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Identification Thresholds of the Human Visual System for an Alphanumeric Resolution Test Object

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ABSTRACT

Many investigations of the detection threshold of the human visual system have been conducted, and a few recognition threshold studies can be found, however no identification threshold data are available. This paper documents research on the observer's identification threshold for an alphanumeric resolution test object presented at various average luminance levels, contrasts, and contrast polarities. These factors affected the identification threshold in a similar way to the effects they exert on the observer's detection and recognition thresholds; the test object contrast being the most significant factor. Direct numerical comparisons between the various thresholds were not possible due to the large inherent differences between the test object visual task complexities found in the many threshold investigations.

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1. INTRODUCTION

In the field of visual research most investigators fail to recognize the relationship between the design of a test pattern and the degree of difficulty of the identification task performed by the observer's eye-brain combination. The basis of the problem is that two independent disciplines are involved – physics and psychology. The mathematician or physicist usually lacks the required expertise to predict the effects his carefully designed experiment will have on his human observers. A similar statement can be made of the psychologist with respect to the physical aspects of his testing. Only a small group of investigators can claim competancy in both fields. For this reason, although much is known about the physics of an imaging system, less is understood about the human visual system.

1.1 Physical Investigations

Analytical techniques which were originally developed as pure mathematical tools by Fourier have been applied in the last half century to electrical engineering and optics, providing methods for generalizing a system's operation [Campbell and Robson (1968)]. In general, the analytic technique requires a known sine wave be input into the system under test, and the observed output is noted. Repetition of this procedure with sine waves of other frequencies of the appropriate amplitude and phase results in the frequency response function of the system. Sine waves lend themselves to Fourier analysis since any signal can be characterized as a series of sine waves summed together. This implies that once a system's sine wave response is known then the system's behavior to any input can be predicted.

Fourier analysis has been shown to accurately predict system responses in the fields of electronics and optics, and today it is applied extensively in those areas. But do such analytic techniques hold true for the human visual system? Evidence indicates that this may be so, and the most common application of these methods has been the characterization of the human visual system by the modulation transfer function (MTF).

The human visual system follows the predictions of Fourier analysis over a moderate range of modulations. These modulations can also be described as the amplitudes of the sine waves, or as the contrasts or differences between the high and low values of the input sine waves. This requires the assumption of a linear visual system.

Although the MTF of the human visual system at threshold has been widely accepted, evidence indicates much more needs to be learned. Investigators have published results to show that the eye-brain combination behaves not as a single system responsive to the entire input range, but rather it consists of a multiplicity of channels, each "tuned" to a specific small range of input frequencies [Blakemore and Campbell (1969); Campbell and Robson (1968); Kelly and Magnuski (1975)].

1.2 Human Visual Response

Investigations of the human visual response have relied heavily upon periodic test patterns designed to resemble the test targets used for physical measurements of imaging devices. Repetition of a single form and increasing spatial frequency are dominant characteristics of such targets. Some of the test patterns that have been used in human vision research are reproduced in Appendix A. Each test pattern has drawbacks. Spurious resolution or false resolution (seeing two bars when three are presented) troubles periodic targets. The observer's prior knowledge of the construction of the test pattern introduces bias when the Tri-bar target is used. Although Landolt's rings and Snellen's chart of Es attempt to rectify the bias problem, both still suffer from the observer's fore-knowledge. Some patterns utilized all alphanumeric characters but the question of equally difficult identification tasks can be raised.

The deficiencies of the test patterns briefly discussed here do not in themselves invalidate the results of vision experiments that used them. However more information could have been obtained had a test pattern designed for the human visual system been used. Conclusive evidence testifies to the fact that the human observer behaves in a much more complex manner than the simplistic approach assumed by most vision experimentors. Physiological as well as psychological variabilities have to be accounted for in order to reduce the visual system noise that is present in all experiments. The reader is referred to Hake and Rodwan (1966) for a detailed discussion of this point.

1.3 Detection, Recognition and Identification

Before selecting a test obejct the researcher must determine how much information the observer is to extract from the pattern. It is necessary for the researcher to understand that the eye-brain requiriements, capabilities and responses vary according to the complexity of the visual task. Yonemura (1974) presents a useful description of the levels at which the human visual system operates.

The most elementary level of visual performance requires the detection of the presence or absence of a test pattern. The minimum amount of light necessary for the observer to perceive the onset or the removal of the test pattern is termed the detection threshold for those conditions.

Recognition follows detection and is the process of deciding which of many possible categories the test pattern, or stimulus, belongs to. For example: I see something [detection], it is a square (as opposed to a circle or a polygon) [recognition]. The recognition threshold may be described as the minimum amount of light required under the test conditions to accurately select the category to which a test stimulus belongs.

Identification occurs only after the detection and recognition of the test stimulus. It is the process that selects one of many similar members which the test stimulus most closely resembles. Continuing the previous example: I see [detection] a square [recognition] which is a photograph [identification]. A schematic of this process of extracting information from the visual field is given in Figure 1.

The preceeding discussion contains an admittedly simplified set of distinctions, as it is apparent that both recognition and identification are multi-leveled determinations. For instance, once the stimulus was recognized as a square, decisions about its size, thickness, surface, and the kind of detail it contained were made before it could be identified as a photograph. Further qualifications could be made about what was in the photograph; if people, were they male or female; how old were they; who were they; et cetera.

This author understands that the distinctions made here between detection, recognition and identification become hazy, overlap, and eventually break down under critical examination. Thus they are used in this paper in a purely heuristic manner.

1.4 Target Design

Vision researchers investigating the detection threshold have commonly presented observers a disc of light, the size of which varied from very small to large [stimulus shape was found to have no effect on the detection threshold (Bouman and Blokhuis, 1952)]. Studies have reported that the threshold values for the observer's ability to select between two alternative stimulus shapes (the recognition threshold) are significantly higher than the corresponding detection thresholds. Circles and squares were one type of test stimuli found in such works. Although a number of investigators used test stimuli that were higher-level recognition or low-level identification in nature, none attempted to determine the operating characteristics of the human visual system for identification test patterns.

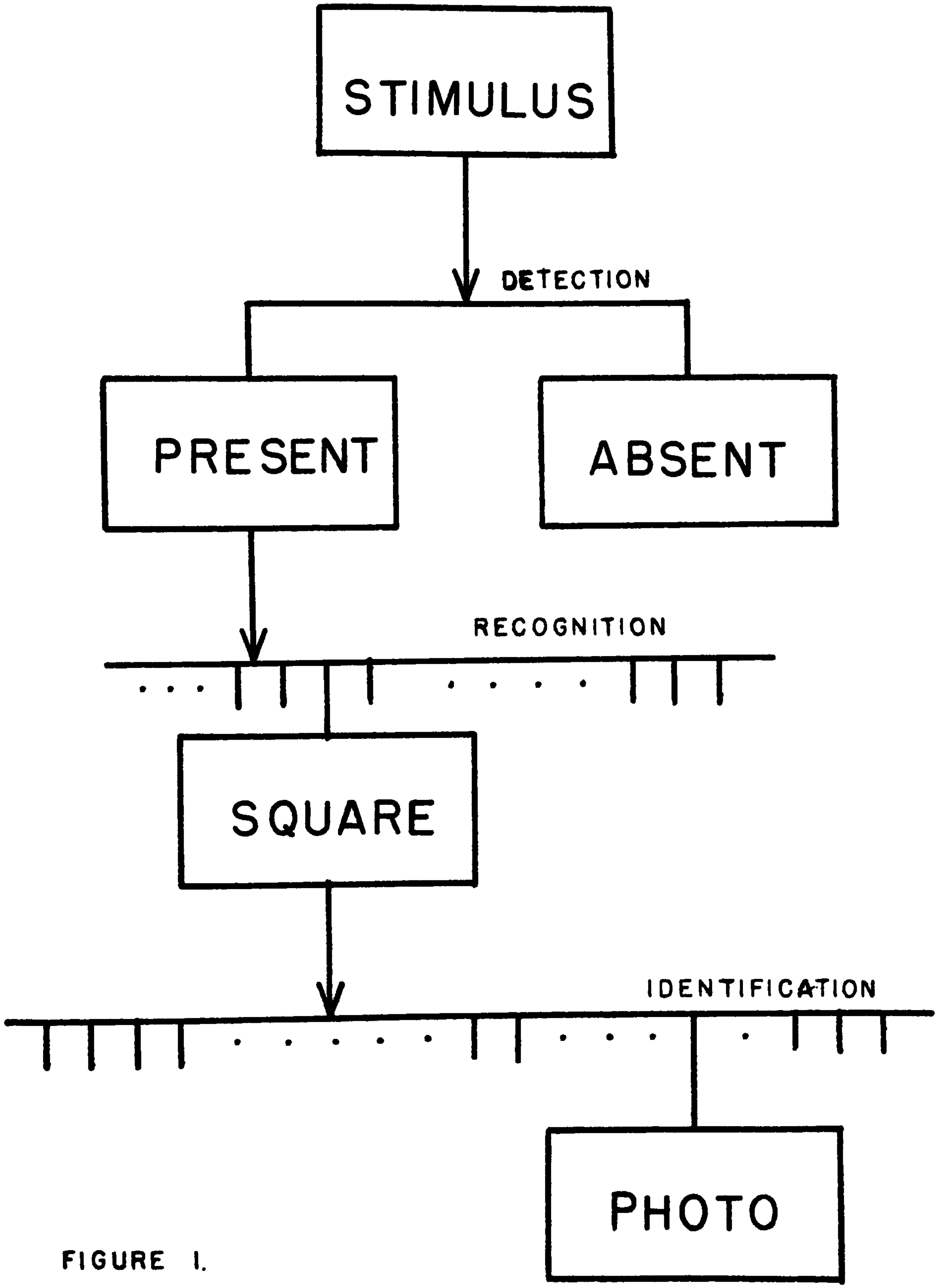

FIGURE 1.

Schematic diagram of information extraction from a stimulus presented to the human visual system.

What test pattern design would be needed to measure the identification thresholds of the human visual system? The deficiencies of present test patterns include the potential of spurious resolution; the observer's expectation of only one pattern, resulting in only detection or at best a low-level recognition threshold measurement; observer fore-knowledge of previous results allows observer bias to distort the data, as exemplified by experienced versus inexperienced readers of Tri-bar targets. When alphanumerics were tested the question of whether the characters used presented equally difficult identification tasks arose, and always present was the question of what constitutes "just detectable" or "just recognizable."

The design of an identification test pattern must provide at least two alternative stimulus categories, and the members of each category should present equally difficult identification tasks to the observer. As the number of categories and/or members increases the chance of correct identification through guessing decreases. Thus the possibility of observer bias could be reduced to a minimum by proper selection of the stimulus categories and members.

Donaldson and Gough (1967), (1968) report that the alphanumeric characters 2, 3, 5, 8, 9 and E appear equally recognizable when presented in block form. Archer (1972), (1974) produced the Rochester Institute of Technology Alphanumeric Resolution Test Object (hereafter designated ARTO), shown in Figure 2, using the five characters 2, 3, 5, 8, and E. Each quadrant is individually randomized and consists of 26 three-character groups of randomly selected Donaldson-Gough characters. The ARTO closely approaches the identification test pattern requirements discussed above, presenting two categories (letters and numerals) of one and four members respectively.

