Perception & Psychophysics, 1971, Vol. 10 (6) (p. 397, column 1)

SIU-C Web Editorial Note: This paper originally was published in three-column text format; it is reformatted in one column for increased readability. Also, the typo in the title, "Simple time reaction . . .", has been corrected. Please download the bitmap version of this document for complete historical accuracy.

Simple reaction time as a function of luminance for various wavelengths*

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Reaction time to white and colored targets was measured on two Ss for stimuli presented over a wide range of scotopic and photopic retinal illuminance levels. The colored targets were each photometrically matched for brightness against a white standard target at one photopic level (1.00 log td). The data show that for both the white and colored stimuli, reaction time is long at low target illuminations and progressively decreases to approach a final asymptotic value as the illumination level is increased. Discontinuities in the experimental curves relating reaction time and retinal illuminance occur at about -1.00 log td for all colors except red, in accordance with predictions based on the duplicity theory of vision. The photopic (cone) segments of the experimental curves overlap, while the scotopic (rod) segments are laterally displaced to progressively lower retinal-illuminance values as target wavelength is decreased, in accordance with expectations based on the differences in the luminosity functions of the scotopic and photopic systems.

The effects of conditions of illumination on visual reaction time (RT) have been extensively studied (see Teichner, 1954, and MacLeod & Alderman, 1961, for reviews of the many major variables which influence RT). Level of illumination has long been known to be an important stimulus variable. Cattell (1886), for example, reported that at low levels of illumination, RT is long and progressively decreases to a final asymptotic value as illumination is increased.

Although the effect of stimulus wavelength on RT at photopic levels of stimulation has received some experimental attention (e.g., Holmes, 1926; Allen, Strickland, & Adams, 1967; and Pollack, 1968), no studies could be found in which a wide range of retinal illuminances was used, including low scotopic levels. Preliminary data of this type were obtained by one of the present investigators (Shaffer, 1964). She used three chromatic stimuli (red, green, and blue), each presented over a wide range of scotopic and photopic retinal illuminance levels. The three colored stimuli were photometrically matched at one photopic level (1.00 log td), based on the criterion of a constant critical flicker frequency (30 cps) threshold. Her experimental curves

* This study was supported in part by research grants from the National Science Foundation (GB 2553) and the U.S. Public Health Service (NB 07617 and EY 00383) awarded to Professor Alfred Lit. Partial support was also provided by the Office of Research and Projects, Southern Illinois University.

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relating RT and illumination level showed that RT was long at low retinal illuminances and progressively decreased to a final low asymptotic level as illumination was increased. Each curve (except that for red) exhibited the characteristic discontinuity representing the transition from rod to cone functioning. The photopic segments of the curves showed that at each retinal illuminance level, RT was constant for all target wavelengths. The scotopic segments exhibited progressive lateral displacements on the abscissa (illumination) axis as predicted by the scotopic and photopic luminosity functions: the magnitude of the lateral displacement increases progressively as target wavelength is decreased (Hecht, 1987).

Pollack (1968) measured RT to six chromatic stimuli presented at four photopic luminances, ranging from -1.3 to 2.6 log mL, but at only one scotopic level (-2.6 log mL). The stimuli were photometrically equated by flicker photometry at one photopic level (1.3 log mL). Her results showed that at all photopic levels, the magnitude of RT was independent of stimulus wavelength; at the single scotopic level used, RT was longest for red and progressively decreased, with one inversion, as target wavelength was decreased.

The present experiment is an extension of the preliminary study by Shaffer (1964). It includes the use of white light and a total of four chromatic stimuli (blue, green, yellow and red), each presented to two additional Ss over a wide range of scotopic and photopic retinal illuminances (-3.50 to 3.00 log td).

METHOD

Subjects

Two highly trained undergraduate students (C.H. and R.K.) served as paid Ss. Each was emmetropic and had normal color vision, as measured with the American Optical Company H-R-R Pseudoisochromatic Plates.

Apparatus

A modified dual-channel Harvard tachistoscope (Gerbrands Model T-1C series) was mounted on the outer wall of the experimental dark room. One channel was modified to present a fixation light, while the other channel presented the stimulus target. Both channels were viewed binocularly.

