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# ABSOLUTE JUDGMENTS OF LIGHT INTENSITY

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## FOREWORD

This study was conducted by Dr. Richard E. Wienke of the Presentation of Information Branch, Human Engineering Division, Behavioral Sciences Laboratory. The research was conducted under Project 7183, "Psychological Research on Human Performance," Task 718302, "Fundamental Parameters in Perception." The report covers research performed between August 1963 and July 1964.

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This technical report has been reviewed and is approved.

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Technical Director
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## ABSTRACT

The assumption was made that absolute judgments of luminance could be made providing the eye remained in a relatively constant state of dark adaptation during the judgmental process. This hypothesis was tested by presenting each of twelve naive subjects with a preselected, random series of five stimuli which ranged from stellar magnitude 2.30 to 5.33. Each subject made 200 judgments at the approximate rate of three per minute. Results indicated two stimuli lying about 0.90 steller magnitudes apart were confused, but near certainty of discrimination occurred when two stimuli were separated by approximately 1.40 steller magnitude.

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## SECTION I

## INTRODUCTION

Hyman (ref 2) has suggested that one method of ranging a space vehicle is to estimate its stellar magnitude, that is, its illuminance. Then, with a rough estimate of its intensity, it is possible to determine its range either by calculation or by nomograph. While it is not difficult to make very accurate photometric judgments when the reference standard is in close proximity to the unknown, the reliability and accuracy of judgment is reduced as a function of the distance between the two stimuli. The worst case, of course, is when there is no other stimulus in the observation field.

Walsh (ref 6) has explained the difficulty in making absolute judgments as one of adaptation. He states: "The enormous range of sensitivity possessed by the eye can readily be appreciated from the fact that the ratio of the luminance of objects seen by direct sunlight to that of the same objects seen by starlight on a clear, moonless night is at least 10 million to 1. So perfect is the adaptation over a very extensive part of this range that alterations in luminance in a ratio of as much as 10 to 1 or even 100 to 1 are often scarcely noticed if the change is not too sudden. . . . The power of adapting itself to different conditions of lighting makes the eye useless for the direct measurement of luminous energy and in all practical visual photometry the eye is relied upon solely for the determination of the "equality" of the two adjacent fields as regards either brightness or contrast."

Baker et al (ref 1) have shown that the state of the adaptation of the eye is a function of the luminance of the entire visual field. In a star field, the total luminance will be nearly constant and, consequently, the state of the adaptation of the eye should be nearly constant. If absolute judgments of luminance depend on the stability of the adaptation of the eye, it is probable that absolute judgments of intensity can be made of low intensity stimuli in a star field.

The hypothesis tested in this experiment was that subjects with normal visual acuity could successfully scale, or place into categories, stimuli which were of differing intensities when the subject had no external cues if the eye is held in a constant state of dark adaptation.

## SECTION II

## APPARATUS

Point sources in dark surrounds may be produced in several different fashions. Experimental considerations indicated that the point source must have a substantial area for measurement but little or no area so that it would be a physiological point source. The fulfillment of these two conditions is not difficult providing the terms "substantial area" and "physiological point source" can be adequately defined.

The area required is a function of the field of view of the measuring instrument. The Spectra Brightness Spot meter with a 1/2° field of view and with the appropriate supplementary lens will measure the light flux of a circular field with a diameter of about 3.2 mm. Thus, a 3.2 mm field is adequate.

The visual angle of a 3.2 mm field at the experimental distance of 14.2 m will be $\frac{0.0032}{14.2} = 0.00015$, or about a 32-sec. arc. According to Tschermak (ref 5), the apparent size of a 2- to 3-min. image is, because of the aberrations of the eye, a function of the intensity of the source and essentially independent of the physical size of the source. The limiting visual angle for a point source, according to Middleton (ref 3) is a 10-min. arc. This value is in conformance with Ricco's law. Accordingly, the 32-sec. target fulfills all of the physical and physiological requirements for a point source.

A projector system was selected as the best available method of producing the point source. It is schematically shown in figure 1. The optical components are mounted on a lathe-type optical bench. The source, mounted at 0 mm, is an 18 AT10/1P-6V incandescent lamp with a C-8 filament. A coiled filament lamp rather than a ribbon filament was selected because the coil produces an image of higher luminance than the ribbon with only a minor degradation of image quality. Fluctuations in the lamp's luminous emittance were reduced by supplying the lamp through a 115-constant-voltage transformer and a 6-volt transformer.

The lamp was placed in a lamp housing and a 44 mm x 50 mm achromatic lens was placed about 175 mm away. This lens concentrated the flux in a relatively small area of a diaphragm, with a 0.76 mm aperture, which was about 25 mm from the lens. The slightly diverging beam was intercepted by a 37.5 mm x -100 mm lens placed about 550 mm from the aperture. The projection lens, 25 mm x 500 mm, was placed 381 mm from the negative lens.

An iris diaphragm was placed a convenient distance between the negative lens and the projection lens to confine the light to the central portion of the projection lens and thus to reduce aberrations. The resulting image has a diameter of about 3.2 mm at 11.6 ± 0.3 m. The image is essentially a yellowish-white patch with two minute blue fringes.

