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FLASHRATE DISCRIMINABILITY OF HUMAN SUBJECTS AT THRESHOLD INTENSITY LEVELS

BY

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ABSTRACT

A study was conducted to determine the ability of human subjects to correctly identify three different flashrates at the differential stimulus threshold of detection. The subject viewed a 40 degree diffusely illuminated surround with a two minute aperture through which the stimulus white light was passed. The five surround luminance levels of white light used were 2700, 100, 1.0, 0,01, and 0.001 ft. lamberts. The observers were instructed to use only foveal vision.

Flashrates of 40, 80, and 160 flashes per minute were randomly presented as stimuli to the five observers. A total of 900 threshold measurements per surround level taken showed that for surround levels of 0.01 and 0.001 ft. lamberts the subjects at or near threshold tended to see each flashrate as faster than it actually was. Thus the 80 flashrate was often confused for the 160 flashrate and the 40 flashrate was confused with the 80 and sometimes the 160 flashrate. Each observer reported this though some manifested it much more clearly in their data. Tenable explanations are offered to explain the appearance of the very fast flashrate for the two lower surround luminances.

INTRODUCTION

A study was undertaken at the Honeywell Research Center Vision Laboratory to investigate flashrate discrimination of human subjects at differential threshold levels of stimuli intensity. The stimulus being a circular aperture which subtended an angle of two minutes from the position of the subject's eye and through which white light from a tungsten source was flashed. Five different white surround luminance levels were chosen as parameters ranging in luminance levels from that of the sky in proximity to the sun, to the sky on a moonless night.

The purpose of the investigation was to conduct a basic expriment on flashrate discrimination at threshold levels of intensity as well as to acquire information on the effectiveness of a flashing light system for a simplified visual telecommunication system. The three flashrates chosen coincided with the three different flashrates used by an air anti-collision light system to inform the observer of the directional path of the observed plane with respect to that of the observer.

BACKGROUND

Very little can be found in the visual literature on flashrate discrimination or of the subjective appearance of different flashrates. Bartley (1) reports that at dim levels of stimulus intensity when the critical fusion frequency is about four flashes per second, a flashrate just lower than this will produce a flutter which has an appearance of being much faster. Increasing the stimulus intensity will produce a subjective flashrate corresponding approximately to that of the actual flashrate. Bartley postulates that this apparent "fast" flashrate should be attributed to the visual pathway at a higher level than the receptors.

An earlier experiment not employing a flashing light in the true sense but rather a rotating disc with an illuminated radial slit was conducted by Charpentier (2). While fixating the center of the rotating disc the illuminated radial slit produced an intermittent stimulus to the retinal receptors in the image pathway of the illuminated radial slit. Charpentier observed that a succession of light and dark bands followed the moving slit and that the magnitude of this effect was dependent upon the adaptive state of the eye, the intensity of the stimulus and the region of the retina stimulated. Computations made by Charpentier showed that the first recurrent image appeared about 200 msecs after the primary image.

Adler (3) in discussing Charpentier's observation points out that after a single stimulus of light of shorter duration than the action time, the primary image will consist of a rapid rise in intensity followed by a less intense fluctuating or pulsing sensation before termination of the primary image.

Experiment I - Apparatus

The experimental apparatus used in this experiment is diagrammed in Figure 1. In the optical system, light emanating from a single source, traverses two separate channels producing the uniform surround luminance in the integrating sphere and the stimulus light. The light source was provided by an incandescent 18 ampere-6 volt, medium prefocus, single coiled filament bulb. Line current run through a varitran and a 6 volt transformer supplied the power for the lamp. Attached by leads to the varitran was a voltmeter which provided for accurate checking and adjusting of the voltage before each judgement. The varitran was run throughout the experiment at 120 volts.