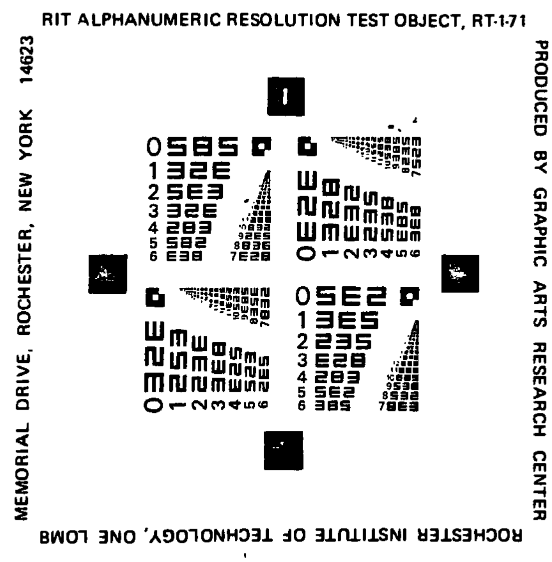

FIGURE 2. The Rochester Institute of Technology Alphanumeric Resolution Test Object.

1.5 Parameters Affecting the Visual Response

Ronchi and Villani (1970) emphasize that the design of any test pattern intended for a human observer should be guided by the known operating characteristics of the eye-brain combination. Unfortunately, as Hake and Rodwan pointed out, too many investigators overlook this necessity and treat the visual system as a black box, a machine, not accounting for the known psychological and physiological effects their experiments have on the observer. Thus a summarization of the results in visual research as regards the human observer's ability to detect or recognize a stimulus follows.

Many investigations of the relationship between the luminance level and the visual response conclude that the eye-brain response decreases with decreasing luminance. Whether testing detection or recognition stimuli, the contrast between the background and the test pattern has been shown to significantly affect the observer's abilities to perceive the presented patterns. At low luminance levels, negative contrast polarities (or the negative generation) of a test pattern produce higher thresholds than positive contrast polarities (positive generation) of the same pattern. Human visual sensitivity decreases with the increasing spatial frequency of the test pattern. Finally, evidence indicates that detection thresholds are lower than recognition thresholds in the same observer for the same test pattern. [Blackwell (1946); Bouman and Blokhuis (1952); Vos, Lazet and Bouman (1956); Herrick (1956); Cornsweet and Teller (1965); Ikeda (1965); Campbell and Green (1965); Short (1966); Campbell and Gubisch (1966); Patel and Jones (1968); Blakemore and Campbell (1969); Rashbass (1970); Van Esen and Novak (1974); Cavonius (1974); Vicars and Lit (1975); Ives and Shilling (1941); Craik and Vernon (1942); Semeonoff (1950); Miles (1953); MacDonald and Watson (1956); Barrows (1957); Fox (1957); Carman and Charman (1964); Campbell and Robson (1968); Cohn, Thibos and Kleinstein (1974); Cohn and Lasley (1974); Cohn and Lasley (1975); Kelly and Magnuski (1975)].

This paper documents an investigation using the RIT–ARTO to determine how luminance, contrast and contrast polarity affect the identification threshold of the human visual system.

2. METHODOLOGY

2.1 Apparatus

A schematic diagram of the optical design for the experimental apparatus is presented in Figure 3. The 100-watt zirconium arc source provides white light. The colimator,

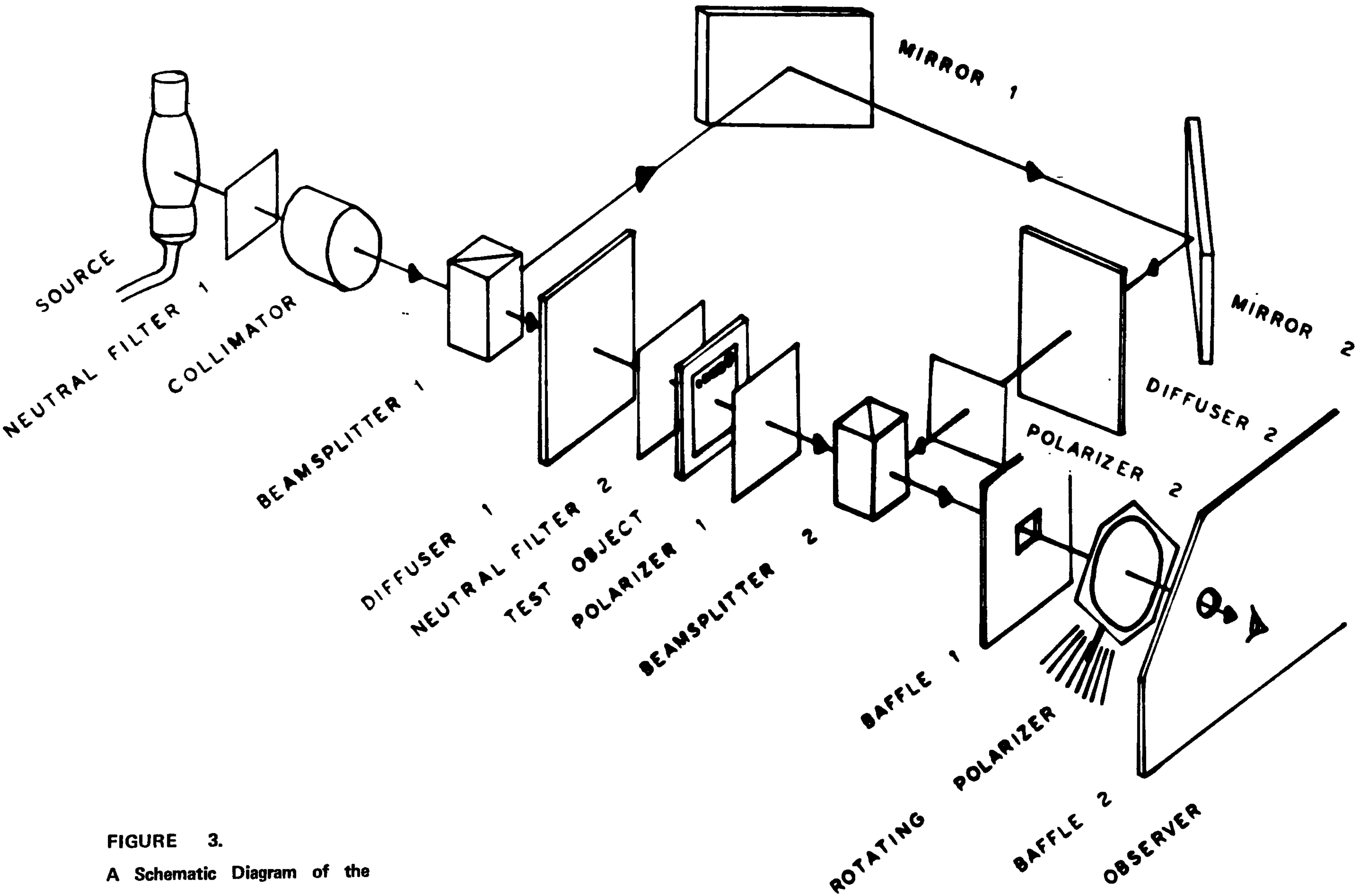

FIGURE 3.
A Schematic Diagram of the Test Apparatus.

a Wollensak 6" f/2.5 Raptar lens, was used at the maximum aperture and focused by auto-collimation and subsequent measurements of beamwidth further down the optical path. Neutral density filters could be placed between the source and the collimator to attenuate the overall luminance level; three densities were used – 0.00, 0.60 and 1.00 ND. Cube beamsplitters 1 and 2 measured approximately two inches to the side and transmitted-reflected about 35% of the incident light. The transmitted beam from beamsplitter 1 forms the image beam in the apparatus, and the reflected beam eventually provides non-image-forming light.

The non-image beam is reflected by first-surface mirrors 1 and 2. Such mirrors reflect only about 90% of the incident light, thus causing an approximated 20% attenuation of this beam. After reflection from mirror 2 the beam falls upon opal glass diffusor 2. Immediately against diffusor 2 is polarizer 2, made of Polaroid Corporation's HN–38 polarization material. Not shown in the diagram is a mask limiting the visible portion of glass-and-polarizer to 35 mm slide format size.

After the image-forming beam emerges from beamsplitter 1, it falls upon another piece of opal glass, diffusor 1. A removable 35mm slide holder was constructed to properly position the test objects and yet allow for the quick withdrawal and exchange of slides. Neutral filter 2 was 0.30 ND to compensate for the attenuation in the non-image beam caused by the mirrors and increased scattering of light. Polarizer 1, another piece of Polaroid HN–38, was oriented 90° to the axis of polarizer 2. Neutral filter 2 was taped to the back of the removable slide holder and polarizer 1 taped to the front, so that these materials aided in holding the test object in place. The holder itself formed a mask to limit the visible portion of glass to slide-format size. The usefulness of the slide holder will be discussed later.

Beamsplitter 2 re-combined the now cross-polarized image and non-image beams. Care was taken to insure that the optical path distances from beamsplitter 2 to the two diffusors were equal and co-linear. Baffle 1 restricts the observer's view such that he cannot see beamsplitter 2 itself, its holder, or the holders for the diffusor-polarizer assemblies. Through baffle 1 the observer could view an area only the size of the test quadrant image, and was unable to see even the borders of the slide mount.

Baffle 2 was the outer cover of the apparatus with a half-inch diameter hole centered on the optical axis. The rotating polarizer consisted of a third piece of Polaroid HN–38 mounted on a circular ball-bearing turntable. The turntable was mounted on the back of baffle 2 and provided with a notched handle. Accurately determined degree markings had previously been ruled on the back of baffle 2 and registration pins were positioned to provide accurate rotation (relative to polarizer 1) of 0°, 35°, 50° and 65°. The notched handle closely fit the registration pins and the entire assembly could be operated by the experimentor by touch alone.

The observer's eye was approximately 93 millimeters from baffle 2, and approximately 510 millimeters from the test object. The distance from the eye to the ARTO was chosen to place the non-identification point approximately in the middle of the presented frequencies. Had some other distance been chosen the breakpoint would merely have been shifted on the ARTO but almost the same values of spatial frequency at threshold would have resulted. A vertically-adjustable chinrest was provided for the observer.

The two optical benches on which the apparatus was set up were clamped to a wooden platform to insure optical alighnment, and the entire apparatus was enclosed in a light-tight covering. The light source was separately enclosed and ventilation ports were heavily light-trapped. Extra baffling around the diffusors, beamsplitter 2 and the rotating polarizer was added to reduce stray light from apparatus surfaces. The light-tight apparatus occupied a table in one of two very dark connecting darkrooms.

2.2 Observers

The assumption was made that the sample of observers constituted a random sample, thus the effect of the observers on this experiment was not considered. Eighteen volunteers aged 13 to 36, were evaluated with the Snellen Chart of Es prior to testing. One observer tested 20/25, two were 20/20, and the remaining fifteen tested as 20/15. If the observer normally used corrective lenses then the testing was conducted with the lenses in place. Monocular foveal viewing of the test imagery was done always with the same eye, whichever one the observer chose to use.

2.3 Test Imagery

Many, sometimes conflicting, definitions of positive and negative imagery can be found in the literature. Therefore it is necessary to define the meaning of these terms as used within this paper. A positive transparency is schematically represented in Figure 4A as an opaque bar on a clear background. Scanning this transparency with an ideal microdensitometer would result in Figure 4B. The recorded luminance would decrease as the measuring aperture passed onto the opaque bar from the background, and would increase again as the aperture moved from the bar to the background. A negative transparency (Figure 4C) would produce opposite readings (Figure 4D). Since the positive image produces a decrease in the background luminance at the point of interest (i.e., the bar) it can alternatively be referred to as a decremental stimulus. Negative imagery equates similarly to incremental stimuli. Most vision researchers tend to use these latter two terms.

