, Adapt Dim, 6 CPD White

	2	3	4	5	6	7	8	9	10	11
A:	24.9	30.1	37.2	25.6	44.5	64.3	70.2	90.9	88.8	90.9
B:	26.2	32.0	39.2	25.8	51.0	75.1	73.9	91.4	101.8	100.3
C:	23.6	28.3	35.4	25.5	38.9	55.1	66.6	90.4	77.5	82.4

Data for Fig. 26. CCS, Test Bright, Adapt Dim, 6 CPD White, (Right eye closed)

	2	3	4	5	6	7	8	9	10	11
A:	37.2	45.6	30.1	22.8	41.3	59.0	54.1	63.3	83.4	93.0
B:	39.2	51.9	35.1	26.6	58.2	70.4	57.9	89.2	99.5	106.6
C:	35.4	40.0	25.8	19.6	29.3	49.5	50.6	44.9	69.9	81.2

Data for Fig. 27. CCS, Test Bright, Adapt Dim, 6 CPD White, (Average for adapting right eye, testing left eye)

	2	3	4	5	6	7	8	9	10	11
A:	59.3	58.4	43.1	33.8	45.7	61.6	64.3	60.7	68.9	68.5
B:	64.9	82.7	51.8	37.7	48.7	75.2	73.3	75.3	86.9	78.2
C:	54.3	42.7	35.9	30.4	43.0	50.4	56.7	48.9	54.6	60.1

Table V (continued)

Data for Fig. 28. MJK, Test Bright, Adapt Bright, 0 CPD (20 minutes after adapting to 6 CPD grating)

A:	2	3	4	5	6	7	8	9	10	11
B:	90.9	122.6	161.6	171.2	132.7	276.6	268.3	237.3	251.3	248.9
C:	100.3	130.4	178.4	183.2	190.3	314.9	313.1	270.1	326.0	380.7
D:	82.4	115.3	146.5	160.0	92.5	243.0	229.8	208.4	193.7	162.7

Data for Fig. 29. MJK, Test Bright, Adapt Bright, 0 CPD (48 hours after adapting to 6 CPD grating)

A:	2	3	4	5	6	7	8	9	10	11
B:	83.4	136.0	209.4	203.5	195.8	279.3	239.1	250.3	279.3	244.6
C:	87.8	144.6	220.6	231.7	223.0	294.2	279.1	345.6	294.2	285.6
D:	79.1	127.9	198.8	178.7	172.0	265.1	204.8	181.3	265.1	209.6

Table VI

Contrast Sensitivity Data for Supporting Graphs

A: Spatial Frequency in CPD C: High Contrast Response
 B: Contrast Sensitivity D: Low Contrast Response

Data for Fig. 33. CGS, Test Bright, Adapt Bright, 0 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	153.9	209.4	274.5	203.5	128.4	141.3	99.1	89.4	93.5	98.2
C:	184.7	249.8	291.9	224.6	129.1	183.3	104.4	142.7	98.5	126.5
D:	128.1	175.6	258.2	184.4	127.7	109.9	94.1	56.0	88.8	76.1

Data for Fig. 34. CGS, Test Bright, Adapt Bright, 6 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	181.4	155.5	174.5	88.3	74.3	81.0	106.0	102.0	128.4	138.6
C:	182.4	166.4	186.7	93.0	78.3	81.4	136.6	116.1	129.1	148.3
D:	180.4	145.4	163.1	83.8	70.6	80.6	82.2	89.6	127.7	129.6

Data for Fig. 35. CGS, Test Dim, Adapt Dim, 6 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	29.2	41.2	61.6	30.3	21.9	45.2	46.2	71.2	71.6	112.8
C:	32.8	60.1	65.9	34.5	26.5	51.7	51.0	96.1	98.8	118.8
D:	26.4	28.2	57.6	26.6	18.0	39.4	41.9	52.7	51.9	107.1

Data for Fig. 36. CGS, Test Bright, Adapt Dim, 6 CPD

A:	2	3	4	5	6	7	8	9	10	11
B:	31.3	37.6	25.1	24.9	29.9	34.1	36.2	49.4	55.2	66.2
C:	37.4	46.1	33.6	26.2	206.3	42.2	36.4	62.6	59.0	89.4
D:	26.3	30.6	19.4	23.6	4.3	27.7	36.0	39.0	51.6	49.0

Table VI (continued)

Data for Fig. 37. CGS, Test Bright, Adapt Dim, 6 CPD

	2	3	4	5	6	7	8	9	10	11
A:	36.2	57.4	64.3	41.8	53.1	75.0	51.1	90.0	52.3	61.9
B:	42.3	63.3	73.3	152.6	68.5	85.4	61.9	166.0	60.0	66.3
C:	31.0	52.0	56.5	11.4	41.2	65.9	42.2	49.8	45.7	57.9

Data for Fig. 38. CGS, Test Bright, Adapt Dim, 6 CPD

	2	3	4	5	6	7	8	9	10	11
A:	49.7	57.4	37.6	18.6	18.8	38.3	55.2	79.5	114.4	223.1
B:	59.3	63.3	40.2	21.2	20.2	52.6	59.0	394.9	115.1	447.3
C:	41.6	52.0	35.2	16.2	17.6	27.9	51.6	16.0	113.8	111.3

Data for Fig. 39. CGS, Test Bright, Adapt Dim, 4 CPD

	2	3	4	5	6	7	8	9	10	11
A:	18.8	26.1	47.7	47.7	36.2	54.1	68.2	77.4	62.5	81.0
B:	21.5	29.2	61.1	61.1	45.5	57.9	72.9	82.3	84.5	89.4
C:	16.5	23.4	37.2	37.2	28.8	50.6	63.7	72.8	46.3	73.4

Data for Fig. 40. CGS, Test Bright, Adapt Dim, 4 CPD

	2	3	4	5	6	7	8	9	10	11
A:	16.9	29.4	31.0	28.8	51.1	45.6	49.2	61.9	78.7	84.2
B:	21.7	40.6	35.3	31.7	95.7	45.8	76.4	66.3	96.6	90.0
C:	10.9	21.3	27.3	26.0	27.3	45.3	31.7	57.9	64.1	78.7

Table VI (continued)

Data for Fig. 41. MJK, Test Dim, Adapt Dim, 6 CPD

	2	3	4	5	6	7	8	9	10	11
A:	40.9	51.2	57.8	34.9	72.2	39.4	53.5	67.4	79.1	77.3
B:	50.2	63.5	65.8	50.0	84.2	52.0	53.8	74.3	92.4	106.8
C:	33.3	41.3	50.7	24.3	61.8	29.8	53.2	61.0	67.8	56.0

Data for Fig. 42. MJK, Test Bright, Adapt Dim, 6 CPD

	2	3	4	5	6	7	8	9	10	11
A:	20.4	49.7	31.5	30.8	37.9	57.4	148.9	82.4	39.4	106.0
B:	38.1	75.5	43.5	39.5	40.3	63.3	188.6	116.0	53.3	120.6
C:	10.9	32.7	22.8	24.1	35.6	52.0	117.6	58.4	29.2	93.1

Data for Fig. 43. MJK, Test Bright, Adapt Dim, 6 CPD

	2	3	4	5	6	7	8	9	10	11
A:	31.3	39.4	34.6	31.0	35.2	60.0	93.0	96.3	110.7	66.2
B:	37.4	47.1	77.5	41.0	47.5	63.9	460.8	154.3	140.2	89.4
C:	26.3	33.1	15.4	23.5	26.0	56.5	11.5	60.1	87.4	49.0

Data for Fig. 44. MJK, Test Bright, Adapt Dim, 4 CPD

	2	3	4	5	6	7	8	9	10	11
A:	31.4	20.4	86.8	65.6	260.4	130.9	114.4	131.4	72.2	102.0
B:	49.9	33.6	111.2	85.1	367.0	265.7	147.5	150.5	105.4	131.5
C:	19.8	12.3	67.7	50.6	184.8	64.5	88.8	114.7	49.4	79.1

Table VI (continued)

Data for Fig. 45. MJK, Test Bright, Adapt Dim, 4 CPD

	2	3	4	5	6	7	8	9	10	11
A:	48.2	22.8	60.7	166.4	250.4	248.9	210.3	173.2	128.4	197.2
B:	59.6	26.0	65.0	227.2	345.6	305.6	386.8	202.2	129.1	460.8
C:	39.1	20.0	56.8	121.8	181.3	202.7	114.3	148.4	127.7	39.3

Data for Fig. 46. CGS, Test Bright, Adapt Dim, 6 CPD Red

	2	3	4	5	6	7	8	9	10	11
A:	23.9	31.3	27.9	21.6	28.7	52.3	55.2	52.1	66.9	57.4
B:	25.4	33.0	29.4	23.1	28.9	59.9	59.1	58.2	71.5	77.7
C:	22.5	29.7	26.5	20.1	28.6	45.7	51.6	46.6	62.5	42.3

Data for Fig. 47. CGS, Test Bright, Adapt Dim, 6 CPD Red

	2	3	4	5	6	7	8	9	10	11
A:	16.6	18.1	22.2	17.1	53.1	87.5	47.3	58.5	72.2	82.9
B:	19.8	18.2	23.4	23.5	56.8	93.6	50.6	88.0	72.6	95.0
C:	13.9	18.0	21.1	12.5	49.6	81.8	44.2	38.8	71.8	72.4

Data for Fig. 48. CGS, Test Bright, Adapt Dim, 6 CPD White (Adapt right eye, test left eye)

	2	3	4	5	6	7	8	9	10	11
A:	52.3	56.0	44.7	33.8	37.2	45.8	52.0	60.1	69.5	53.5
B:	59.9	64.2	49.9	39.4	39.2	51.2	64.7	76.9	89.6	56.9
C:	45.7	48.9	40.0	28.9	35.4	40.4	41.8	46.9	53.9	50.3

Table VI (continued)