Light from the source traveled nearly identical routes for the two channels. The light was collected and the focused in the plane of the chopper blade. A collimating lens then collected the light past the chopper and directed it to a front surface mirror (M1 and 2) wich reflected the light at right angles to the incident beam. The parallel beam then traveled through a filter holder aperture where neutral density filters were used to make gross attenuations of the light intensity. A subsequent lens then converged the beam for passage through the optical wedge aperture. The optical wedge provided a means to more precisely attenuate the light beam. A rack and pinion mechanism enabled the operator to position the optical wedge to the

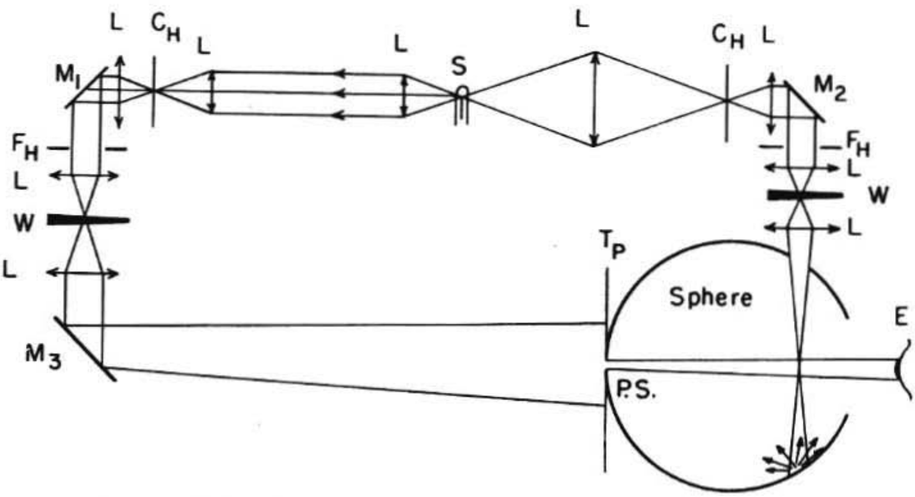

Fig. 1. EXPERIMENTAL APPARATUS

S = Light source; L = Lens; Ch = Chopper blade;
M = Mirror (rt. angle); Fh = Filter holder;
W = Wedge (optical neutral density); Tp. = Target plate;
P.S. = Point source aperture; E = Eye.

desired density. After passing through the wedge aperture the light was then collected. At this point the light is treated differently in each channel. The light illuminating the integrating sphere is converged and directed through a small aperture into the sphere. It is then reflected and uniformly diffused after the first reflection inside the sphere. The chopper blade intersecting the light to the integrating sphere was removed to provide steady light for the surround luminance. Light traveling in the opposite channel is reflected through 90 degrees by a front surface mirror (M_3) which directs it to a target plate. The target plate has a circular aperture with dimensions that provide a 2 minute source of light as subtended at the entrance pupil of the eye. The surround field subtends 40 degrees at the eye.

In order to obtain the two highest surround luminance levels an incandescent bulb, operating at the same voltage to assure a nearly identical color temperature, was placed inside the integrating sphere. The lamp was positioned so that the observer saw no part of the bulb.

This optical system provided the desired surround luminance levels and by using neutral density filters in conjunction with the optical wedge, attenuation to an adequate number of point source intensities was possible.

Eye allignment with the stimulus was assured by a bite-board mechanism. The three flashrates used were 40, 80, and 160 flashes per minute. These were determined by adjustment of the voltage supply to a variable speed motor which drove the chopper. The sector width of the disc was adjusted for each speer to maintain a constant stimulus duration of 4 msecs.

Experimental Procedure

The observers were five young male employees of the Honeywell Research Center, who were screened with their dominant eye and no history of visual disorder. The subjects used only their dominant eye for flashrate determinations. They were given several experimental training sessions during which data was collected. When these data showed a leveling off of the visual thresholds, the observers were considered trained. At the beginning of each session the observer was again shown the flashrates at a high intensity level in order to refresh his memory of them. After the flashrate familiarization period the subject dark adapted for 10 minutes and then light adapted to the surround luminance selected for that session for 5 minutes.

The flashing light stimulus was exposed continually. The neutral density wedge and filters were adjusted so that at the beginning of each trial series the source was too dim to be seen. The intensity was then raised by a .01 density step on each trial, accompanied by a "now" signal from the experimenter. The observer was instructed to judge "no" meaning. I do not see it or, if he saw the light, he was asked to say either "fast", "medium", or "slow".

Flashrates were randomly changed from series to series and frequently a series was continued 3 to 6 steps beyond correct identification so that it was impossible for the observer to obtain information other than visual cues of the correct flash rate. The intensity level of the first of three successive positive responses was taken as the detection threshold. The first of the three successive correct identifications was taken as the correct identification threshold.