Positive and negative transparencies were produced of each quadrant of the Rochester Institute of Technology's Alphanumeric Resolution Test Object RT–1–71 (the ARTO). The transparencies were on 35 mm film format ($\bar{D}_{min}$ = 0.05 , $\bar{D}_{max}$ = 5.50) mounted in glass slide covers and labeled for identification. Examples of a positive and a negative quadrant are shown in Figure 5. Since each quadrant is unique there are effectively four different test objects. This helped eliminate the chances of the observer learning the test character sequence and thus reduced observer bias to a minimum.

The spatial frequency of each of the eight test objects was determined be measuring the line size for one character in each row of the ARTO quadrants. An Olympus FHA microscope with a calibrated Bausch and Lomb Filar eyepiece was used for this purpose. Preliminary measurements showed the line size values to be consistently accurate both within a specific character and for all three characters in a given row. In the experimental apparatus the observer's eye was approximately 510 millimeters from the test object. With this value spatial frequencies for every row were computed for all test objects and then plotted. The average

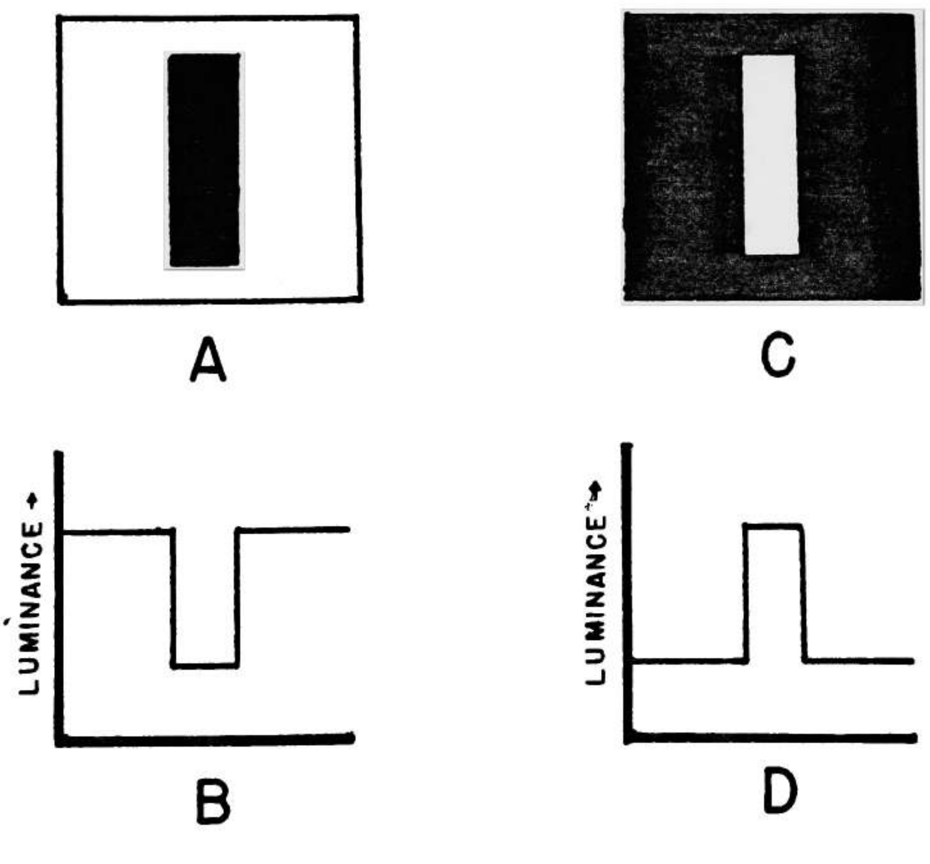

FIGURE 4. A Schematic Representation of Positive and Negative Imagery.

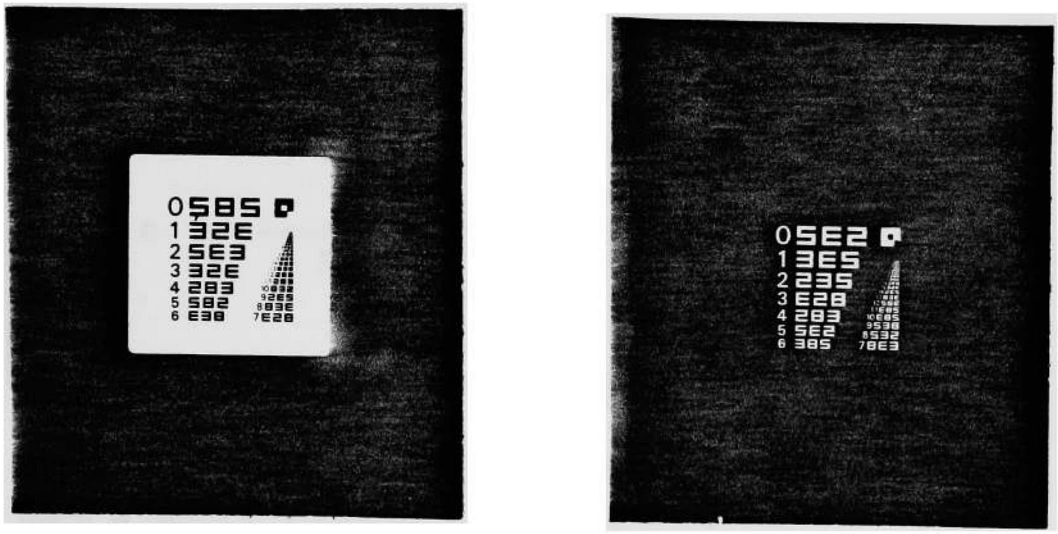

Figure 5. Examples of a positive and a negative test quadrant as seen by the observer at maximum contrast. (view from half a meter)

for each row was determined and those values were used for all data analysis in this paper. For rows 0 to 10 the average spatial frequencies presented in this experiment ranged from 8.69 to 50.00 cycles per degree.

2.4 Definition of Contrast

The measure of the relative contrast of the test stimulus to its background can be found in a number of previously mentioned articles [Blackwell (1946); MacDonald and Watson (1956); Campbell and Green (1965); Patel and Jones (1968); Vicars and Lit (1975); others]. The most common definition of contrast found in these articles can be stated as:

$$\text{Relative Contrast} = C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \qquad \text{(Eq. 1)}$$

Accounting for relevant transmission factors as they apply to this experimental set-up, Equation 1 becomes:

$$C = \frac{(T_{max} - T_{min})}{(T_{max} + T_{min}) + 2(T_2 L_2 / T_1 L_1)} \qquad \text{(Eq. 2)}$$

where T_{min} and T_{max} are the minimum and maximum transmission values of the test objects as calculated from the average densities, T_1 and T_2 are the transmission values of the crossed polarizers in the image and non-image beams respectively, and L_1 and L_2 are the integrated luminance values for the light transmitted by the diffusor-filter-polarizer assemblies (without the test quadrant in place) for the image and non-image beams. The derivation of Equation 2 is detailed in Appendix B.

Four contrast values were tested in this experiment: $\bar{C}1 = 0.96$, $\bar{C}2 = 0.68$, $\bar{C}3 = 0.41$, and $\bar{C}4 = 0.19$. These levels were chosen by visual selection for approximately equal perceptual changes in contrast as perceived by the human eye. (Stevens, 1961)

2.5 Experimental Procedure

As already stated, the observers were tested with the Snellen Eye Chart at the beginning of the session. A large drawing of each of the five ARTO characters (2, 3, 5, 8, and E) and an actual test quadrant itself were presented to the observer to familiarize him with the quadrant design. The observer next adjusted the chinrest to allow easy viewing and then a 30-minute dark adaptation period followed.

The lengthy period of total darkness was deemed necessary when preliminary tests on practiced observers resulted in high day-to-day variability. This variability was evidenced in two ways: (1) Trial Observer 1 spent a cloudy morning outdoors prior to testing on day 1. The next day was very sunny, and when tested that evening Observer 1 could not achieve half the results he had been capable of on day 1. (2) On both days Trial Observer 2 spent much of the time in a windowless room. When tested Observer 2 produced repeatable results of generally higher quality than Observer 1. Dark adaptation periods on these days ranged from 10 to 15 minutes. The 30-minute dark adaptation time was therefore chosen in an attempt to overcome some of the variability between observers. Researchers Bouman and Blokhuis (1952), Patel and Jones (1968), and Vicars and Lit (1975) were the only ones to use adaptation periods similar to that chosen for this investigation.

The presentation sequence to be used for all observers was determined prior to any experimentation. First the order of contrast levels was randomized within each polarity, and then the order of quadrant presentation was randomized, again within each polarity. Thus each observer saw a unique presentation sequence, and hence the sequence did not significantly affect the results.

The experimental design required each observer to view positive and negative imagery at four contrasts each and at only one level of luminance. Six observers were tested per luminance condition and three luminance conditions were evaluated according to the densities described earlier. Eight observers viewed positive imagery before negative, and ten the reverse. Variability among observers obscured any differences caused by the two polarity presentation orders, thus it was assumed that no difference between the two orders existed.

At the end of the dark adaptation period the observer started at row 0 of the first ARTO quadrant—contrast level combination to be tested, and identified the characters as he believed they were presented to him. Row 1 was next viewed and identified, et cetera, until the observer claimed he could see no more characters. At this point the experimentor would request the observer to guess and generally a few more rows of observations were obtained before total non-identification was evidenced.

The observer looked away from the apparatus while the experimentor altered the contrast level and changed the test quadrant. Since all experimentation took place in a very dark room, the pin registration on the rotating polarize and the automatically-positioned slide holder were necessary to operate the apparatus. All changes could be performed accurately and rapidly, generally taking less than 30 seconds. The observer again looked into the apparatus and proceeded to identify/guess at the characters presented in the new quadrant-contrast combination.

The observer's identifications were recorded by the experimentor on the standardized data collection forms shown in Appendix C. An extremely small light was used by the experimentor to view the forms, however care was taken so that no illumination was visible to the observer (whose back was to the connecting doorway) and no stray light entered the main testing room from the smaller data-recording room. Only the observer's incorrect identifications were recorded, thus allowing immediate analysis of not only where errors occurred but what the test characters were mis-identified as.

3. RESULTS

3.1 Definition of Threshold

A number of alternative methods for defining the identification threshold of the observer were investigated. Analysis of the data using three different threshold criteria was performed and it was found that the resulting curves were very similar except for a shift by a constant value along the spatial frequency axis. Figure 6 contains curves resulting from the three alternative criteria.