Data for Fig. 49. CGS, Test Bright, Adapt Dim, 6 CPD White (Adapt right eye, test left eye)

A:	2	3	4	5	6	7	8	9	10	11
B:	66.2	60.7	41.4	33.8	54.1	77.4	76.5	61.3	68.2	83.4
C:	69.8	101.1	53.7	35.9	57.9	99.1	81.8	73.6	84.1	99.5
D:	62.9	36.5	31.9	31.8	50.6	60.4	71.5	51.0	55.2	69.9

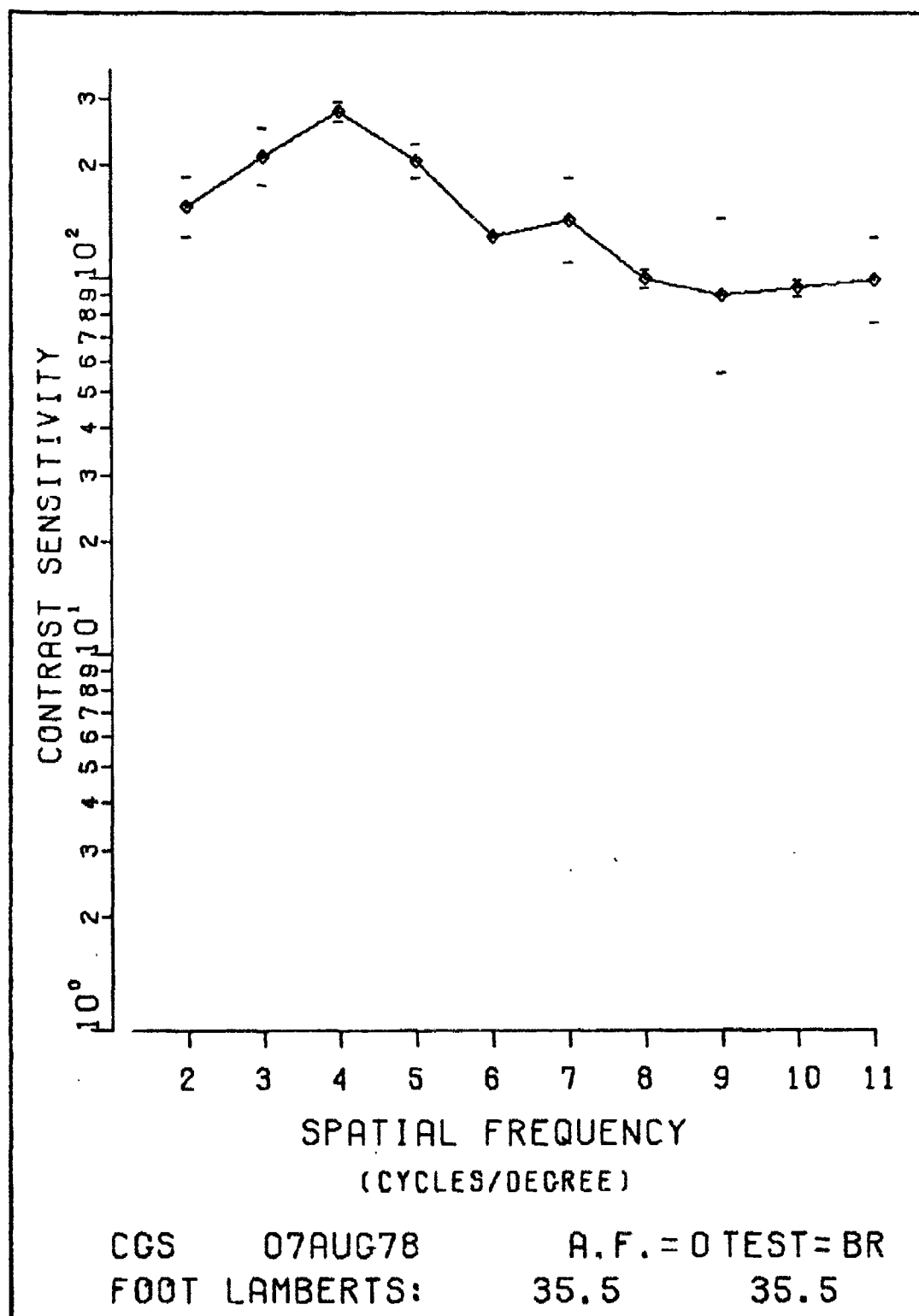


Fig. 33. CGS, Test Bright, Adapt Bright, 0 CPD

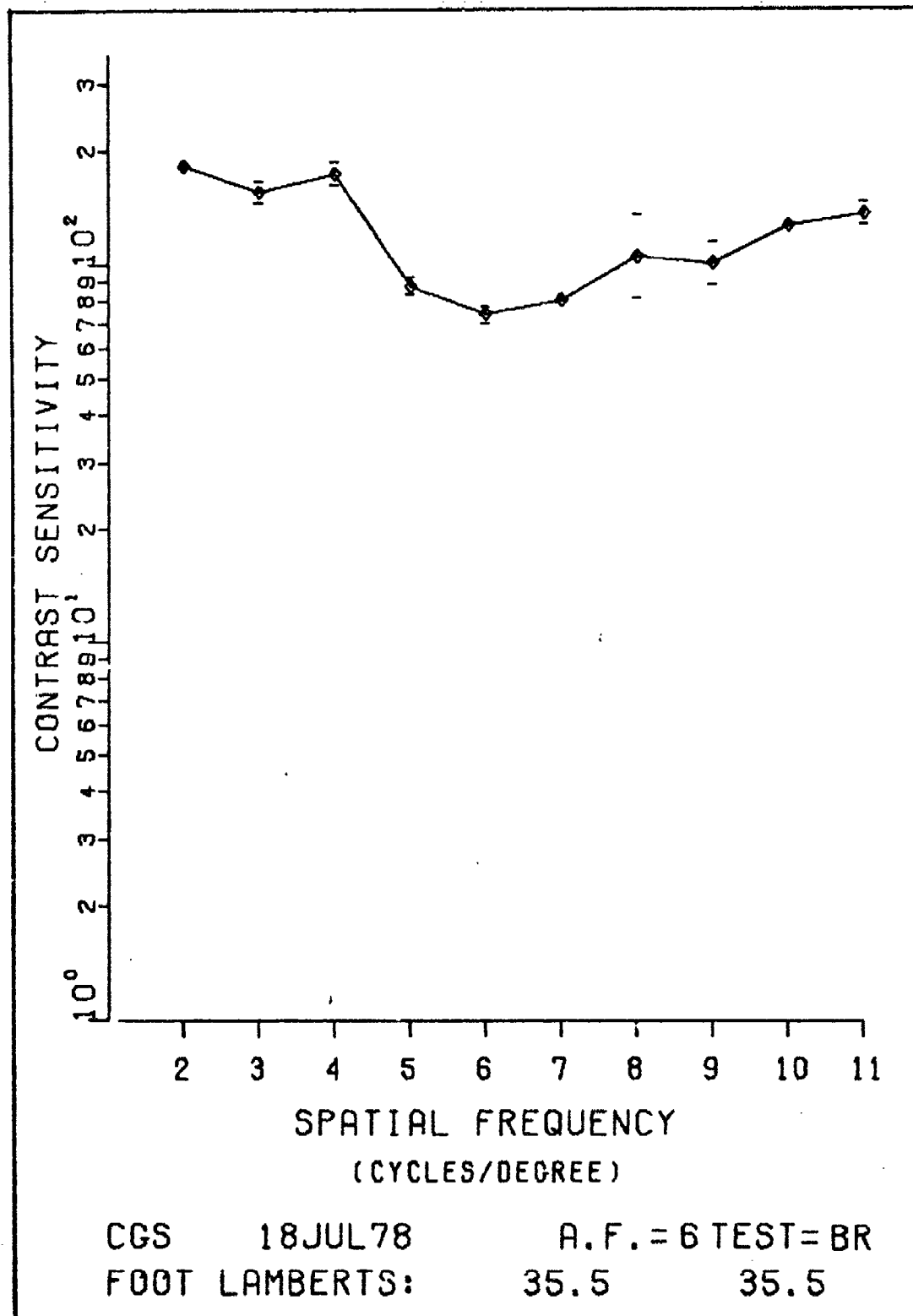


Fig. 34. CGS, Test Bright, Adapt Bright, 6 CPD

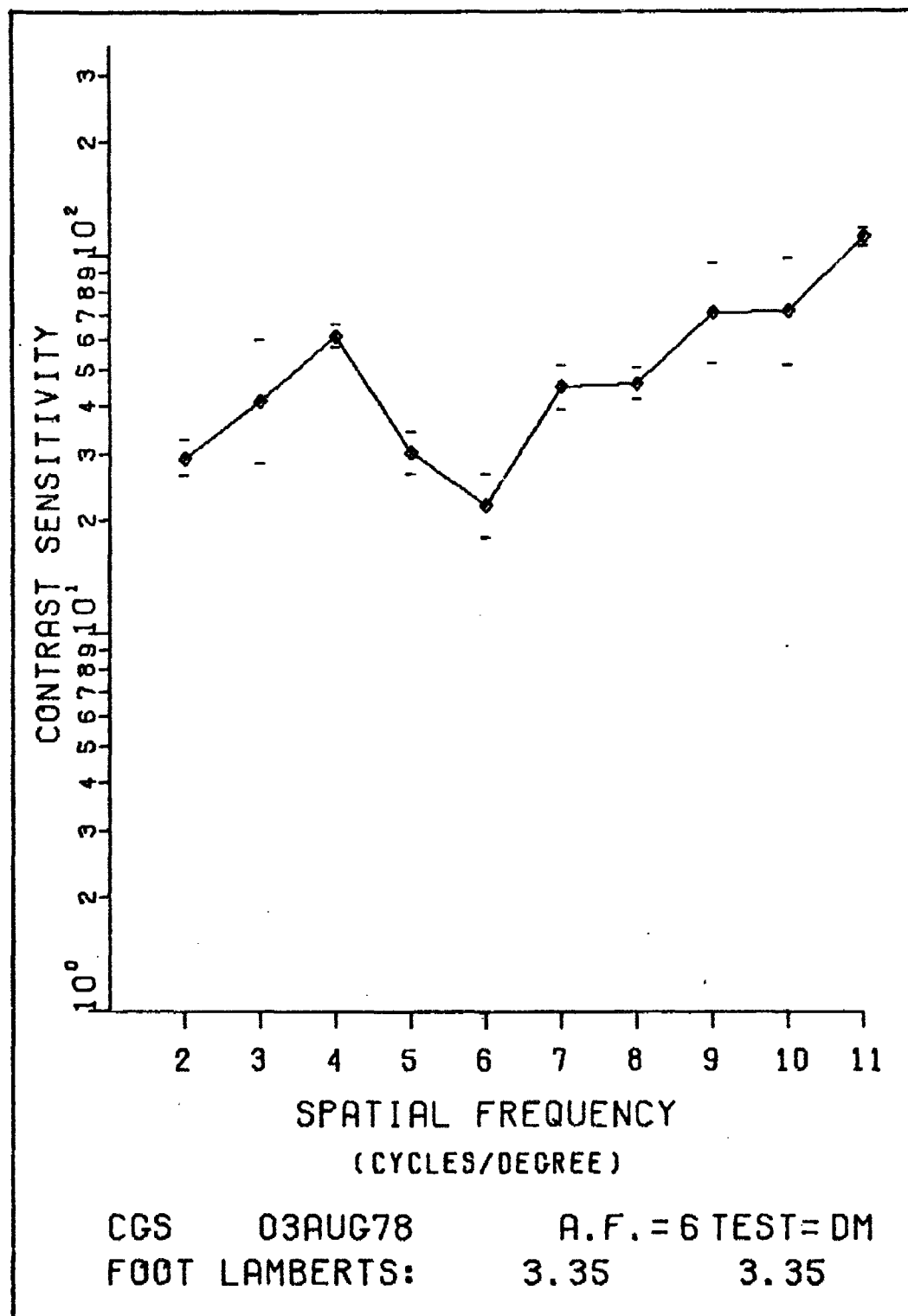


Fig. 35. CGS, Test Dim, Adapt Dim, 6 CPD