Thirty trial series producing 30 determinations of the detection and identification thresholds were obtained for each of three flashrates and for each of the five luminance levels of the surround. The surround levels were: .001 ft. 1 (moonless clear night sky), .01 ft. 1 (twilight), 1.0 ft. 4 (20 minutes after dawn, clear sky), 100 ft. 1 (overcast day sky), 2700 ft. 1 (clear bright daylight sky close to sun). Each of the five observers replicated the entire experiment, producing 450 detection thresholds and 450 correct identification thresholds per condition or 4500 thresholds in all.

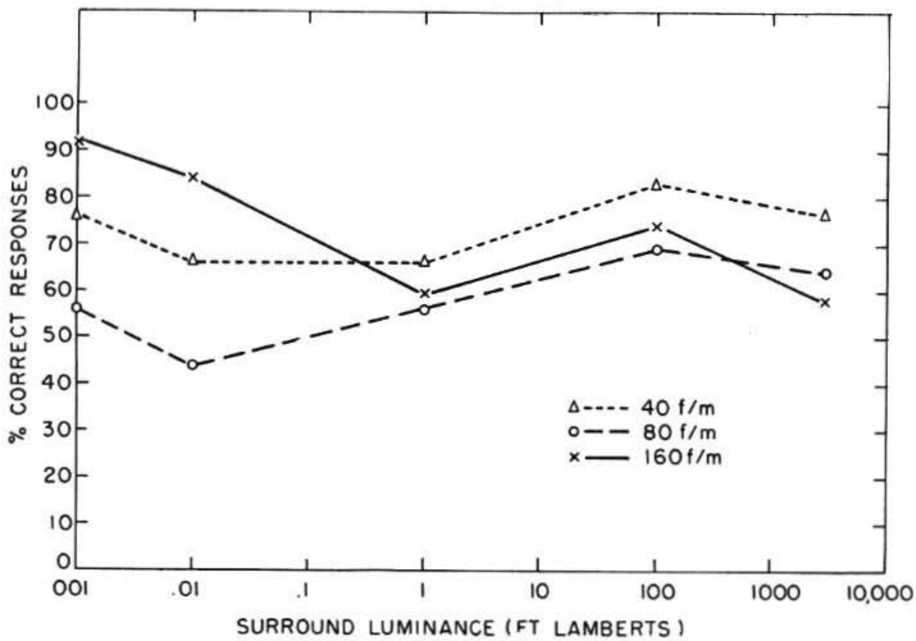

Fig. 2. The percentage of correct identification responses at the threshold level of seeing are plotted against the luminance level of the surround. Each percentage value represents an average of the five subjects combined results.

Results

Figure 2 shows that for the brighter levels of surround luminance (2700 and 100 ft. lambert levels) the slow flashrate (40 f/m) is more frequently identified correctly at the detestion threshold level than the medium (80 f/m) and fast (160 f/m) flashrate. In contrast, the 160 f/m flashrate is more frequently identified correctly with the two lower surround luminance levels. The 80 f/m flashrate was very confusing at the two lower levels of surround luminance as manifested by the graph. With the exception of the 2700 ft. lambert level of surround luminance the 80 f/m was confused more often than either the 40 f/m or 160 f/m flashrates.

Figure 3a, b, and c, display the distribution of wrong responses for the five different surround luminance levels. Of significance for the 160 f/m flashrate is