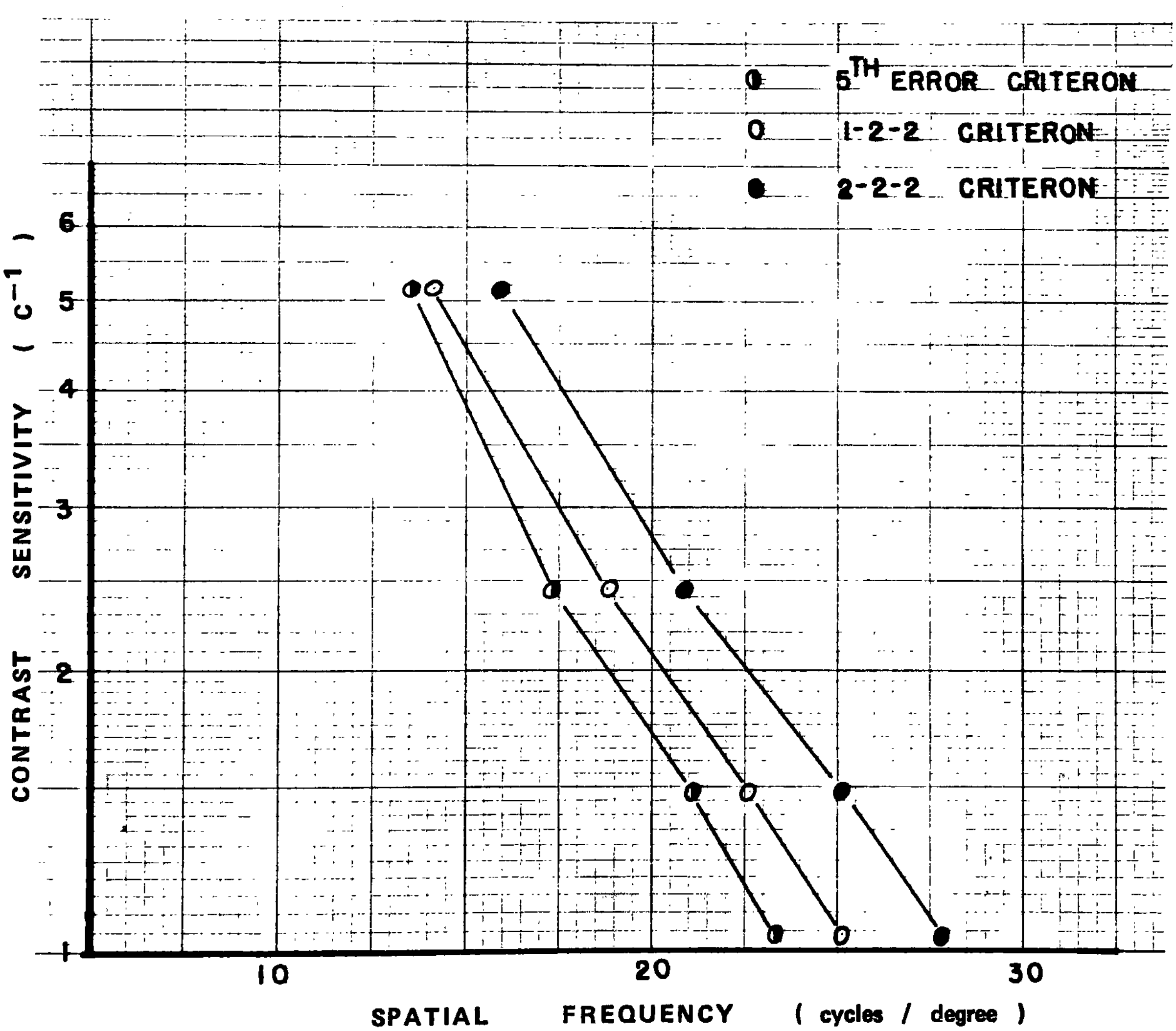

FIGURE 6. Comparison of three alternative identification threshold criteria. The criteria used to generate these curves were: 5th error – that spatial frequency at which the fifth error occured; 1–2–2 – the spatial frequency of the first line of the first consecutive pair of lines in which two or more errors occured in each line; 2–2–2 – the same as 1–2–2 except based on the second line of the pair.

It was concluded that the relationships involved in determining threshold values were not easily affected by the evaluating criteria used, and the criterion most reasonable to this experiment was chosen for all threshold determinations. Thus the identification threshold criterion applied in this paper is defined as:

> The IDENTIFICATION THRESHOLD of the human observer for the RIT–ARTO is defined as the lowest spatial frequency of the first pair of consecutive lines to contain two or more errors per line.

Identification thresholds for each treatment combination were obtained through the application of this definition and the results were reported in terms of spatial frequency at threshold in cycles per degree.

3.2 Significance of Factors

An analysis of variance (ANOVA) was performed on the threshold data and the results are presented in Table 1. With an alpha-risk of 0.005 it may be said that the contrast of the test imagery, the imagery's contrast polarity (generation), and the integrated luminance level of the test imagery all significantly affected the identification threshold of the human observer. All interactions between the tested factors were insignificant.

By inference, the 30-minute dark adaptation period seems to have reduced observer-to-observer variability to a low value. This is evidenced by the clarity of the data, the large differences between the F-ratios and their respective critical values, and the confidence level of 99.5% (alpha-risk = 0.005).

3.3 Graphical Results

The threshold contrast required for the perception of a stimulus has been found to be

source	source code	error term	F-ratio	$F_{0.005,}$		sum of squares	ν	mean square	estimate of variance
MEAN	mean	S(A)	679.7050	–		58488.97	1	58488.97	405.5759
INTEGRATED LUMINANCE LEVEL	A	S(A)	12.2102	7.7008	*	2102.39	2	1050.69	20.0967
CONTRAST POLARITY (GENERATION)	B	SB(A)	12.9838	10.798	*	82.17	1	82.17	1.0534
CONTRAST LEVEL	C	SC(A)	138.2701	~ 4.9759	*	2482.00	3	827.33	22.8153
	AB	SB(A)	1.4969	7.7008	NS	18.95	2	9.47	0.1310
	AC	SC(A)	1.6218	~ 3.7129	NS	58.23	6	9.70	0.3101
	BC	SBC(A)	2.7176	~ 4.9759	NS	45.45	3	15.15	0.5120
	ABC	SBC(A)	1.7157	~ 3.7129	NS	57.39	6	9.56	0.6649
OBSERVERS, nested within factor A	S(A)					1290.76	15	86.05	10.7563
	SB(A)					94.93	15	6.33	1.5822
	SC(A)					269.26	45	5.98	2.9917
	SBC(A)					250.87	45	5.57	5.5748

TABLE 1. ANALYSIS OF VARIANCE FOR IDENTIFICATION THRESHOLDS

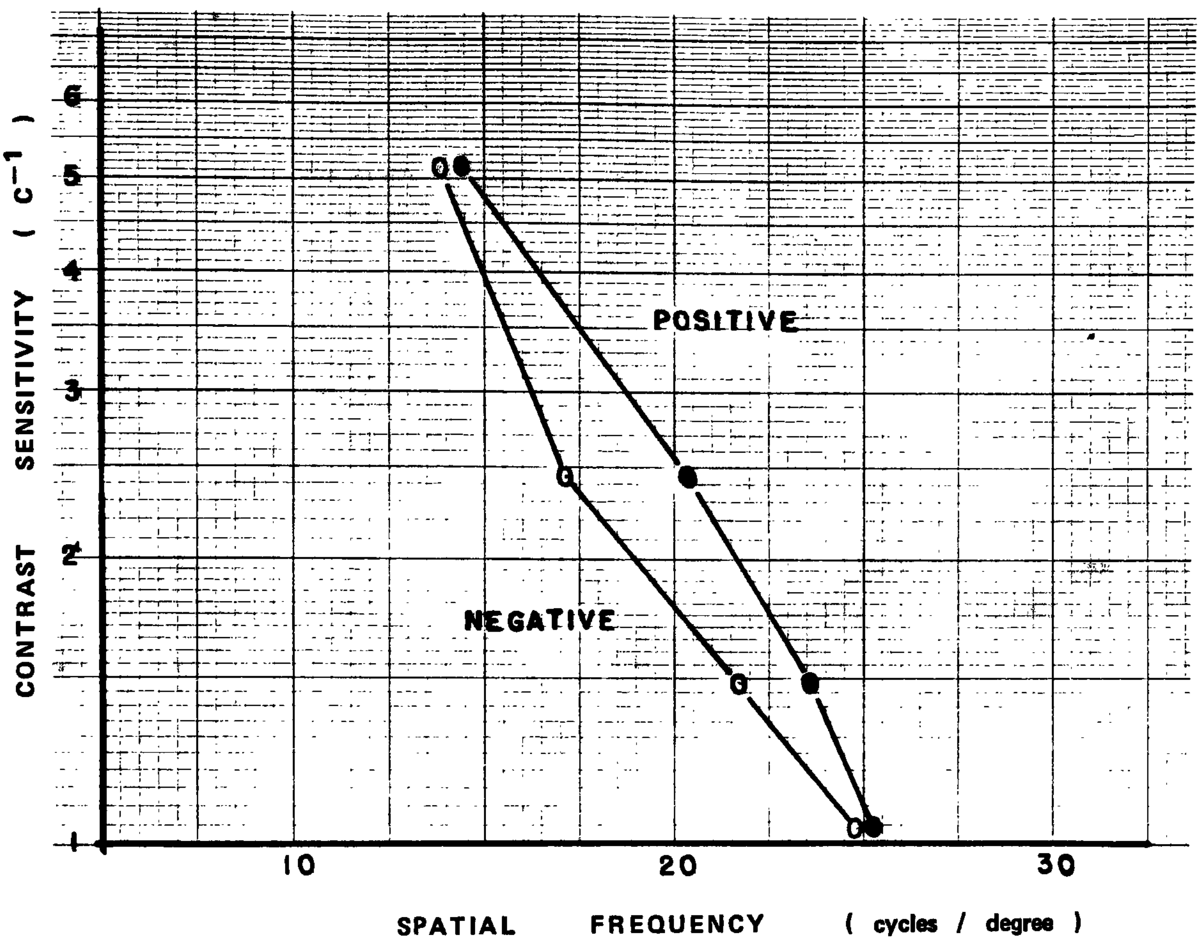

FIGURE 7. Effect of Contrast Polarity on the Identification Threshold.

a function of the spatial frequency of the stimulus. Campbell and Robson (1968) defined contrast sensitivity as the reciprocal of the threshold contrast, and the contrast sensitivity function is described as "the variation of sensitivity over a range of spatial frequencies." The results of this investigation are reported in terms of the contrast sensitivity function.

The contrast polarities (or generations) affect the human visual system's identification threshold differently, depending upon the contrast of the test imagery. The maximum and minimum contrasts produce similar identification thresholds for both polarities. When intermediate contrast values are selected the difference between the polarities is more pronounced. The difference between contrast polarities as contrast sensitivity increases is more clearly shown in Figure 8. This plot indicates that as the contrast sensitivity approaches a value of 2.5 (or a contrast of 0.40) the maximum difference between the identification thresholds for positive and negative imagery is found for this investigation.

For the factor combinations used in this experiment the maximum spatial frequency change was about 3.2 cycles per degree, which corresponds to a 15.6% change in spatial frequency at the identification threshold.

This author was unable to locate any article in the literature which displays or discusses the difference between decremental and incremental (positive and negative) imagery in a way similar to Figure 8. Further, none of the data presented in those articles were amenable to manipulation in any way that would produce a plot similar to Figure 8.