In the target channel, a ground-glass plate was illuminated from behind by four fluorescent bulbs (G.E. F4T5-cw). The plate was masked by a black screen with a centrally placed, vertical rectangular aperture, 87 x 3.9 mm (187 x 20 min of arc at the target distance of 67.8 cm). The target illumination was transmitted into S's eyes through a half-silvered mirror positioned at a 45-deg angle to the fixation light. The target was binocularly viewed through a pair of circular artificial pupils, 2.5 mm in diam, which were adjustable for interpupillary separation. The highest obtainable retinal illuminance level was 3.15 log td.

In the fixation-light channel, a 25-W incandescent bulb was masked by a black screen with a centrally located hole, 1 mm in diam (5 sec of arc at the fixation distance of 67.8 cm). S kept the luminance of the continuously present fixation light at a barely visible level by means of a rheostat control. The fixation light was reflected by the 45-deg mirror to a central position in S's field of view.

Four matched pairs of Kodak Wratten colored filters were used: No. 72 (red-orange), No. 73 (yellow-green), No. 74 (green), and No. 75 (blue-green), with respective peak transmittance at about 605, 575, 530, and 485 nm, as measured by a Beckman spectrophotometer. The filters were placed in the pair of filter boxes located on the outer dark room wall between the artificial pupils and the tachistoscope. Thus, the wavelength of the fixation light and that of the stimulus target was identical.

The duration of the foreperiod, initiated by a buzzer, was randomized between 1 and 4 sec by means of a variable interval cam timer. At the end of the foreperiod, the stimulus target was automatically presented for a constant duration of 1.0 sec.

RT to the onset of the stimulus was measured to the nearest millisecond by means of a Beckman (Model 5230) universal EPUT and timer. The timer was stopped when S depressed a trigger mechanism, located in a pistol

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grip, with the index finger of his preferred hand.

Procedure

Photometric matching: Prior to the main experiment, it was necessary to obtain a photometric match for each of the different chromatic stimulus targets used. To accomplish this specification, the "equivalent neutral density" (END) value of each colored filter was determined by the criterion of a constant critical flicker frequency (CFF) threshold at 30 cps. This procedure was identical to that reported by Lit, Dwyer, and Morandi (1968) in their study of stimulus wavelength effects in stereoscopic acuity. A CFF vs log retinal illuminance curve was first obtained from each S for "white" light presented at eight retinal illuminance levels that yielded CFF values ranging from about 10 to 45 cps. The retinal illuminance of the white light that yielded a threshold value of 30

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cps was 1.0 log td. Similar CFF determinations were obtained for each of the four colored filters by adding the colored filter to the same eight combinations of neutral density filters used in determining the CFF values for the white light. The extent of the reduction in CFF produced by the addition of the colored filter at each of the eight retinal illuminance levels varied with the colored filter used. The CFF threshold curves for the four colored filters were plotted on the same eight abscissa values as those used for the white CFF threshold curves. The END value of each colored filter was obtained graphically by measuring the lateral separation (in density units) between the curve for the white light and that for the colored stimulus at the criterion response level of 30 cps.

Thus, the END value of any colored filter obtained by this graphical method specifies the magnitude of a neutral density filter which theoretically is required to replace the

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given colored filter in order to produce in both cases a constant (30-cps) CFF threshold response. The END values obtained for each of the colored filters are given below for each S:

S	Red (No. 72)	Yellow (No. 73)	Green (No. 74)	Blue (No. 75)
R.K.	2.03	1.91	1.54	1.95
C.H.	2.02	1.78	1.42	1.89

Reaction time measurements: Prior to each experimental session, S was dark adapted for 30 min. Only one stimulus wavelength was used in a given session. At each retinal illuminance level in a given session, five successive RT responses were measured. Four experimental sessions were employed for white and for each

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of the four chromatic stimuli, presented in a counterbalanced order.

RESULTS AND DISCUSSION

The obtained results for each S are presented separately in Figs. 1 and 2. The average median RTs are plotted in milliseconds (on a log scale) as a function of retinal illuminance (in log td) for the white light. The experimental curves for white light and for each of the four chromatic stimuli were fitted by visual inspection.