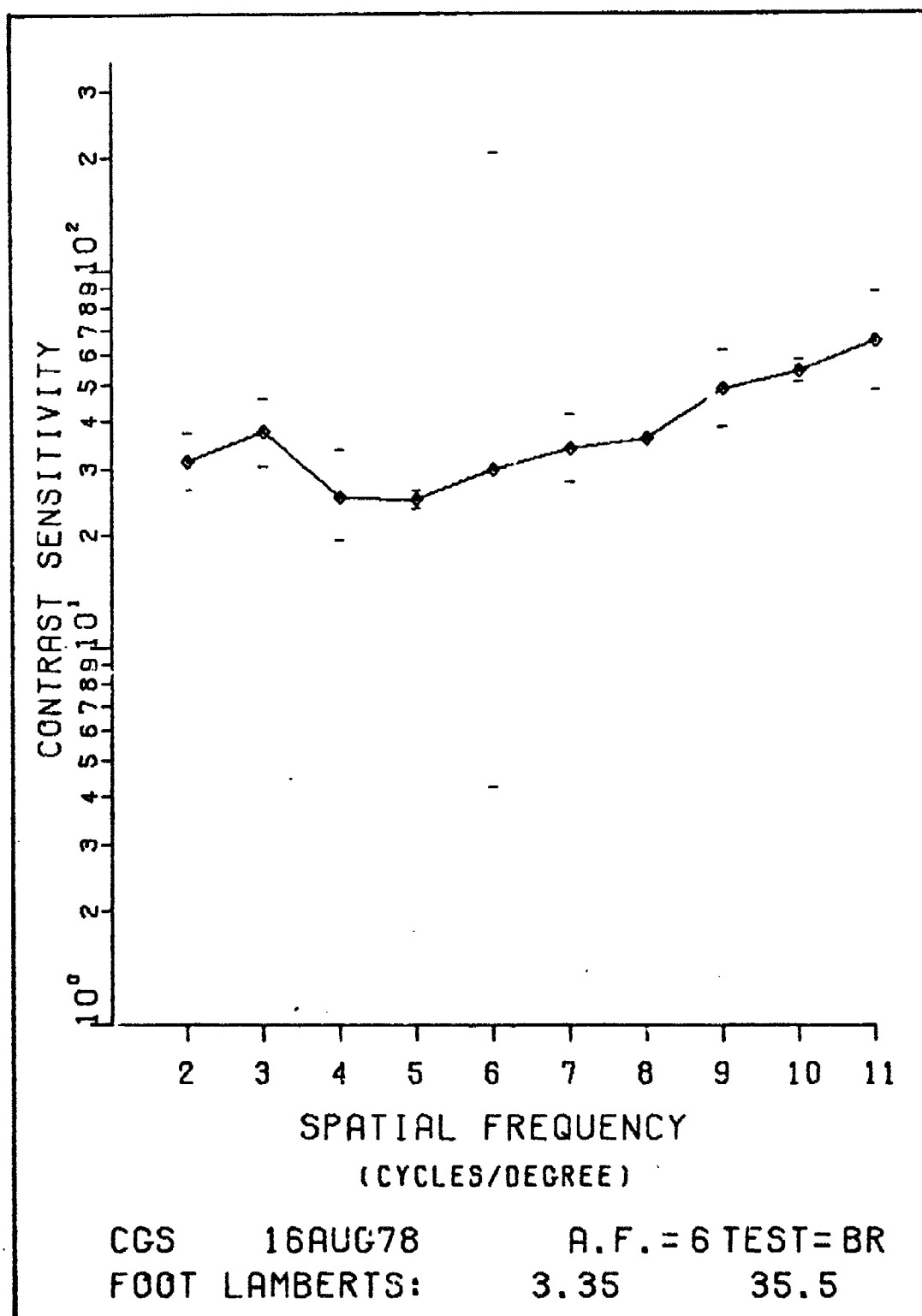


Fig. 36. CGS, Test Bright, Adapt Dim, 6 CPD

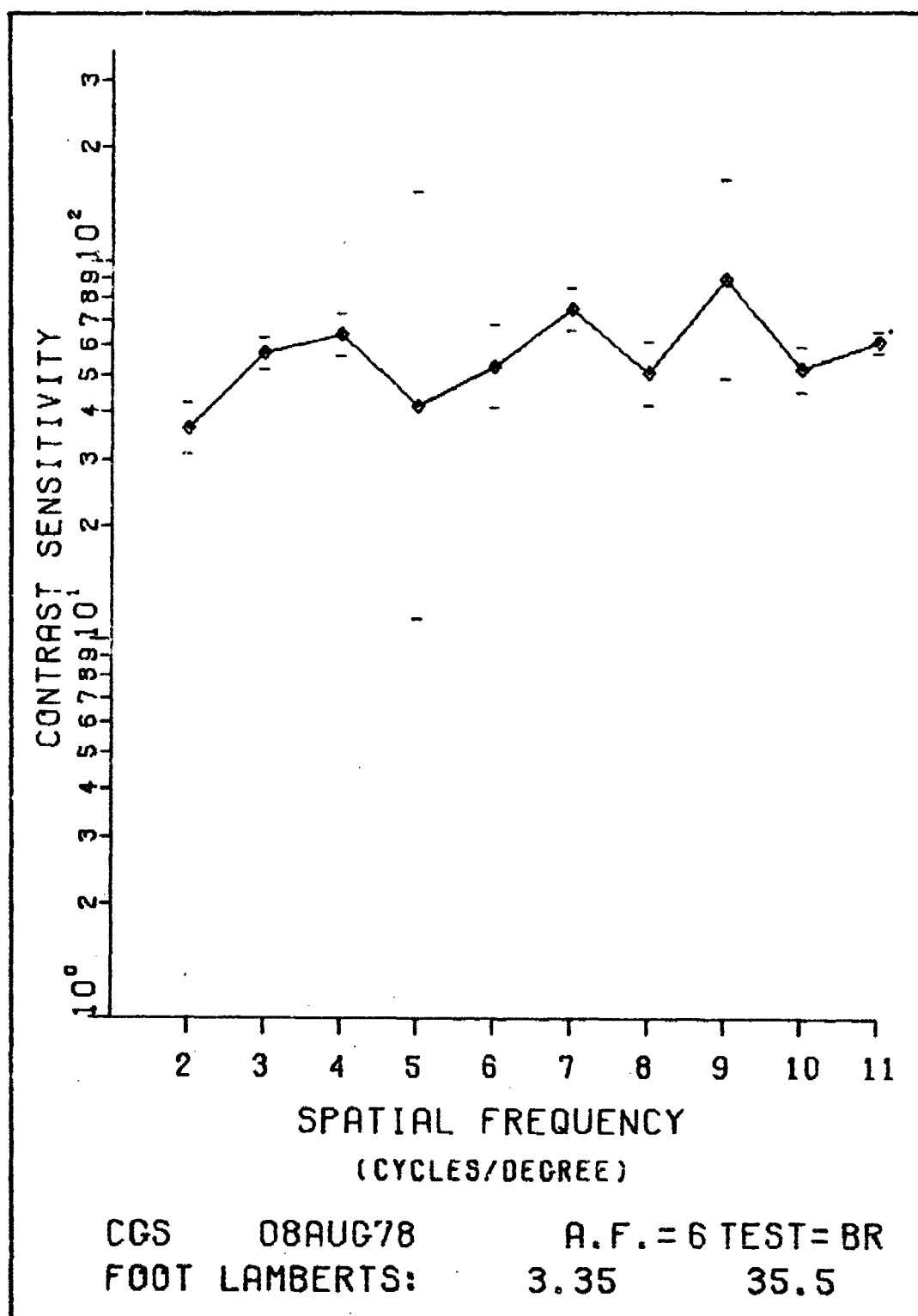


Fig. 37. CGS, Test Bright, Adapt Dim, 6 CPD

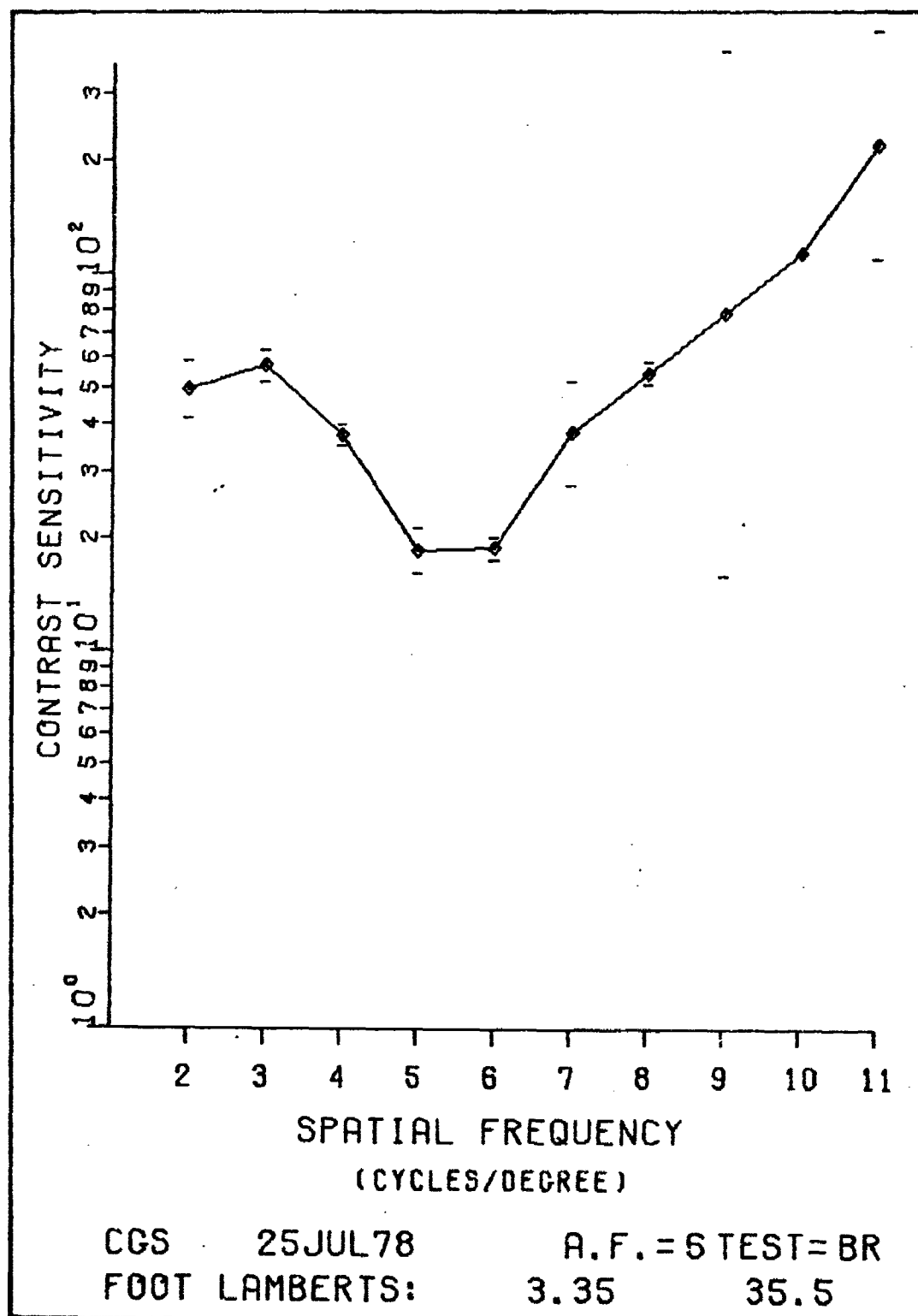


Fig. 38. CGS, Test Bright, Adapt Dim, 6 CPD