As shown in Figure 9, a decrease in average luminance (measurement method described in Appendix D) results in decreased spatial frequency at the identificaiton threshold. Two potential explanations exist for the difference between the high luminance curve and the two others. It is possible that the experimental procedure or apparatus contained an inherent flaw which produced an erroneous data point for contrast sensitivity = 1.47 at the 0.200 ft-L Alternatively, the 1.04 contrast sensitivity point could indicate that the limit of the maximum

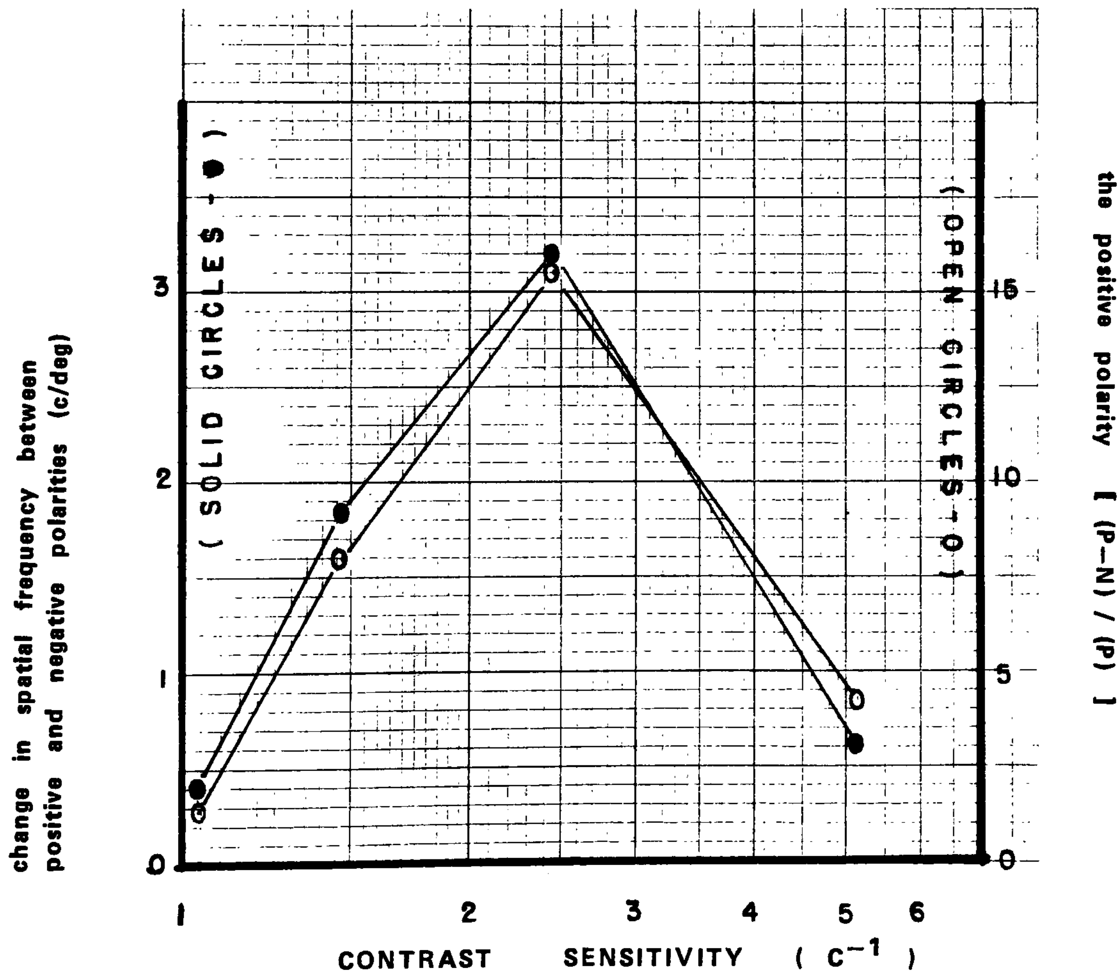

FIGURE 8. Change in Spatial Frequency between Contrast Polarities.

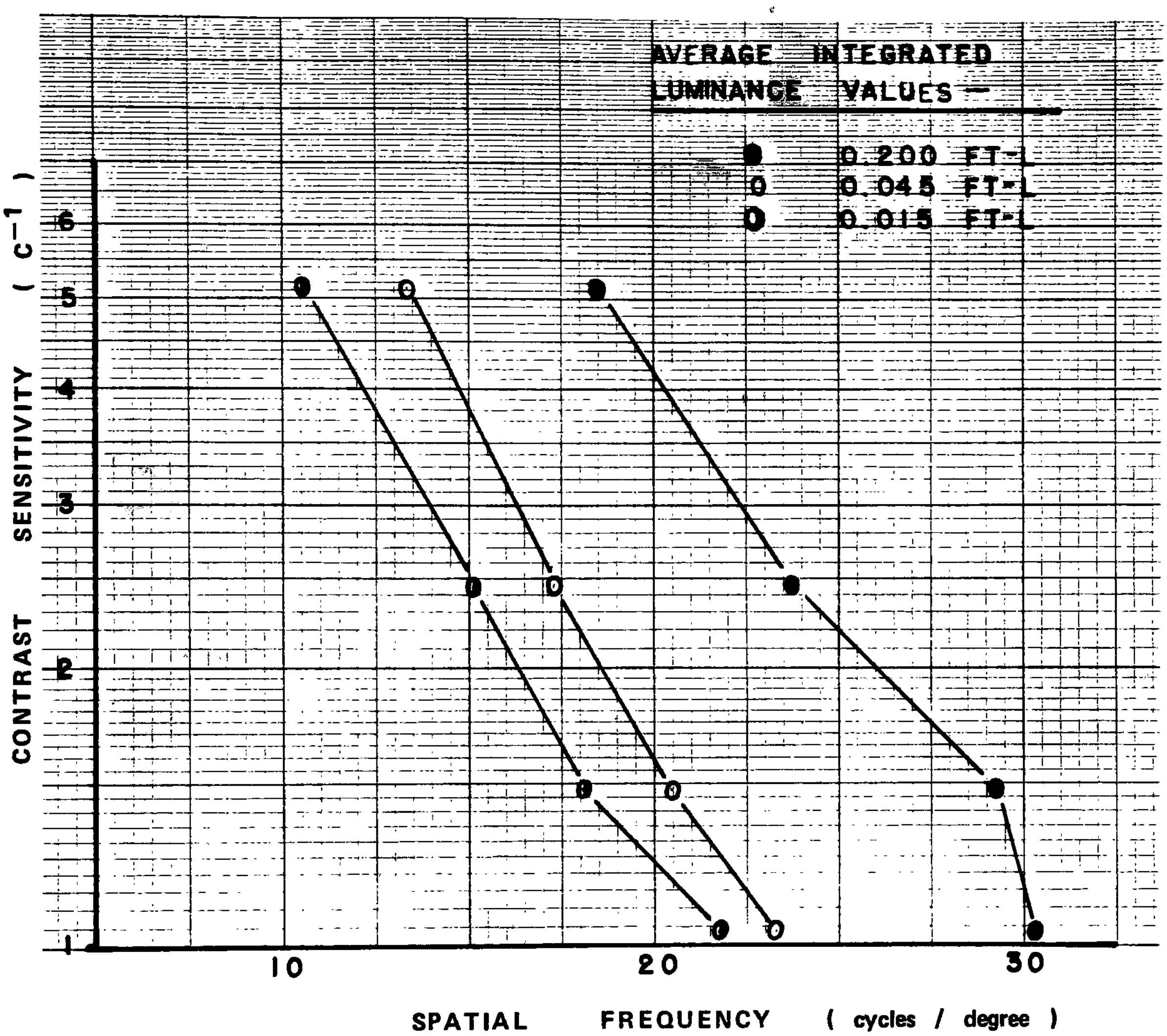

FIGURE 9. Effect of Change in Average Luminance on the Identification Threshold.

identifiable spatial frequency that can be perceived by the human visual system was reached. Either of both these explanations could be correct.

The spatial frequency of the identification threshold decreased with increasing contrast sensitivity (Figure 10). The statistical analysis showed contrast to be the most significant factor in this experiment. The F-ratio of about 138, when compared to the critical F-ratio of about 5, indicates that contrast is the most crucial characteristic to be specified about a stimulus.

3.4 Evaluation of the Alphanumeric Resolution Test Object (ARTO)

Donaldson and Gough (1967) investigated a set of eight alphanumeric characters in an attempt to locate a group of characters that were equally recognizable to the human observers. The characters were presented at a contrast of 0.78 and at 125 footcandelas. The distance from the observer to the test character (which were individually presented) was variable, hence the spatial frequencies experienced by the observers are unknown. From the set of E, G, S, 2, 3, 6, 8, and 9 the investigators concluded that E, S, 2, 3, 8, and 9 were of equal recognizability with an alpha-risk of 0.10 . (note that the block-form "S" and the block-form "5" in Archer's target are identical)

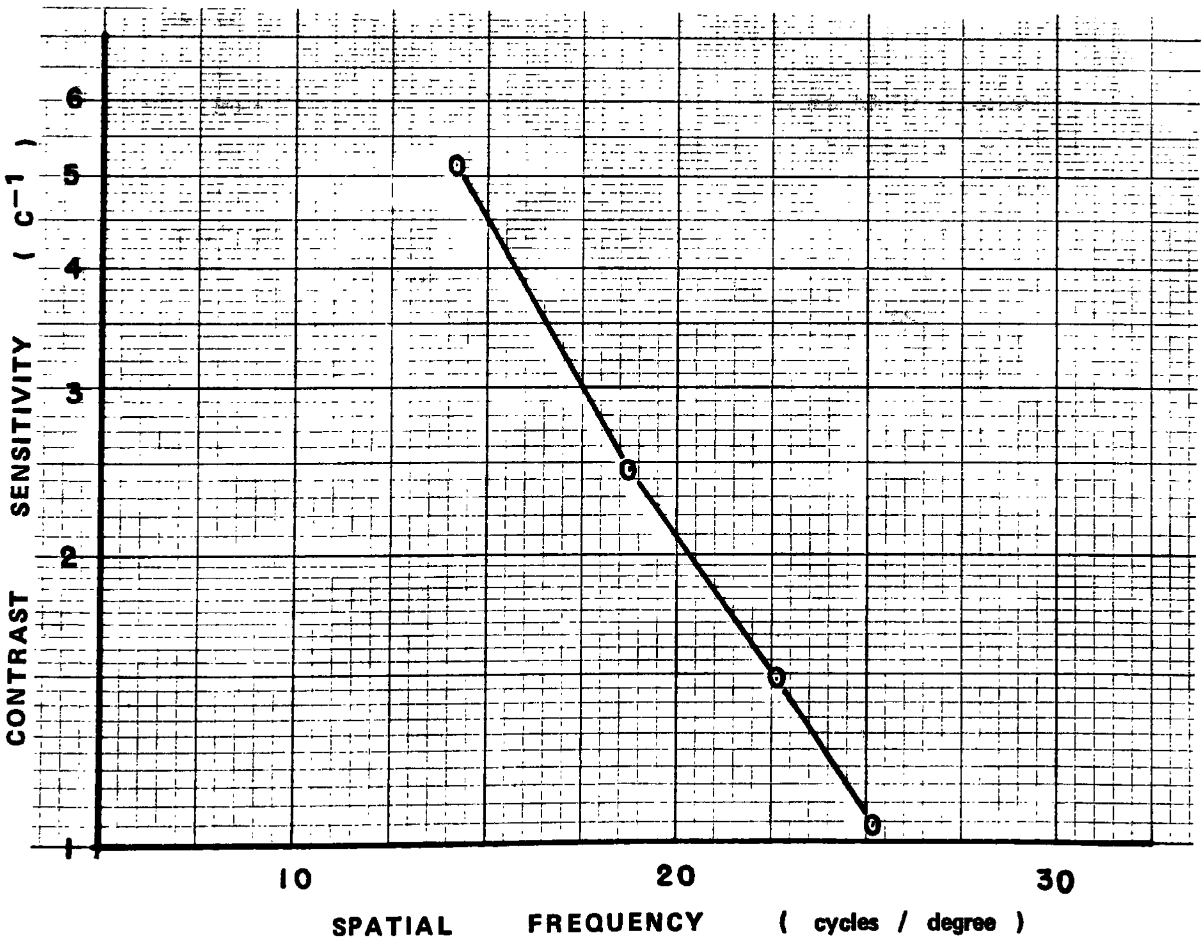

FIGURE 10. Effect of Contrast on the Identification Threshold.