The optical system, with the exception of the projection lens, was placed within a light-tight structure so that there was no stray light within the laboratory.

The luminance of the light patch and the distance of the patch from eye are the two critical factors in the calibration of the stimulus. Moon (ref 4) demonstrates that illuminance of a circular target may be found from the following formula:

$$E = \frac{Br^2}{D^2}$$

where E = the illuminance

B = the luminance

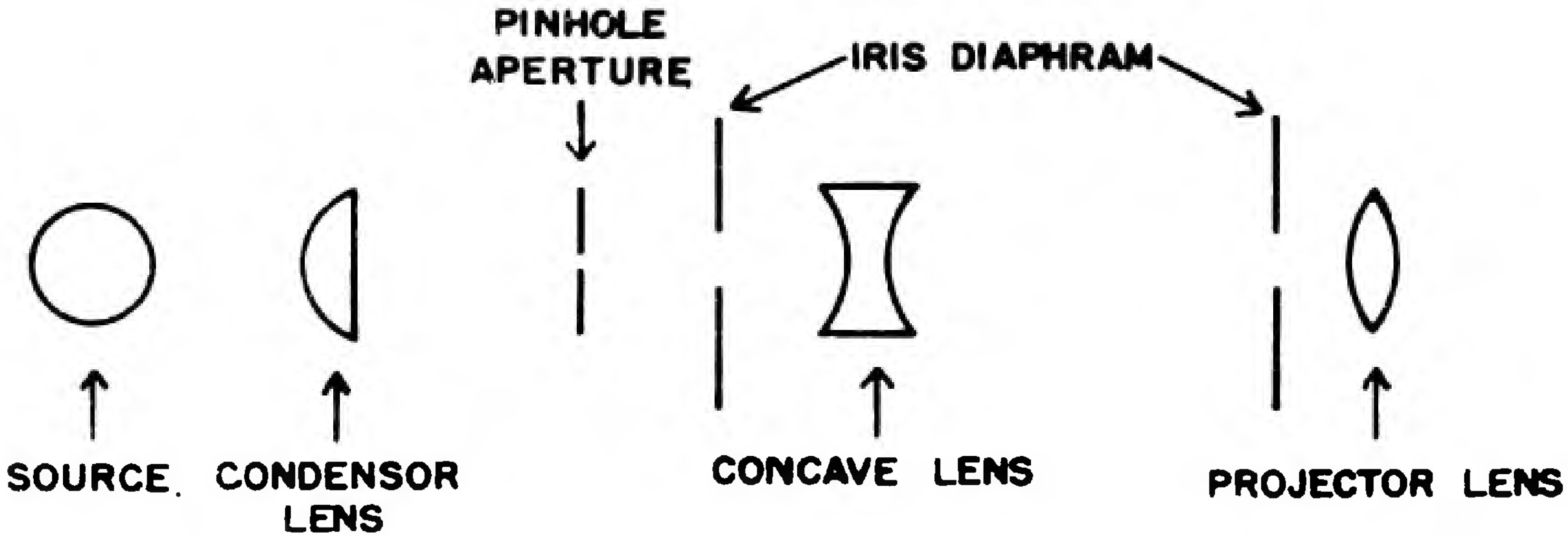


Figure 1. Schematic View of Apparatus

$r$ = the radius of the patch

$D$ = the distance

Since $\frac{r^2}{D^2} = c$, the illuminance may be found by multiplying the luminance of the light patch by the appropriate constant.

In the present experiment, the luminance was varied by projecting the image on small cardboard screens of differing reflectance. The mean luminance, in footlamberts, was found by determining the luminance on three successive days after the lamp had been seasoned.

After the luminance values had been transformed to illuminance, the equivalent stellar magnitudes (SM) were determined by means of the following equation:

$$m = -2.5 \log E_M - 16.72$$

where $m$ = stellar magnitude

$E_M$ = the illuminance in kmc

Table I gives the mean luminance, the illuminance in kmc at 14.2 m, and the stellar magnitude for each of the five stimuli.

TABLE I

CALIBRATION VALUES

| Stimuli | mL | $E_{kmc}$ | Stellar Magnitude |
|---|---|---|---|
| 1 | 2.14 | 0.26 | 2.30 |
| 2 | 1.24 | 0.15 | 2.89 |
| 3 | 0.56 | 0.07 | 3.76 |
| 4 | 0.30 | 0.037 | 4.43 |
| 5 | 0.13 | 0.016 | 5.33 |

The subject sat in a light-tight booth which, in turn, was in a dark room which had a minimal ambient illuminance level. The subject viewed the stimulus through a 15 x 25 cm shutter. This shutter was closed except throughout the actual time of observation.