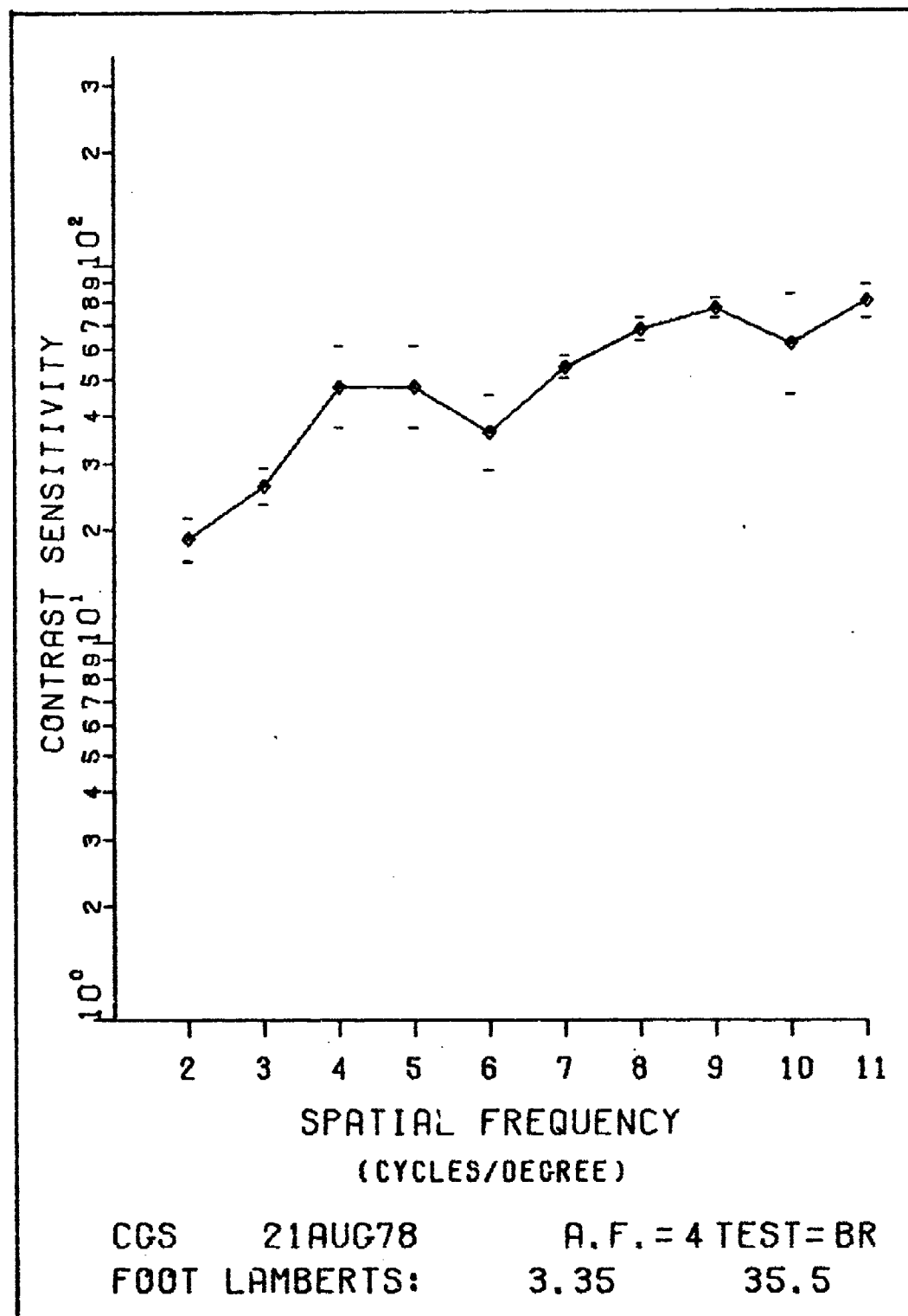


Fig. 39. CGS, Test Bright, Adapt Dim, 4 CPD

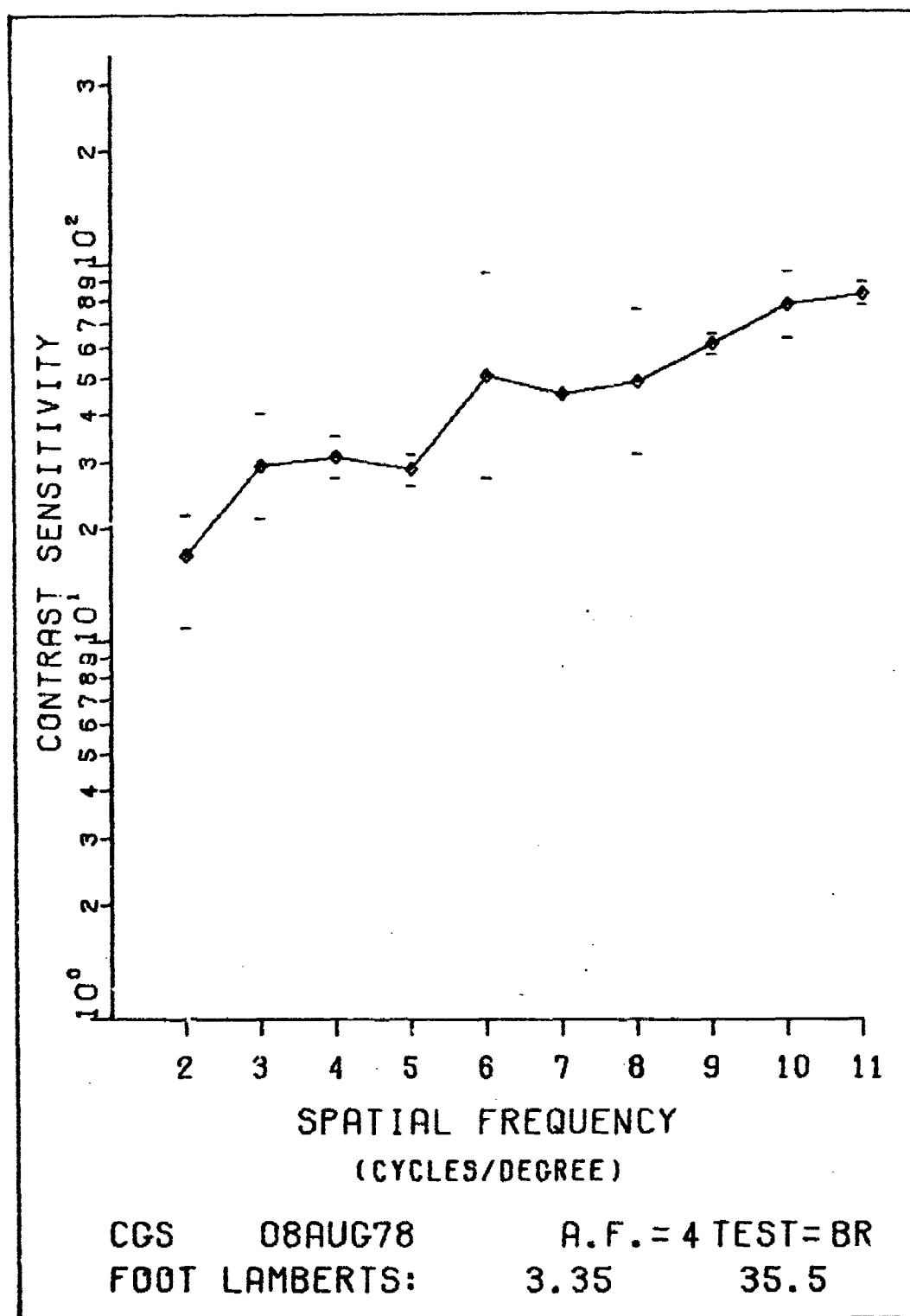


Fig. 40. CGS, Test Bright, Adapt Dim, 4 CPD

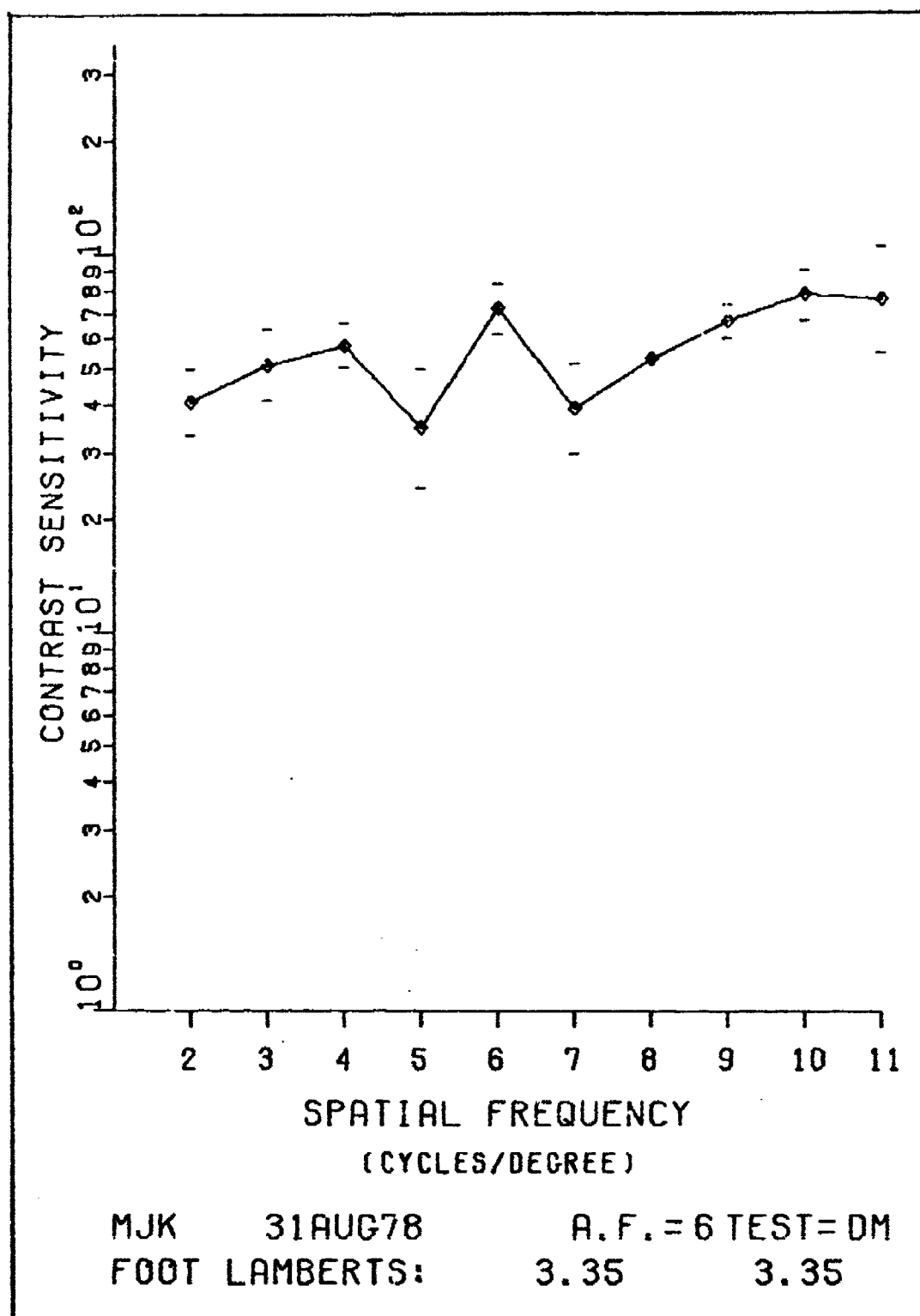


Fig. 41. MJK, Test Dim, Adapt Dim, 6 CPD