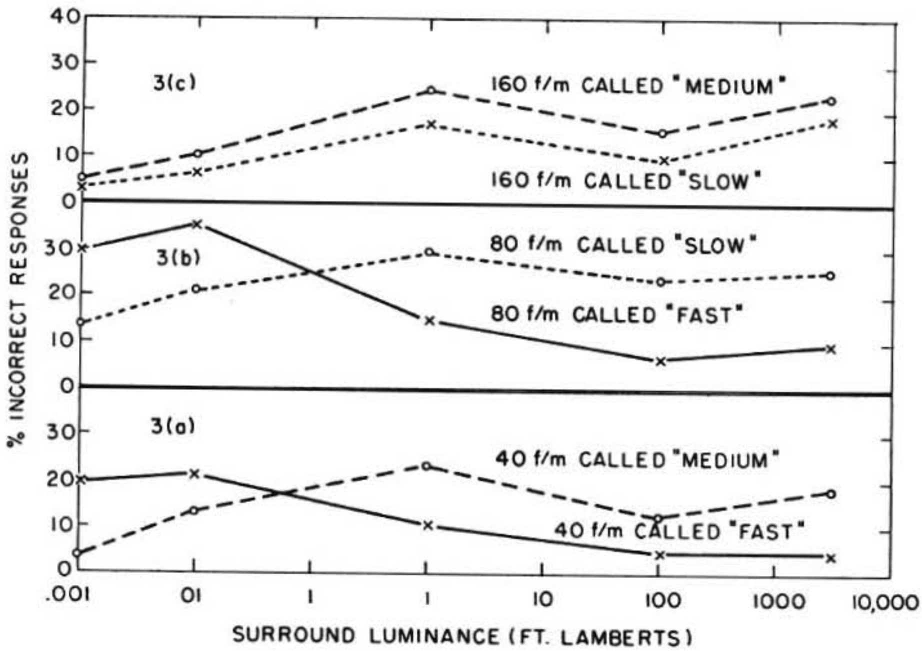

Fig. 3a, b, c. The above graph shows the distribution of the incorrect responses as reported by the five subjects. This is to demonstrate for which flashrate the correct flashrate was confused with at each of the five levels of surround luminance employed in the experiment.

the decrease in incorrect responses for the 0.01 and 0.001 ft. lambert level of surround. Of additional interest is that for all surround luminance levels the

160 f/m flashrate when reported incorrectly was reported more often as the "medium" flashrate rather than the "slow" flashrate.

Of importance for the 80 f/m and the 40 f/m flashrates is that the incorrect responses are more frequently the slower flashrate of the two possibilities for the higher levels of surround luminance and the faster flashrate of the two possibilities for the two lower levels of surround luminance. To elaborate on this, Figure 3b shows that above the 0.1 ft. lambert surround level the 80 f/m flashrate is reported, when reported incorrectly, as "slow" more often than "fast". Figure 3a demonstrates that above the 0.1 ft. lambert surround level the 40 f/m flashrate, when reported incorrectly, is more frequently called "medium" than "fast".

Observer's Reports

The two lower levels of surround luminance proved to be the most interesting and will be the two levels dealt with most extensively in this paper. When adapted to the two dimmer surround levels the subjects at times reported that a flashrate appeared very fast at first. This was reported by all subjects.

Experiment II - Flash Rate Discrimination in Different Retinal Locations and With Chromatic Stimuli.

The objective of this supplementary experiment was to determine if the apparent "very fast" flashrate is evident with conditions other than with foveal vision and white light stimuli.

Apparatus

The apparatus was the same as that used for the previous experiment except that an interference filter to provide chromatic stimuli was inserted into the optical system at F_H (Figure 1) in the channel providing the flashing light stimulus. In addition small red fixation points, two minutes in angular size as subtended from the observer's eye, were placed at 1, 2, 3, 4, 7.5, 10, 12.5 and 15 degrees outward in the right eye field of vision. The intensity of the fixation spots were reduced to just above foveal threshold. A switching mechanism enabled the operator to select the desired fixation spot.

Experimental Procedure

Two male observers who were subjects for Experiment I were used for this experiment. Because of their training in the previous experiment, it was assumed that the subjects were well trained without any additional training sessions for this experiment.

The flashrate was set at 40 f/m. This same flashrate was used throughout the experiment. The same procedure was followed as described under Experiment I. After dark adaptation, the subject was instructed to look at the red fixation spot, or, when foveal vision was desired, to look at the aperture while the operator increased the intensity of the flashing light by assigned increments. He was instructed to report after each increment "NO" if he did not see a flashing light, or to report, "slow", "medium" or "fast". When the black surround was used the one degree fixation spot was left on to help orient the subject with respect to the aperture.

In addition to studying the dependence of confusion upon chromatic stimuli and eccentric foveal angles of fixation, two luminance surround levels were selected. The two surround levels chosen were 0.0 and 0.01 ft. lambert of luminance. The 0.0 surround was established by completely blocking of the channel of light which could enter the sphere. The observer's aperture was left open but the minute amount of stray room light which may have entered the sphere was not measurable. The 0.01 ft. lambert surround level was established by setting the sphere at one ft. lambert using the McBeth illuminometer and then introducing a neutral density filter and wedge setting to obtain a density of 2.0.