## SECTION III

## PROCEDURE

Each subject was seated in the booth and allowed approximately 15 minutes for dark adaptation. At the end of the adaptation period, the subject was given the following instructions:

> "In this experiment we wish to find out if it is possible to judge the brightness of lights. Therefore, we will show you a series of five lights ranging from fairly bright to very dim. The brightest will be number one and the dimmest, five. Each time you see a light, give the number which indicates its brightness. Just before you see each light, I will say ready-now so that you will know the next observation is coming up. First, we will show you each of the five lights twice and tell you their numbers. Are there any questions?"

The stimuli were then presented serially from number one to number five. As each stimulus was presented, the subject was told: "This is stimulus number __. Do you see it?"

Normally the subject had little difficulty seeing either number one or number two. Some subjects did have occasional difficulty with number three and progressively greater difficulty with numbers four and five. If difficulty did occur, the subject was instructed in the proper techniques of scotopic search and viewing. Only occasionally did a subject have difficulty in viewing during the second demonstration trial.

After two series of five different stimuli were presented, a practice series-trial of twenty stimulus presentations was made. This was followed by ten series of test trials for a total of 200 stimulus presentations per subject. The stimuli were always presented in a predetermined random order, but the restriction was placed that each stimulus was presented an equal number of times. The subject was not informed of the difference between the practice series trial and the performance series trials. There was no knowledge of results given the subject. The subject was given a brief rest after the fifth series-trial.

Twelve male college students were employed. Other than a requirement for 20-20 vision, either corrected or uncorrected, no restrictions were placed on the subjects.

## SECTION IV

## RESULTS

The responses were correlated against the stimulus by means of the Pearson product-moment method. The values, given in table II, suggest that intrasubject validity is sufficiently high to proceed with additional analysis. The correlation coefficients approximate a symmetrical distribution and since the median and composite coefficients are essentially the same, it may be concluded that the sample is a satisfactory representation of the population.

TABLE II

THE INTRASUBJECT VALIDITY OF ABSOLUTE JUDGMENTS OF INTENSITY

| Subject | r |
|---|---|
| 1 | .88 |
| 11 | .87 |
| 7 | .86 |
| 9 | .86 |
| 10 | .85 |
| 4 | .81 |
| 5 | .79 |
| 6 | .76 |
| 12 | .74 |
| 2 | .69 |
| 8 | .64 |
| 3 | .59 |
| Median | .80 |
| Composite | .81 |

Examination of the individual scatter diagrams suggested that the subjects could generally make valid judgments of illuminance. If the stimulus was miscalled, it would be most likely the next larger number (lower illuminance level). The validity of this hypothesis was tested by means of the "t" test for proportions in the composite data which is given in table III. The statistical hypothesis proposed was that there was only a chance difference in response between the correct response to a given stimulus and the other responses made to that stimulus.

TABLE III

FREQUENCY OF RESPONSES

| Stimuli | Responses | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1 | 159 | 192 | 91 | 29 | 9 |
| 2 | 43 | 195 | 160 | 66 | 16 |
| 3 | 1 | 45 | 195 | 178 | 61 |
| 4 | 0 | 11 | 86 | 230 | 153 |
| 5 | 0 | 2 | 8 | 119 | 351 |

Table IV gives the "t" values. It will be seen that there is a gradient established which suggests that generally the subjects cannot discriminate between a stimulus and the next dimmer stimulus, but otherwise they can discriminate between a stimulus and all other stimuli.

TABLE IV

THE PROBABILITY THAT CORRECT JUDGMENTS HAVE BEEN MADE AS TESTED BY THE "t" TEST

| Stimuli | Responses | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1 | | 1.76 | 4.30* | 9.48* | 11.57* |
| 2 | 9.85* | | 1.86 | 7.98* | 12.32* |
| 3 | 13.85* | 9.67* | | 0.88 | 8.38* |
| 4 | * | 14.11* | 8.11* | | 3.93* |
| 5 | * | 18.58* | 18.11* | 10.70* | |

*Null hypothesis is rejected at the 0.001 level of confidence.

## DISCUSSION

The correlation coefficients indicate that difficult intensity judgments can be made by essentially naive subjects. The characteristics of the distribution of the correlation coefficients suggest that the population has been adequately sampled. Consequently, any conclusions which are drawn may be accepted with a high degree of confidence.

Examination of the "t" values in table IV shows that a stimulus is never confused, on a reliable statistical basis, with a more intense stimulus. Any confusion of stimuli lies with the less intense adjacent stimulus. There is seldom any confusion of two stimuli which are separated by one or more stimuli.

If these results are translated into stimulus units, then the subjects confused two stimuli which lay 0.90 stellar magnitude apart, but not two which lay as little as 1.40 stellar magnitudes apart. It should be recalled that there is a constant judgmental error so that these values are always in a positive direction, that is, the magnitudes are always larger and never smaller.

Traditionally in psychophysics, it is expected that an increase by a factor of two will bring a stimulus from its threshold to near certainty of observation. In the present case, the data indicate that a factor of two is inadequate and that they must be increased more nearly by a factor of four if certainty of discrimination is to be obtained. In comparison with visual discriminations where the stimuli lie in juxtaposition, this is a very coarse discrimination. However, it is a discrimination which can be reliably made if proper conditions of observation can be established and maintained.

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