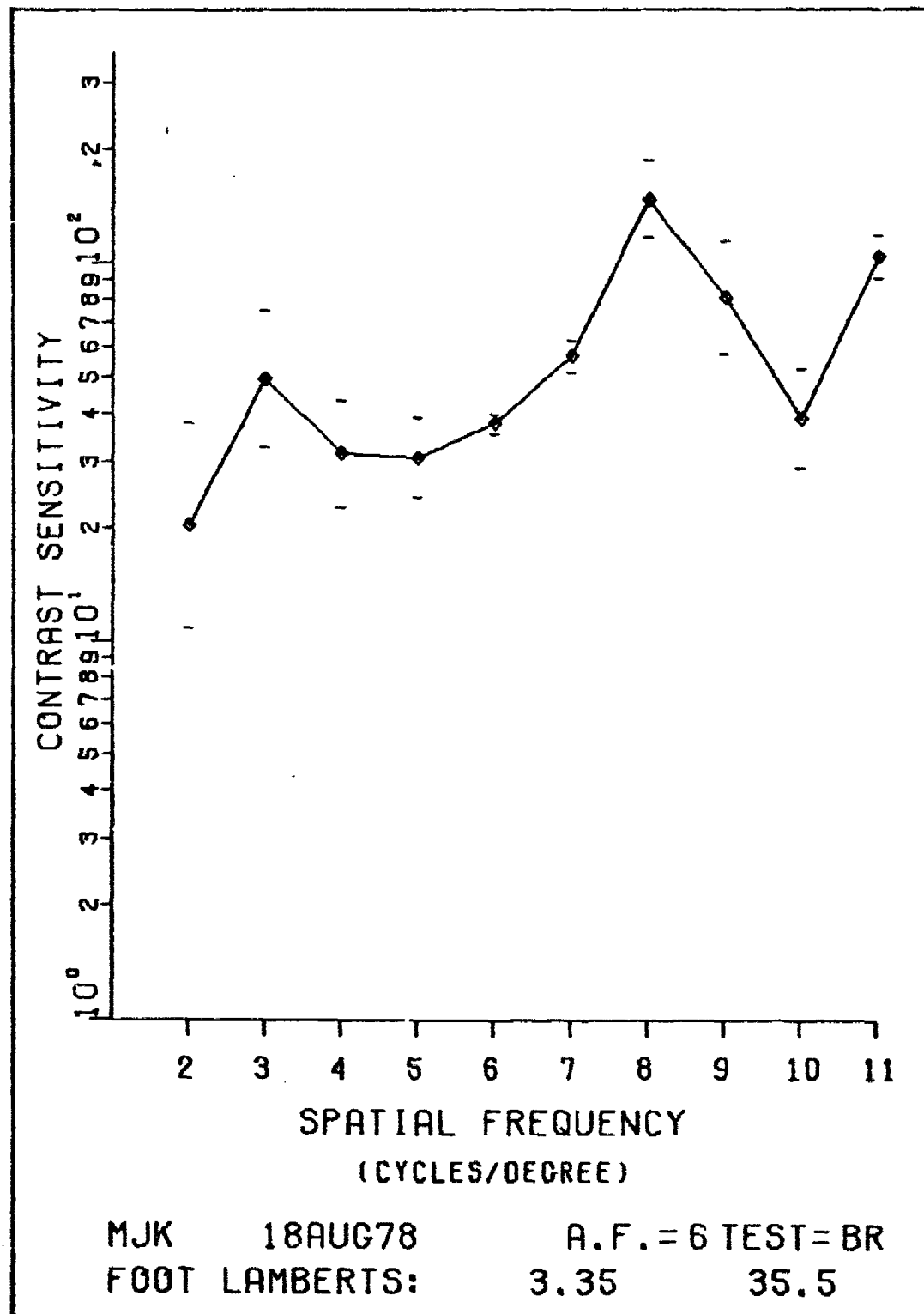


Fig. 42. MJK, Test Bright, Adapt Dim, 6 CPD

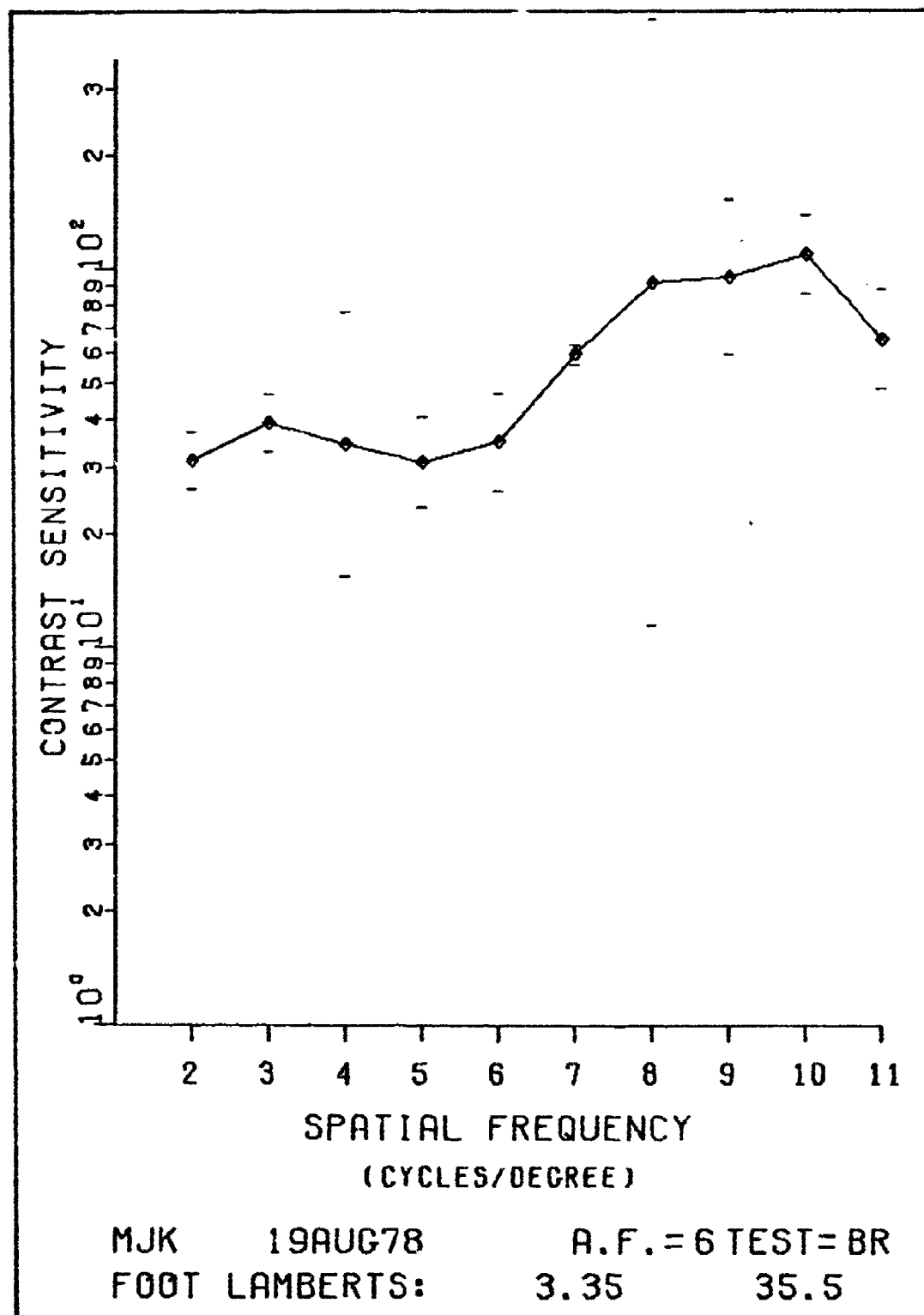


Fig. 43. MJK, Test Bright, Adapt Dim, 6 CPD

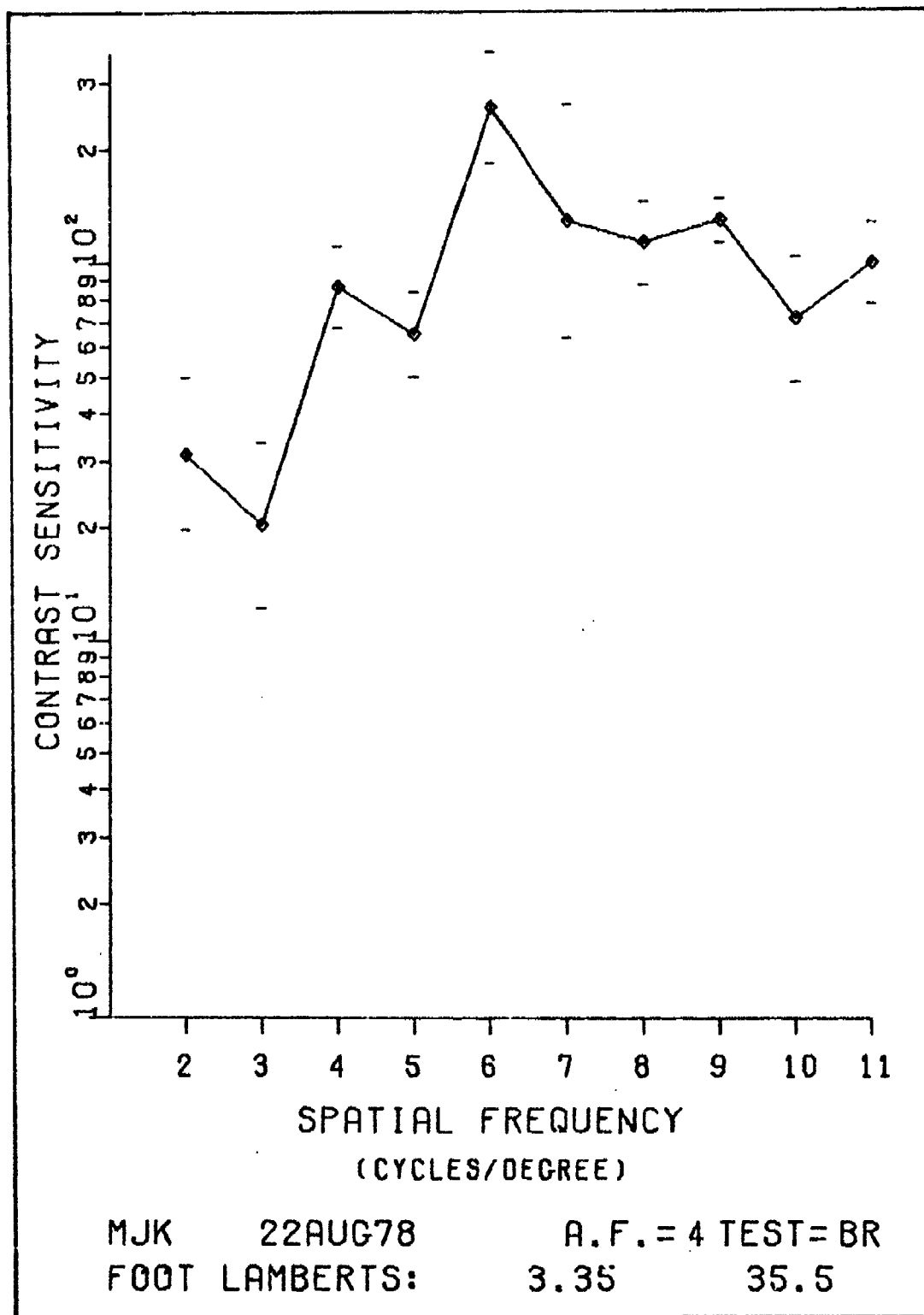


Fig. 44. MJK, Test Bright, Adapt Dim, 4 CPD