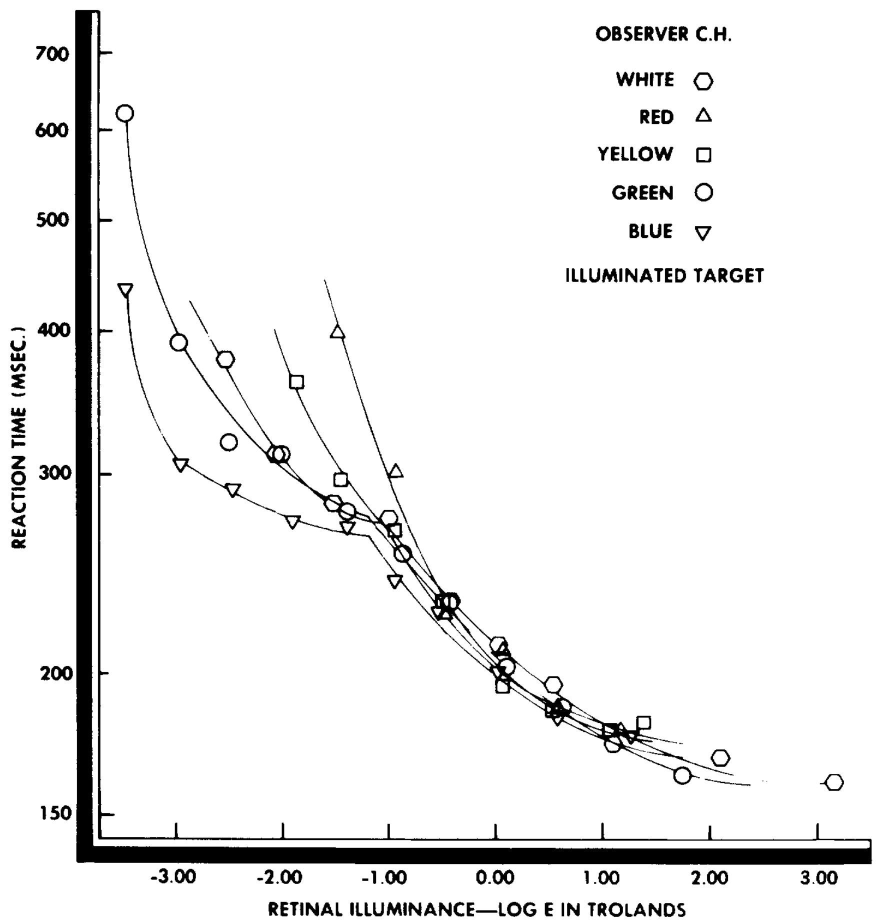

Fig. 1. Average median reaction time (milliseconds) on a log scale plotted as a function of retinal illuminance of the white light (log td) for Subject C.H.

The experimental curves demonstrate the well-established inverse relationship between RT and retinal illuminance: RT is long at low retinal illuminances and progressively decreases as the illumination level is increased to approach a final low asymptotic value. A marked discontinuity is noted in all of the curves, except that for red, at a retinal illuminance value of about -1.0 log td, in accordance with expectations based on duplicity theory.

The photopic (cone) segments of the curves for the white and chromatic stimuli essentially overlap, indicating that stimulus wavelength has no differential effect on the magnitude of RT. This finding is in complete agreement with the photopic data reported by Allen, Strickland, and Adams (1967) and by Pollack (1968) on RT. It also agrees with the data reported by different investigators on other visual functions at photopic levels, e.g., Shlaer, Smith, and Chase (1941) on visual acuity; Hecht, Peskin, and Patt (1936) on luminance discrimination; Hecht and Shlaer (1936) on critical flicker frequency thresholds; and Lit, Dwyer, and Morandi (1968) and Dwyer and Lit (1970) on stereoscopic acuity.