The present experiment allowed the direct testing of the Donaldson-Gough assertion of equally-recognizable characters. More than 3650 ARTO characters were presented before the total non-identification point was reached, and a breakdown of the presented characters and their elicited responses is shown in Table 2. The top of the table lists the characters presented in the ARTO and the side indicates the possible categories of responses. The last row tabulates the number of times the observers refused to guess the identity of the presented character, or else when the observer (as occassionally happened despite the experimentor's efforts) insisted he saw some character not a part of the ARTO character-set.

Statistical analysis of Table 2 was performed by chi-square test for independent random samples of large sample size. With an alpha-risk of 0.005 it can be said that at least one of the five alphanumerics that comprise the ARTO presented a different identification task for the observer than the others did. After examining Table 2 the character 2 was omitted and the chi-square test was again performed for the four characters 3, 5, 8, and E. These characters were found to be the same at the 99.5% confidence level. [If a lower confidence level were accepted it might be said that the "E" was unlike the other three characters. However in order to maintain one alpha-risk value throughout this experiment (that of 0.005) this author chooses not to accept the last statement.] Thus with 99.5% confidence this author concludes that the character "2" does not belong in the set of equally recognizable characters on which the ARTO is based.

It appears from Table 2 that the distribution of characters in the ARTO is not perfectly random, as evidenced by the large difference in total counts for the character "8" as compared to the other totals. Also the last row of the table indicates more characters belong to the set of equally-identifiable alphanumerics than those used in the ARTO. Based on observer errors it is suggested that the characters 0, 6, and 9 might possibly be part of the set of equally-identifiable characters from which the ARTO was constructed.

4. DISCUSSION

4.1 Additional Comparisons and Conclusions

The assumption was made at the beginning of this experiment that the set of volunteers who acted as the observers constituted a random sample of a potentially infinite population. Despite observer-to-observer differences, the large number of observers averaged out variations. Considering the number of observers tested the data are surprisingly regular and this is emphasized by comparing the observer estimate of variance [S(A) in Table 1] to the estimates

Count / % of Coln	Presented Characters: 2	3	5	8	E
Character Identifications: 2	683 / 85.6	39 / 4.6	17 / 2.4	27 / 4.8	27 / 3.6
3	19 / 2.4	618 / 73.2	23 / 3.2	10 / 1.8	15 / 2.1
5	8 / 1.0	20 / 2.4	561 / 77.5	34 / 6.1	30 / 4.1
8	12 / 1.5	27 / 3.1	25 / 3.5	380 / 67.6	35 / 4.7
E	20 / 2.5	64 / 7.6	19 / 2.6	33 / 5.9	555 / 76.0
Blank or Other	55 / 6.9	76 / 9.0	78 / 10.8	78 / 13.9	68 / 9.3
TOTAL	797	844	723	562	730

TABLE 2. EVALUATION OF THE R.I.T. ALPHANUMERIC RESOLUTION TEST OBJECT

for the significant factors. Had only a few observers been tested, between-observer variations could have obscured significant data, a flaw which has weakened many two-person experiments.

Between-observer variations were further reduced by the thirty minute dark adaptation period, and the significance of this procedural step cannot be over-stated. Many articles are available to indicate the human visual system requires long periods of darkness to stablize; one early reference is Craik and Vernon (1942). Based on the quality of data collected in this experiment, thirty minutes of adaptation to absolute darkness should be considered a minimum requirement for any visual threshold research of this nature.

Previous investigations of identification thresholds could not be located by this author, hence only inferences can be made about the trends in this experiment as compared to previous works on the human visual system. The results of this paper indicate that contrast, contrast polarity, and average luminance all affect the observer's ability to identify the test object correctly. These results have been reported in investigations using detection or low-level recognition test objects, and to that extent this paper agrees with those other works. However plotting the data of, say Campbell and Robson (1968) together with the data from this experiment presents difficult problems of interpretation. No evidence exists to allow the assumption that the detection of sine or square waves and the identification of alphanumeric characters operate by the same psychophysical mechanisms. To the contrary, the redundency of a periodic test object would logically seem to increase the chances of its detection/recognition as compared to the identification of a singly-presented alphanumeric character of complex geometry. Even larger differences exist between this experiment and those of Blackwell or Patel and Jones. Therefore no direct comparisons of this paper to previous works will be made. Only the following statement shall be offered:

The identification threshold of the human visual system manifests characteristics similar to those described in detection/recognition investigations. Specifically the ability of the observer to accurately identify alphanumerics decreases when contrast decreases, or when a negative contrast polarity is presented, or when the average test object luminance decreases. Comparsion of this experiment to those others in any more detailed way is improper due to the large differences between the test objects utilized therein.

4.2 Suggestion for Future Investigations

The results of this research produce many questions which require answers. Some questions have probably been raised before but this only points out how much more important the answers would be.

Parameter manipulation in the present experiment is obvious: larger contrast and luminance ranges should be explored. Will longer dark adaptation periods significantly improve the observer's day -to-day variability or the between-observer variability? Is the 30 cycle per degree cut-off the result of requiring an identification task rather than a recognition/detection task of the human visual system, or is it a procedural flaw of this investigation? Although the present data parallel MTF data the thresholds are significantly different; is this a result of the differences between identification and recognition/detection tasks?

As has been emphasized repeatedly in this paper, test object design is critical to the results obtained. How does the identification threshold vary for the same character constructed in different ways at the same spatial frequency (for instance a block-form "8" and a circular one)? Can a test object be designed (bearing in mind Ronchi and Villani) with really equally identifiable alphanumerics? Can other patterns besides numbers and letters be used? In short, what is the ideal test object for the human visual system?

When first discussing the differences between detection, recognition and identification of visual information this author acknowledged that the definitions presented were heuristic in nature only. Can better, more precise definitions for these terms be devised? While considering such definitions thought should be given to how one would measure the respective thresholds. At the minimum, uniform visual task complexity whould be established.

Finally, how can the results of this experiment be properly explained in terms of information theory or the modulation transfer function? In order to apply information theory analysis one must be able to adequately describe the amount of information input into the (visual) system. A method for determining the number of bits of information an ARTO alphanumeric, or any test pattern, contains must be established. Also to be determined is how that information is affected by the testing apparatus. Only then could information transmission through the human visual system begin. to be analyzed.

Standard opthamological test procedures use maximum contrast test patterns. This involves only one point on the MTF curve of the human observer. How does the MTF correlate with the detection, recognition and identification thresholds of the visual system?

5. ACKNOWLEDGEMENTS

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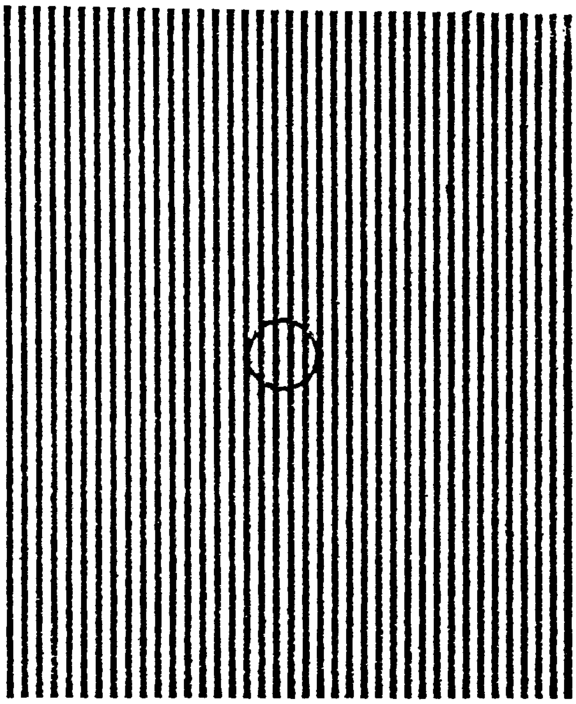
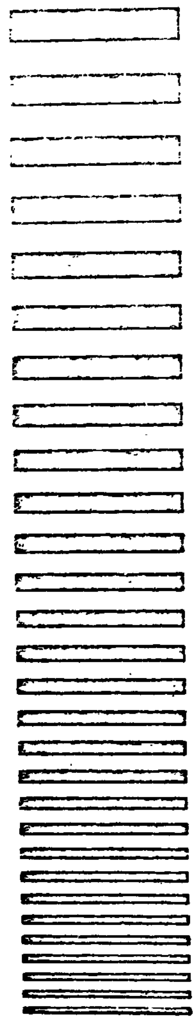
APPENDIX A.

SOME TEST PATTERNS USED IN HUMAN VISUAL RESEARCH

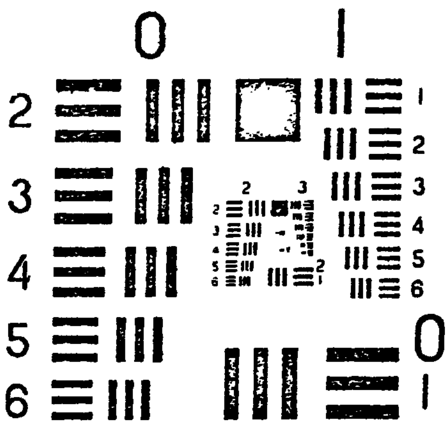
The following patterns are some examples of the designs that have been utilized as test objects by previous researchers in their studies of the human visual system and its responses.



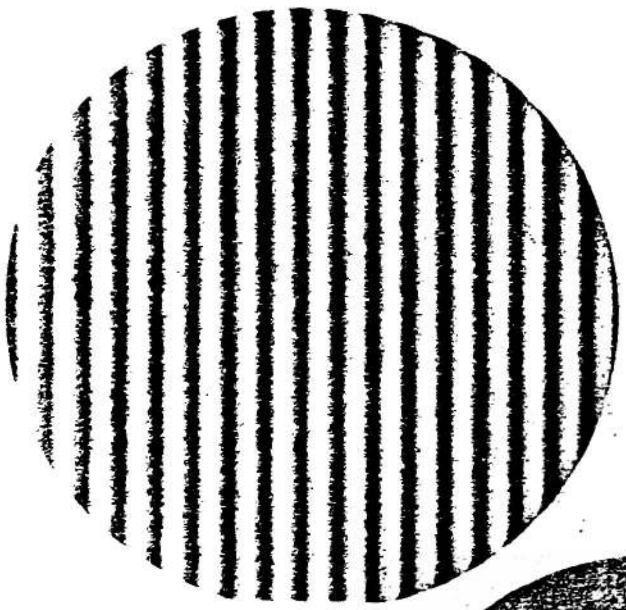
A Square Wave Grating
from Blakemore and Campbell (1969)



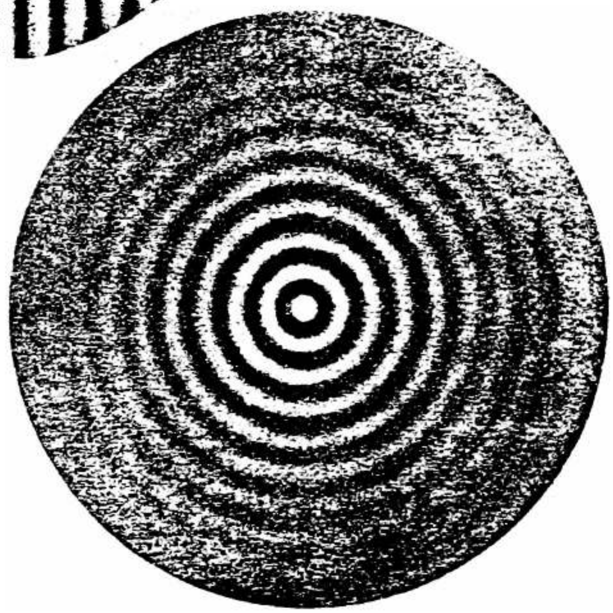
A Log Periodic Target
from Granger and Cupery
(1972)