The color of the flashing light was established with interference filters. The two interference filters used and their characteristics are as listed below:

	Dominant Wavelength
Blue (2nd order)	428 mμ
Red (2nd order)	633 mμ

A blocking red filter with a cutoff between 600 and 605 mμ was used in conjuction with the 2nd order red interference filter.

Results

Figure 4 summarizes the results on two observers. Only preliminary findings were taken concerning the relationship between the colors of the stimulus and the number of "fast" responses reported. These findings indicated that this phenomenon was independent of the color stimulus used. The duration of the dark adaptation period also did not seem to influence the number of "fast" responses.

The most significant dependent variable is retinal position. For angles of fixation beyond 2° the subjects did not report seeing the "fast" flashrate during two trial sessions. Sessions were then begun using only foveal vision and 1° and 2° angles of fixation. Figure 4 illustrates that subject B.E. only reported the flashing light as "fast" when he was observing the light with foveal vision. J. D.'s results are not

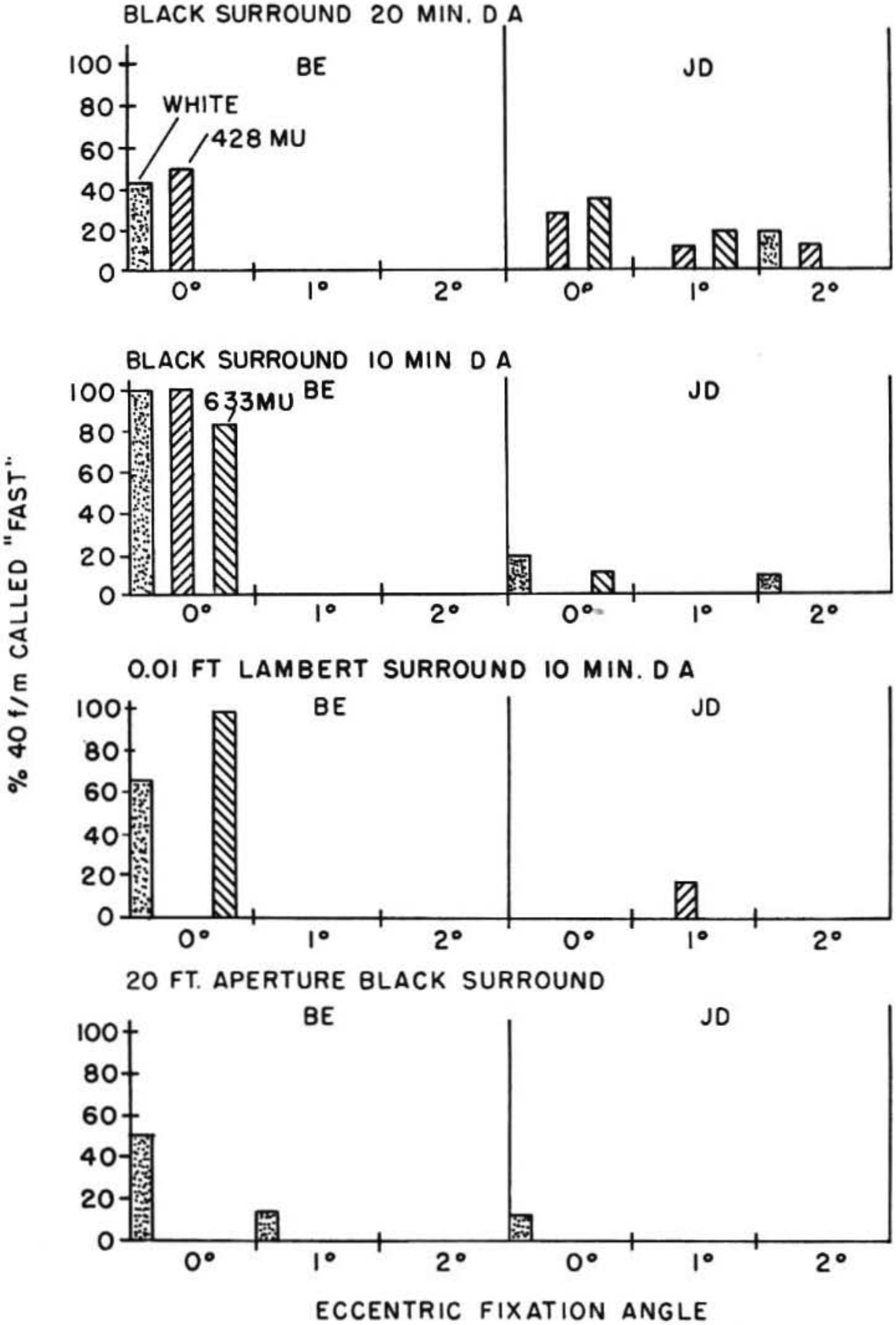

Fig. 4. Per cent distribution of combined "Medium" and "Fast" judgements as a function of fixation angle and stimulus color.

quite as clearcut. With the surround level at 0.01 ft. lamberts he did not report a "fast" response for nine of the colored stimuli with foveal vision. The combined data on the three fixation positions are shown in Figure 5.

In addition to the above results the two minute flashing aperture was replaced with an aperture subtending a 20 minute angle at the eye. Only enough experimental trials were conducted to indicate that this phenomenon was not restricted to a point source of light.