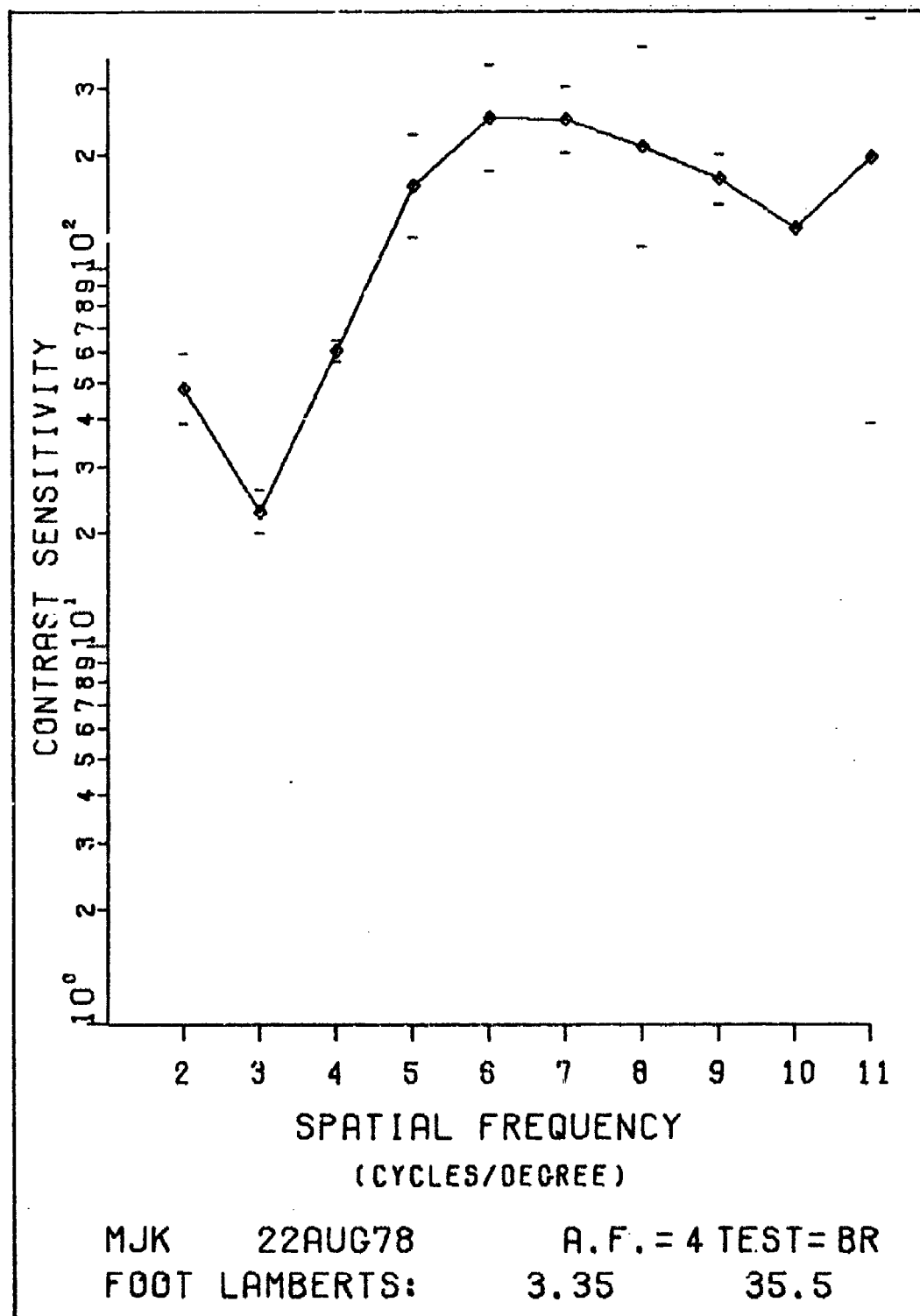


Fig. 45. MJK, Test Bright, Adapt Dim, 4 CPD

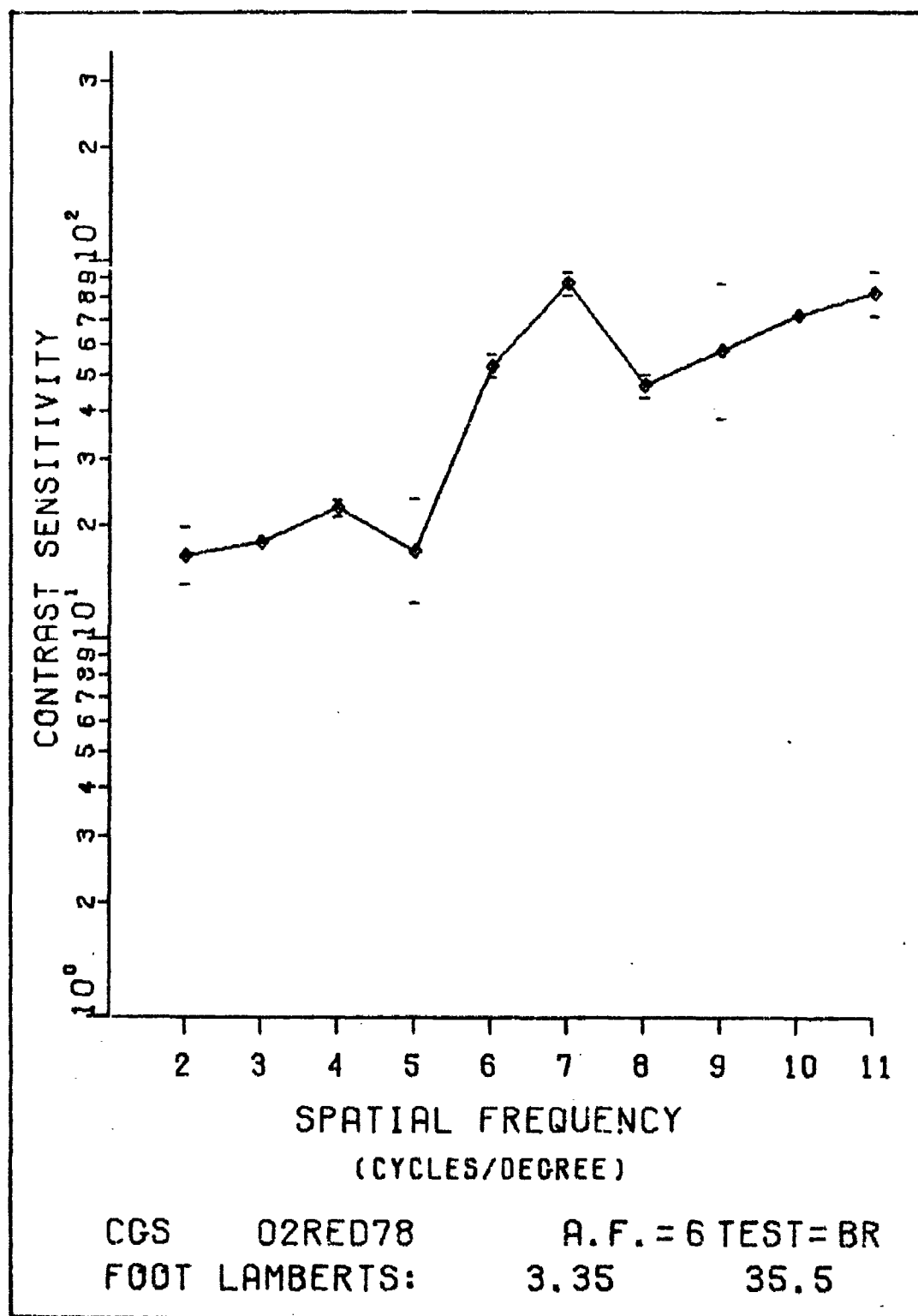


Fig. 46. CGS, Test Bright, Adapt Dim, 6 CPD (Red)

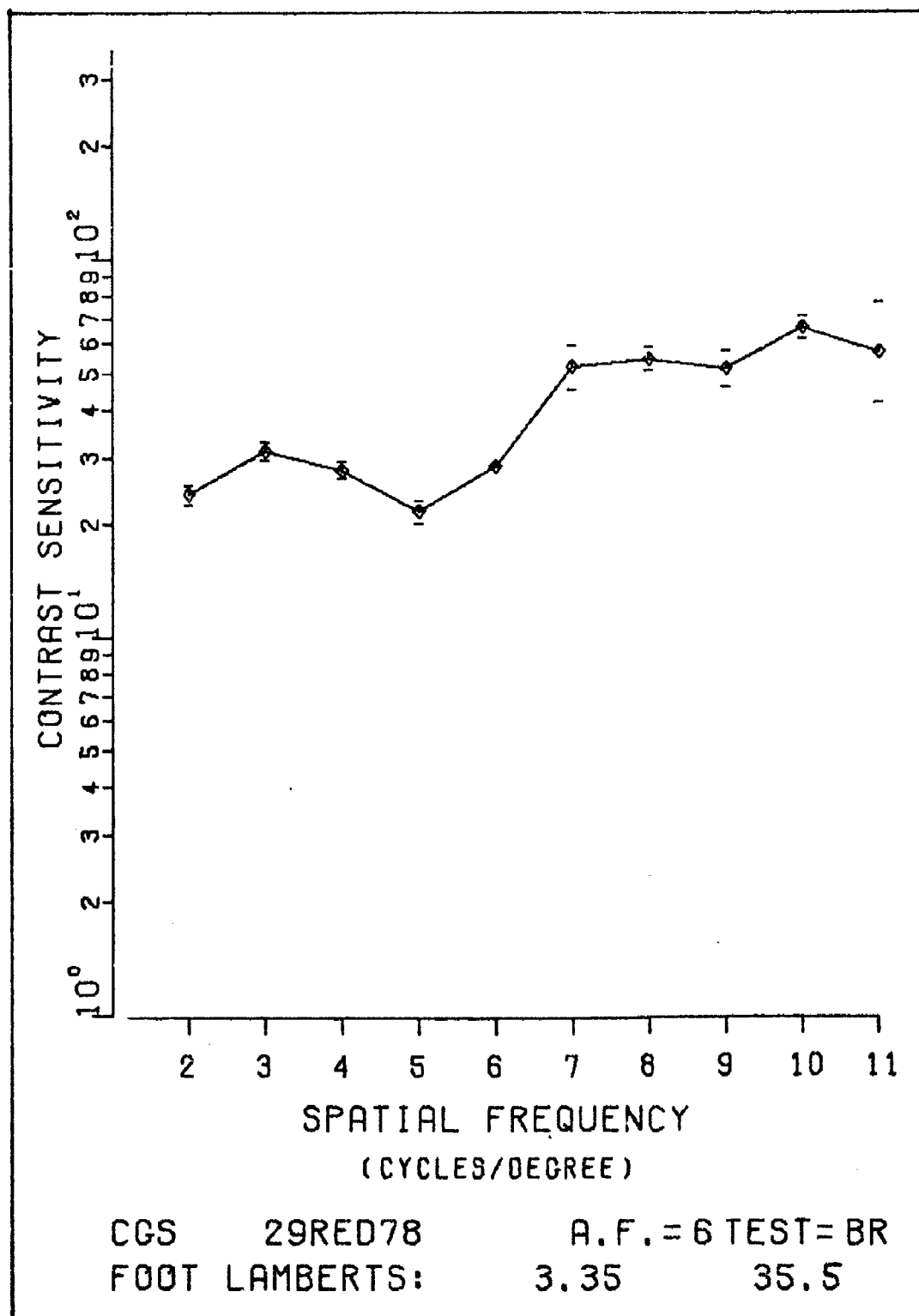


Fig. 47. CGS, Test Bright, Adapt Dim, 6 CPD (Red)