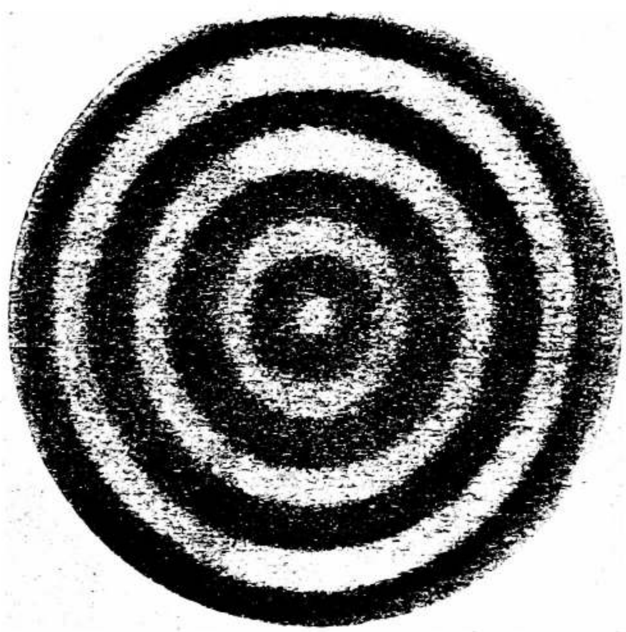
The USAF Tri-Bar Resolution Target
from Archer (1972)



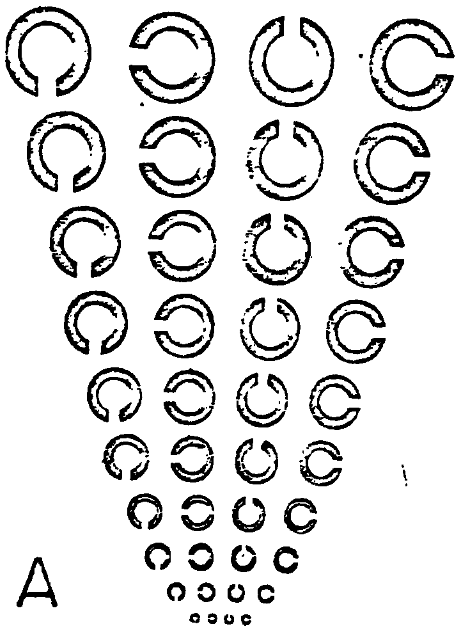
A rectilinear sine-wave target from Kelly and Magnuski (1975)



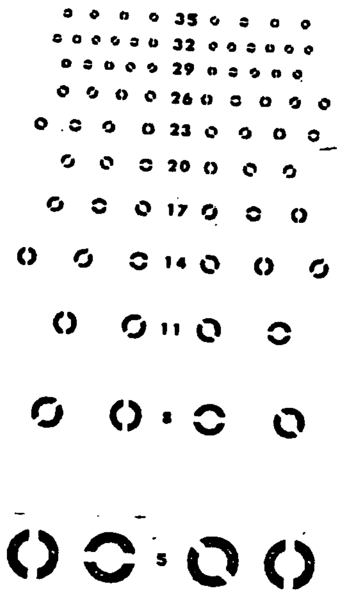
A circular Bessel-function target from Kelly and Magnuski (1975)



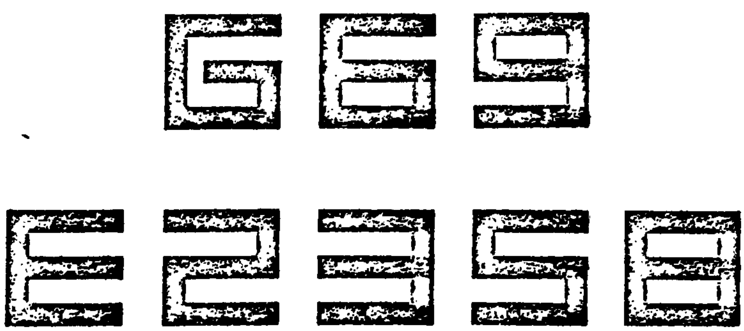
A Circular sine-wave target from Kelly and Magnuski (1975)



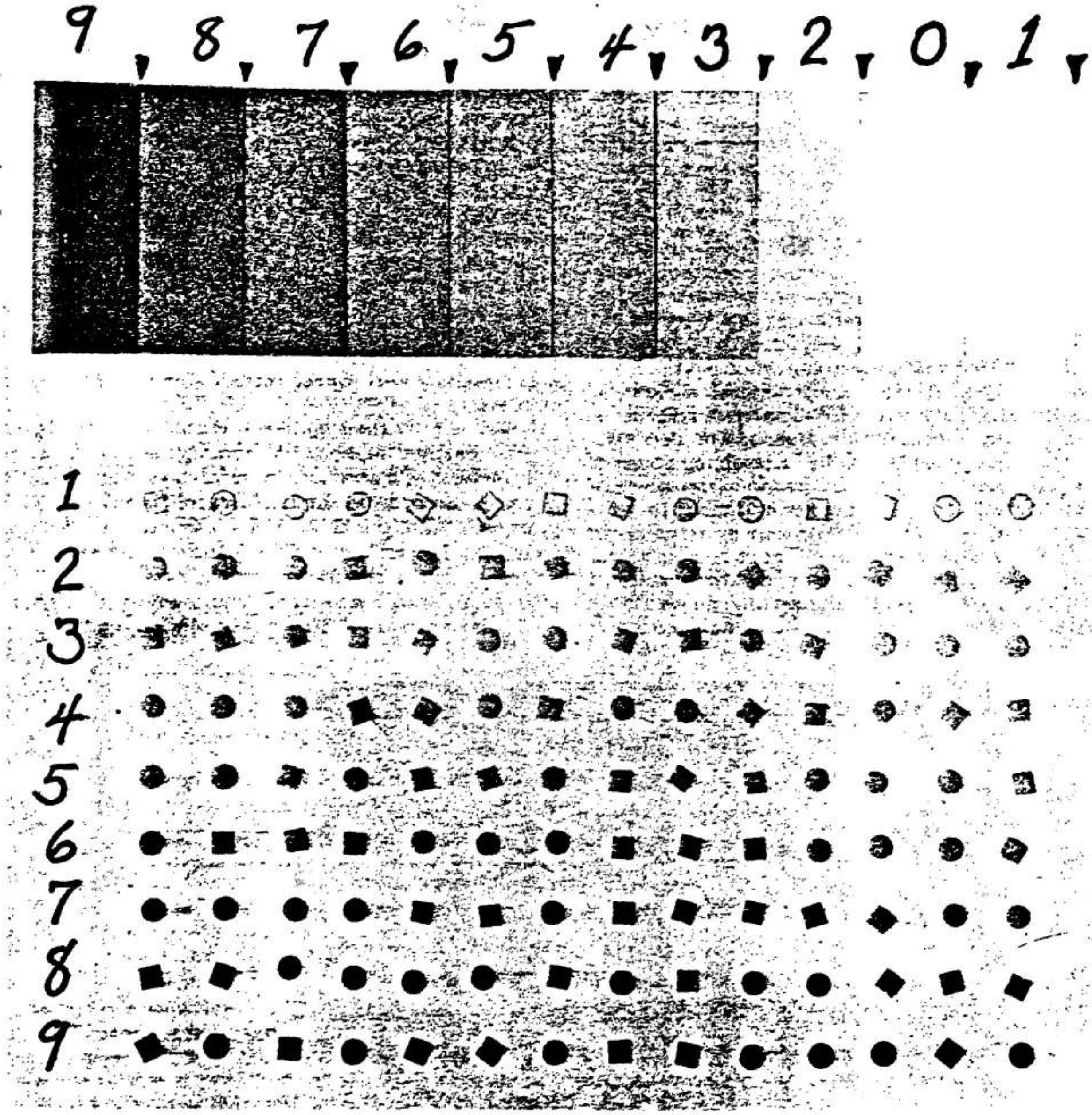
Landolt Rings
from Fry (1957)



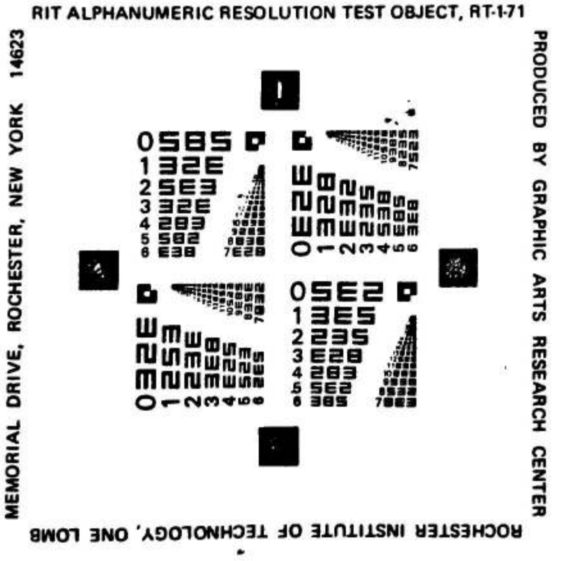
Double-Break Rings
from Villani and Innocenti
(1970)



The characters originally tested by Donaldson and Gough in their investigation of equally recognizable characters. From Archer (1972)



A Circle–Square Recognition Target from Barrows (1957)



The RIT–ARTO

APPENDIX B.

DERIVATION OF THE CONTRAST EQUATION.

As stated in the main body of this paper, the commonly used definition of contrast is written as:

$$\text{Relative Contrast} = C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \qquad \text{Eq. 1}$$

This experiment utilized both positive and negative imagery, and the following discussion applies to both polarities. The known average densities of the test quadrants are represented by D_{min} and D_{max} in the following calculations. The transmission of the test quadrants corresponding to these densities are then:

$$T_{min} = 1 \,/\, \log^{-1} D_{max} \qquad \text{Eq. i}$$

$$T_{max} = 1 \,/\, \log^{-1} D_{min} \qquad \text{Eq. ii}$$

If the luminance transmitted through the diffusor-filter assembly of the image beam equals L_1, and if the luminance transmitted by the diffusor-filter of the non-image beam equals L_2, then the maximum amount of light viewed by the observer is $(T_{max}L_1 + L_2)$ and the minimum would be $(T_{min}L_1 + L_2)$. Substituting these terms into Equation i yields:

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

$$= \frac{(T_{max}L_1 + L_2) - (T_{min}L_1 + L_2)}{(T_{max}L_1 + L_2) + (T_{min}L_1 + L_2)}$$

$$= \frac{(T_{max} - T_{min}) L_1}{(T_{max} + T_{min}) L_1 + 2 L_2} \qquad \text{Eq. iii}$$

Since the polarizers affect the final luminance levels viewed by the observer, factors T_1 and T_2 (see page B–3) are incorporated into Equation iii as follows:

$$C = \frac{(T_{max} - T_{min}) T_1L_1}{(T_{max} + T_{min}) T_1L_1 + 2 T_2L_2}$$

$$= \frac{(T_{max} - T_{min})}{(T_{max} + T_{min}) + 2 (T_2L_2 / T_1L_1)} \qquad \text{Eq. 2}$$

Using Equation 2 the average contrast values presented in this experiment were determined as described in the main body of the paper.