By changing the experimental procedure and allowing the subjects to adjust the intensity of the flashing light, the subjects could find an intensity just above threshold that would produce a "fast" response the majority of the times attempted. This was found to be true when the subjects fixated either the 20 minute or 2 minute stimulus.

Discussion

In attempting to answer why a flashrate may appear slower at threshold with a surround luminance above 0.1 ft. lambert, one may consider the "probability of seeing zone" which is present with threshold judgements.

A light flash of a given and sufficient intensity to fall within the boundries of the "probability of seeing zone" would have a certain probability of eliciting a sensation. A series of light flashes of constant frequency at the same given intensity level may be expected to produce an apparent flashrate proportional to the probability of seeing a single light flash.

The subject, when vie wing a flashrate at such an intensity, may then see only occassional flashes in a randomized order. Because of the uncertainty of threshold measurements these occassional pulses may be judged as a slower flashrate than the actual flashrate. During the comment period the subjects were sometimes questioned as to what they had based their flashrate judgements on. One subject reported that he normally would call the flashrate "slow" when he only saw one or two flashes. One subject stated he would report "medium" when he saw pulses at irregular intervals.

Judgin from these subjective reports it seems safe to say that a flashrate response slower than the actual rate is due to the failure of each flash to elicit a light sensation. It may be suggested that the probability of seeing a light flash at threshold where the number of quanta is critical may rest upon the constancy of the source and experimental apparatus and on the level of the subject's "visual conscienceness" which may be in a constinuous state of vacillation.