The scotopic (rod) segments of the experimental curves do not exhibit overlapping for the white and chromatic stimuli. These segments are laterally displaced to progressively lower retinal illuminance values, the shorter the target wavelength lateral displacements are typical for the scotopic segments of the experimental curves reported on other visual functions by the different investigators mentioned above. The displacements are a consequence of the fact that the photometric matches obtained by the various chromatic stimuli were performed at photopic levels. Thus, the photometric matches would not be expected to hold at scotopic levels, since the luminosity function of the rod system shows a greater relative increase in sensitivity for the short wavelengths as compared to that for the long.

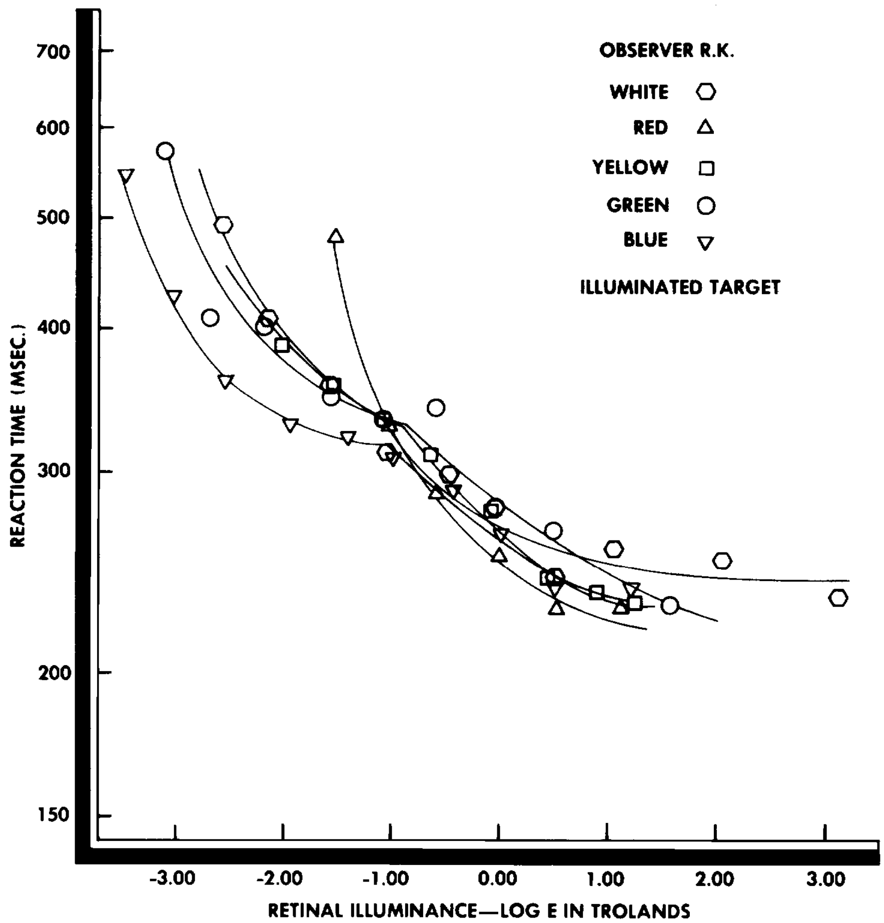

Fig. 2. Average median reaction time (milliseconds) on a log scale plotted as a function of retinal illuminance of the white light (log td) for Subject R.K.

The overlapping of the photopic segments of the present experimental curves justifies the use of a constant short RT as an appropriate response criterion for specifying a constant visual effect in determining a photopic luminosity function. This has been demonstrated by Pollack (1968) with her experimental data, using six different stimulus wavelengths. The use of a constant long RT (obtained at scotopic retinal illuminances) as an appropriate constant response criterion for generating a scotopic luminosity function has yet to be justified. An additional RT experiment (now in progress) would be required to demonstrate overlapping of the scotopic segments of the experimental curves when photometric matches are performed at each of the corresponding scotopic retinal illuminances used. Such complete overlapping has been previously demonstrated in this laboratory in the case of stereoscopic vision, both for equidistance settings of chromatic targets presented on a black background (Dwyer & Lit, 1970) and when black targets were presented against chromatic backgrounds.[1]

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NOTE

1. Young, R. H., and Lit, A. Stereoscopic acuity for photometrically matched background wavelengths at scotopic and photopic levels. In preparation.