<u>Computation of Beam Intensities for Contrast Value Estimates</u>

When two polarizers are crossed, the transmission of the polarizers is given by the formula:

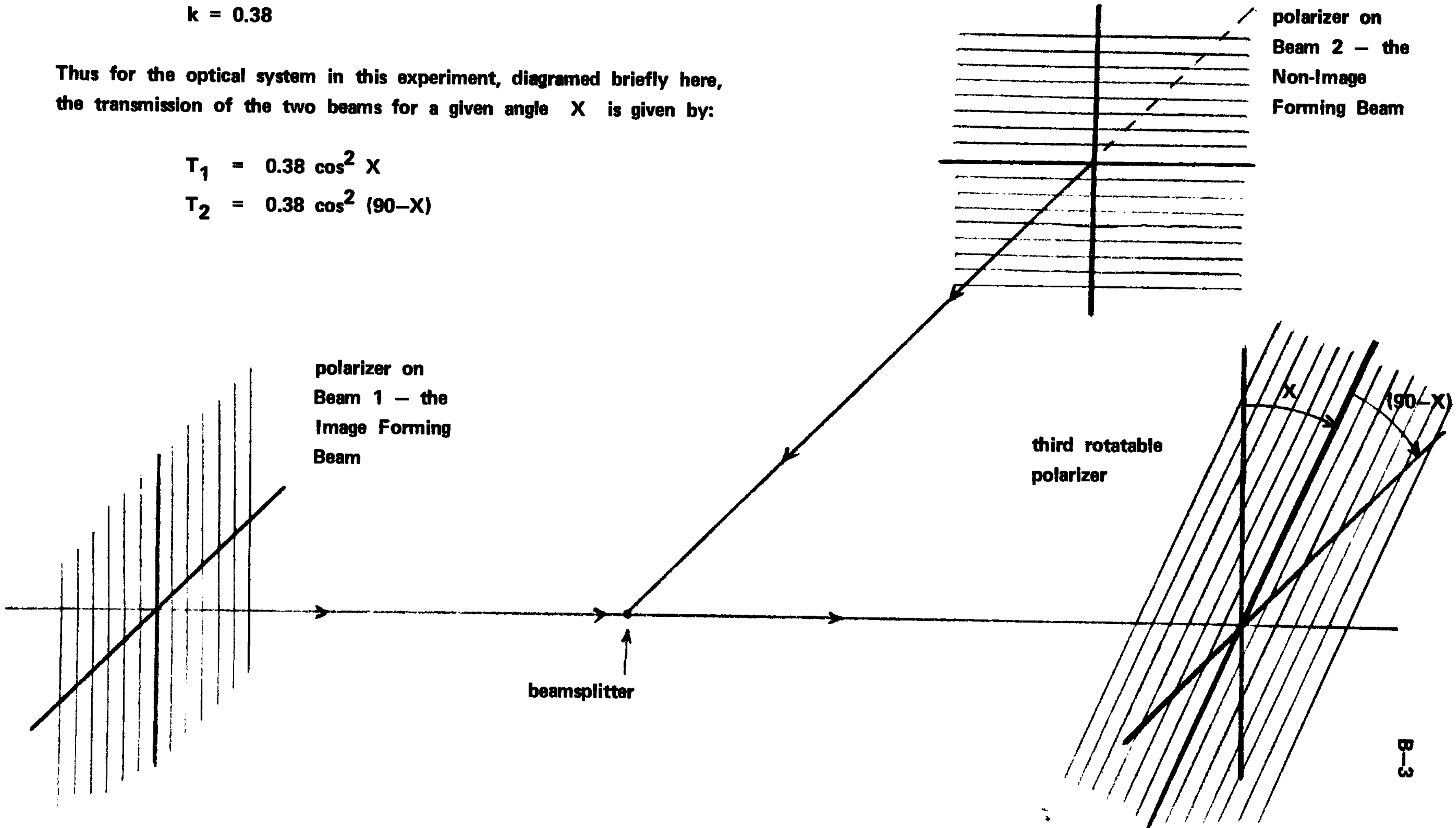
$$T \;=\; k \cos^2 X \,, \quad \text{where k is a constant dependent on the type of polarizer used.}$$

For Polariod Corporation's HN–38 polarization material:

$$T_{max} = 0.38 = k \cos^2 (0^o)$$
$$k = 0.38$$

Thus for the optical system in this experiment, diagramed briefly here, the transmission of the two beams for a given angle X is given by:

$$T_1 \;=\; 0.38 \cos^2 X$$
$$T_2 \;=\; 0.38 \cos^2 (90–X)$$



APPENDIX C.

DATA COLLECTION FORMS USED IN THIS INVESTIGATION.

The following pages are samples of the data collection sheets prepared for this investigation. The numbers to the left of each line indicate the group number of that line. The characters shown are a listing of the correct character sequence as presented on the ARTO quadrant, which has been identified at the top of the page. Along the bottom of the page spaces were provided to code the various test conditions. The contrast, quadrant, luminance level (here identified as "adaptation"), the contrast polarity or generation (identified as "pos./neg."), the observer's number, the date and more data can be entered in this area. By ordering the testing sequences prior to any testing and then filling out these forms to reflect the individual treatment combinations, and finally ordering the forms in the selected presentation sequence, it was possible to conduct the testing of an observer with the minimum of wasted time.

ecremental and incremental recognition thresholds of the human visual system for an alphanumeric test object"

ORIGINAL (raw) DATA COLLECTION SHEET

ONE

0	5		8		5	
1	3		2		E	
2	5		E		3	
3	3		2		E	
4	2		8		3	
5	5		8		2	
6	E		3		8	
7	E		2		8	
8	8		3		E	
9	2		E		5	
0	8		3		2	
1	2		8		3	
2	2		E		8	

13	8		3		E	
14	5		8		3	
15	8		E		5	
16	E		8		5	
17	3		E		8	
18	E		5		2	
19	2		3		5	
20	8		E		5	
21	8		3		E	
22	8		3		2	
23	5		2		E	
24	3		5		E	
25	3		2		E	

	DATE	OBSERVER	POS./NEG.	ADAPTATION	QUADRANT	CONTRAST
					1	

ORIGINAL (raw) DATA COLLECTION SHEET

TWO

0	E		2		E	
1	3		2		8	
2	E		3		2	
3	2		3		5	
4	5		3		8	
5	E		8		5	
6	3		E		8	
7	5		2		3	
8	2		3		5	
9	3		8		5	
0	5		3		8	
1	2		8		5	
2	E		5		2	

13	8		2		3	
14	5		3		2	
15	2		5		3	
16	E		8		2	
17	8		E		5	
18	E		3		8	
19	2		3		5	
20	8		E		5	
21	8		3		E	
22	8		3		2	
23	5		2		3	
24	3		5		E	
25	3		2		E	

	DATE	OBSERVER	POS./NEG.	ADAPTATION	QUADRANT	CONTRAST
					2	

ecremental and incremental recognition thresholds of the human visual system for an alphanumeric test object"

ORIGINAL (raw) DATA COLLECTION SHEET

THREE

	5		E		2	
	3		E		5	
	2		3		5	
	E		2		8	
	2		8		3	
	5		E		2	
	3		8		5	
	8		E		3	
	5		3		2	
	5		3		8	
	E		8		5	
	E		8		5	
	5		8		E	

13	8		3		E	
14	2		E		5	
15	3		2		E	
16	3		E		8	
17	3		5		E	
18	2		E		8	
19	5		8		2	
20	8		3		2	
21	3		E		8	
22	5		E		2	
23	8		3		2	
24	5		3		2	
25	5		8		3	

DATE	OBSERVER	POS./NEG.	ADAPTATION	QUADRANT	CONTRAST
				3	

ORIGINAL (raw) DATA COLLECTION SHEET

FOUR

	3		2		E	
	2		5		3	
	2		3		E	
	3		E		8	
	E		2		5	
	5		2		3	
	2		E		5	
	8		3		2	
	3		5		E	
	E		8		5	
	5		2		3	
	E		5		2	
	E		2		5	

13	2		3		5	
14	E		2		5	
15	5		8		2	
16	E		2		3	
17	8		E		5	
18	E		2		3	
19	2		5		3	
20	5		E		2	
21	8		E		5	
22	5		2		3	
23	5		2		3	
24	E		2		5	
25	3		E		3	

	DATE	OBSERVER	POS./NEG.	ADAPTATION	QUADRANT	CONTRAST
					4	

Appendix D

Measurement of Average Luminance Levels

While the apparatus was turned on and stabilizing, a Spectra Pritchard Photometer (serial number 259) was calibrated to a Spectra Regulated Brightness Source (serial number 2123). The photometer was positioned where the observer's eye would be during testing. The angle of view was adjusted so that the test quadrant was just circumscribed by the circular collecting field of the photometer (see Figure D1). Since light came only from the quadrant the overlapping of the collection field had no effect on the readings, and yet the measurements simulated the actual visual situation under test very closely. With 0.0 ND at neutral filter 1, the total luminance levels presented to the observer by a positive quadrant were measured for all contrast levels. Luminance levels for the 0.6 ND and 1.0 ND filtrations were similaryly evaluated. The entire process was repeated for a negative quadrant. The readings were then averaged within each filtration level (0.0, 0.6, 1.0) and these values were found to be as follows:

0.0 ND . . . . .0.200 ft-L
0.6 ND . . . . .0.045 ft-L
1.0 ND . . . . .0.015 ft-L

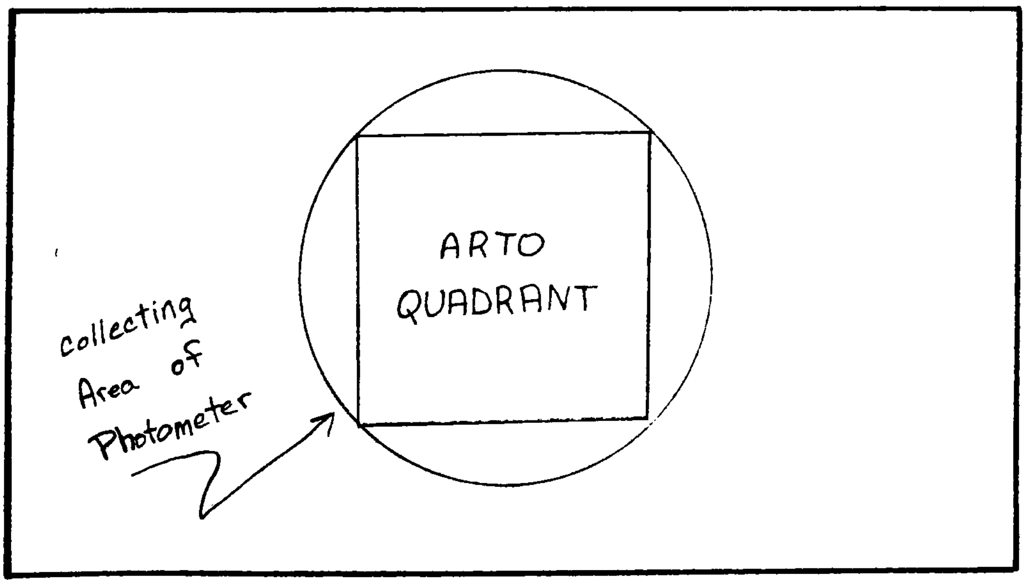


Figure D1. Placement of collecting area of Pritchard Photometer with respect to the ARTO.