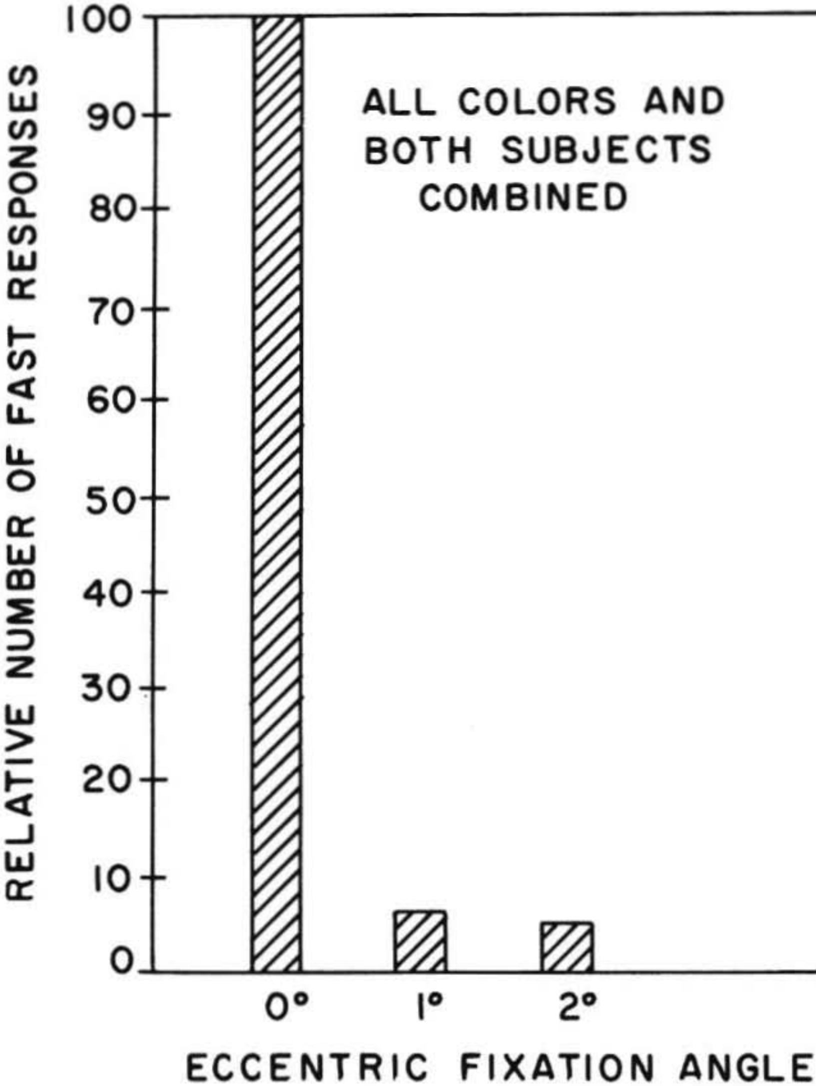
RELATIVE NUMBER OF FAST RESPONSES
100
90
80
70
60
50
40
30
20
10
0
ALL COLORS AND
BOTH SUBJECTS
COMBINED
0°
1°
2°
ECCENTRIC FIXATION ANGLE

Fig. 5.

A conflict arises when one views the results of the data for the luminance surround levels of 0.01 and 0.001 ft lamberts. At these levels of surround luminance the 40 f/m flashrate is not identified correctly as often as the 160 f/m flashrate. Also Figure 2 shows that at the 0.001 ft lambert level the 160 f/m flashrate is identified correctly 92% of the time. One must conclude from this information then that at these levels of adaptation the dimension of the "probability of seeing zone" has been constricted or that another form of visual behavior has become of greater consequence.

The frequency with which the subjects saw all flashrates as "very fast" may answer in part why the 160 f/m was identified correctly most often at these two lower surround levels and also it may explain why, as shown in Figure 3a and 3b, the 40 f/m flashrate and the 80 f/m flashrate was confused more frequently for the faster flashrate.

To explain why a flashrate may appear much faster when observed at or near threshold intensity one may speculate on the retinal activity following a single light flash. When a flash of light is incident on a foveal cone population after dark adaptation, the group of cones excited may discharge not only once but several times thus sending a volley of impulses to the higher visual centers. One may assume that the individual cones would fire in near synchronization to produce an appearance of discrete flashes.

Another postulation may be offered which would permit the excited cones to fire in a random order. This would permit allowance for the fact that each cone may have a different firing threshold or a different latency period. It would be necessary to propose that there is a certain summating and phasing of these foveal receptor impulses to produce a degree of order. Anatomical evidence which indicates that most foveal cones have a "private line" within the retina, as indicated by Polyak(4) would rule out spatial interaction of the foveal impulses on the retinal level. On this premise if summation and phasing of the foveal impulses is assumed to occur it must be relegated to a higher level than the retinal level. The end result of such summating and phasing may be an apparent flashrate which would not be in accordance with the actual flashrate.

A necessary condition for observing the "very fast" flashrate was a critical level of stimulus intensity for a given dim or dark surround. Only when the intensity of the stimulus was adequate would the visual activity which followed the light flash be such as to produce the apparent "very fast" flashrate.

Summary

Flashrate discriminability of human subjects is influenced by the adaptive state of the eye and the retinal location of the stimulus. Dimmer levels of surround luminance may induce an apparent fast flashrate as judged by the subject. Brighter surround levels tend to favor the identification of the slow flashrate.

Failure of every light flash to elicit a sensation may have resulted in judgements slower than the actual flashrate. A very fast flashrate may be produced by groups of receptors firing more than once for a given stimulus or a group of receptors firing randomly with subsequent summating and phasing.

Honeywell Research Center

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