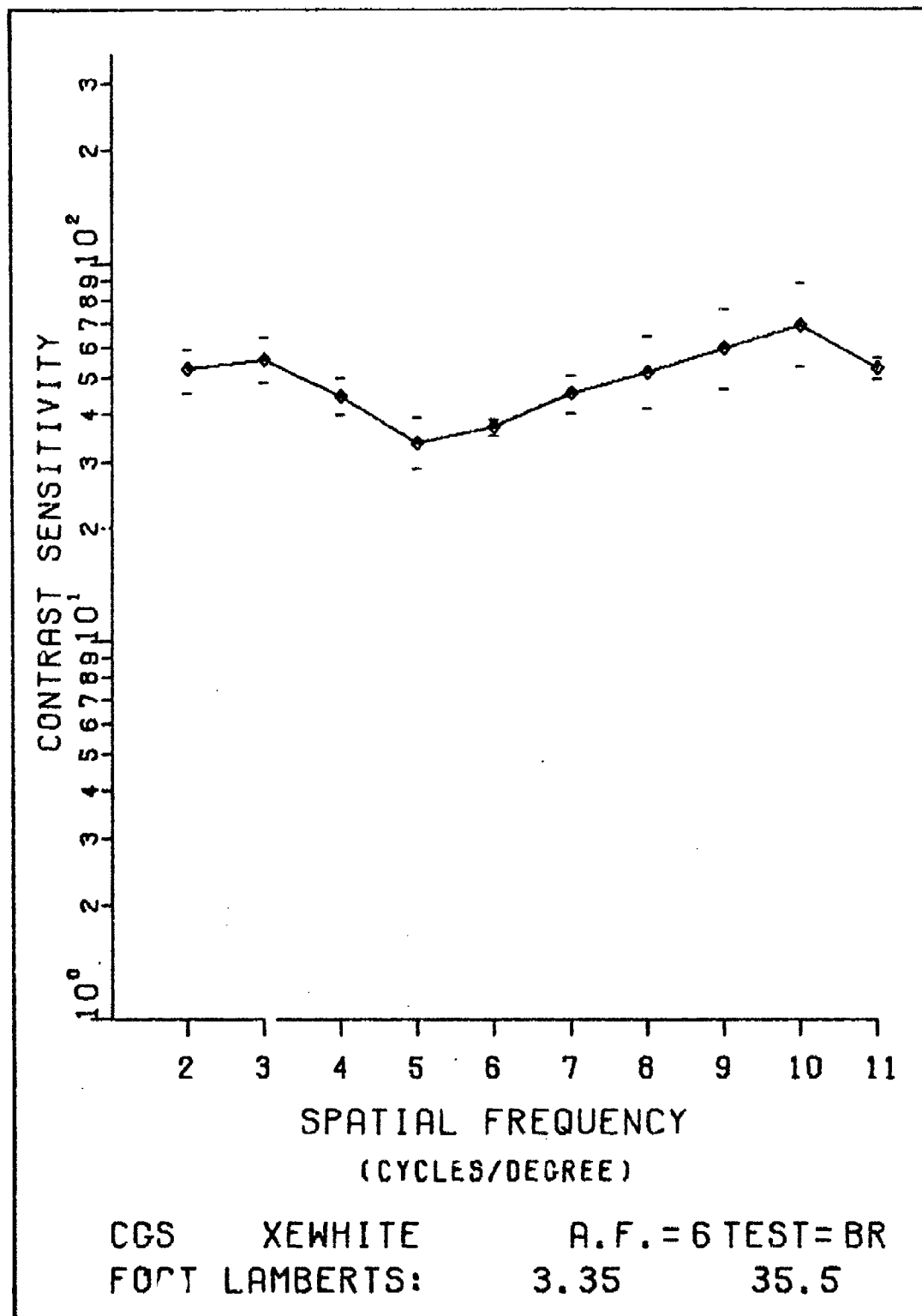


Fig. 48. CGS, Test Bright, Adapt Dim, 6 CPD (White, Adapt Right Eye, Test Left Eye)

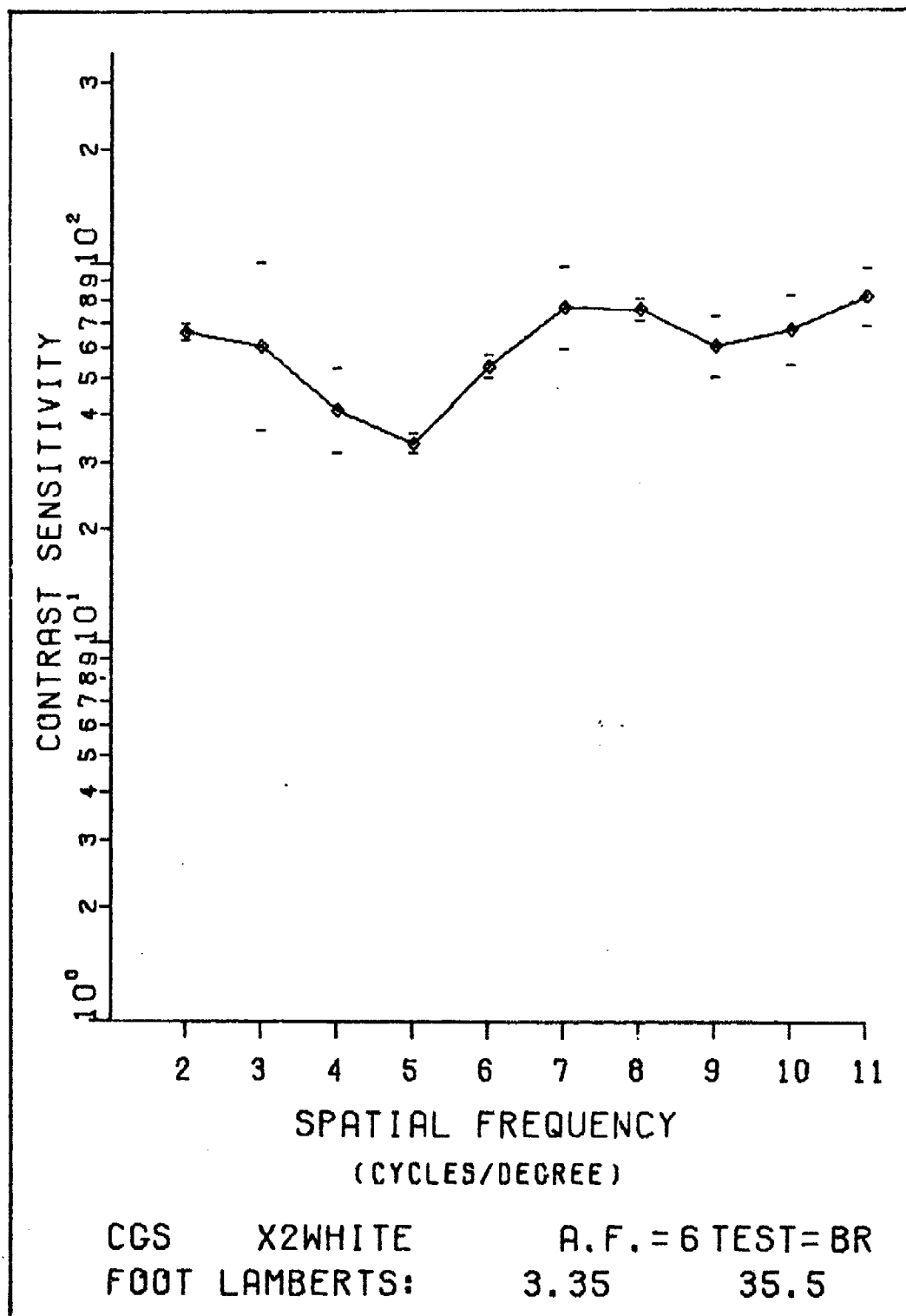


Fig. 49. CGS, Test Bright, Adapt Dim, 6 CPD (White, Adapt Right Eye, Test Left Eye)

VITA

Charles G. Smith was born on 28 January 1942 in Macon, Mississippi. He moved, with his parents, to Akron, Ohio in 1954 and attended Thornton Jr. High and South High Schools. In 1959, while still a high school senior, he entered Akron University under a Ford Foundation Grant. He enlisted in the Air Force in June 1961. In June 1967, Staff Sergeant Smith entered Syracuse University under the Airmen's Education and Commissioning program. He graduated Magna Cum Laude from Syracuse University in June 1969 with a BS in Industrial Management and entered the USAF Officer Training School (OTS). He was an honor graduate of OTS and received his commission in September 1969. He was an honor graduate from the Avionics Officer Training School at Lowry AFB, Colo. and was initially assigned as an Avionics Maintenance supervisor for bomber, tanker, and Post Attack Command and Control Aircraft and later as a Staff Avionics Officer at Strategic Air Command Headquarters. In June 1976, he entered the School of Engineering at the Air Force Institute of Technology in the Engineering Science program. In June 1977, he completed the Engineering Science program and began course work toward a Master of Science in Electrical Engineering.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report documents an investigation of the hypothesis that the organization of the receptive fields in the human visual system changes to compensate for changes in the average luminance of the visual stimulus. Foveal measurements of contrast sensitivity to sinusoidal spatial frequency were made at one luminance level while the sub- jects were adapted to a spatial sinusoid of a different average		

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luminance. The luminance levels used were 3.65 and 35.5 ft-lamberts.

Contrast sensitivity curves were generated for the range of spatial frequencies from 2 through 11 cycles per degree for adapting spatial frequencies of 4, 6, and 8 cycles per degree.

Adaptation and testing at the same average luminance level produced a depression in the contrast sensitivity curve centered over the adapting spatial frequency. Adapting to a low luminance level stimulus and testing at a higher luminance level produced a shift in the adaptation depression to a lower spatial frequency. Adapting to a high luminance level and testing at a lower luminance level produced a shift to a higher spatial frequency. The shift in the adaptation depression was observed for red, green, blue, and white light stimuli and was observed for the unadapted eye of a subject whose other eye was adapted.



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