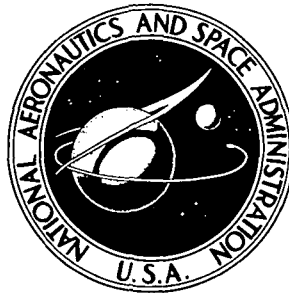


**NASA TECHNICAL
MEMORANDUM**



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**PERIPHERAL VISUAL RESPONSE TIME
TO COLORED STIMULI IMAGED
ON THE HORIZONTAL MERIDIAN**

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16. Abstract Two male observers were administered a binocular visual response time task to small (45' arc), flashed, photopic stimuli at four dominant wavelengths (632 nm red; 583 nm yellow; 526 nm green; 464 nm blue) imaged across the horizontal retinal meridian. The stimuli were imaged at 10° arc intervals from 80° left to 90° right of fixation. Testing followed either prior light adaptation or prior dark adaptation. Results indicated that mean response time (RT) varies with stimulus color. RT is faster to yellow than to blue and green and slowest to red. In general, mean RT was found to increase from fovea to periphery for all four colors, with the curve for red stimuli exhibiting the most rapid positive acceleration with increasing angular eccentricity from the fovea. The shape of the RT distribution across the retina was also found to depend upon the state of light or dark adaptation. The findings are related to previous RT research and are discussed in terms of optimizing the color and position of colored visual displays on instrument panels.			
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INTRODUCTION

Simple peripheral visual response time (RT) along the horizontal meridian has been the topic of many studies (refs. 1–15). Despite differences in the procedures and apparatus used in these studies, they generally agree that the RT to a flashed, photopic stimulus is significantly shorter when imaged upon the fovea than when imaged upon more peripheral locations of the retina.

Other investigators, using white light, have studied the relationship between RT and the stimulus' location on the retina along various meridians,¹ including the horizontal. Kobrick (ref. 16) studied four light positions with angular displacements of 12°, 38°, 64°, and 90° arc from the line of sight (here after referred to as θ), along four different meridians, 60° – 240°, 90° – 270°, 120° – 300°, and 170° – 350° [here after meridians will be referred to as ϕ and are measured in a clockwise direction from the vertical (0°)]. His data suggest that RTs to stimulation were not significantly different in an area extending from 90° < θ < 270° arc along the horizontal and 38° arc above to 64° arc below the line of sight.

These results, however, are not in full agreement with other data collected along the horizontal meridian (refs. 10, 12, 14, 17, 18). Payne (ref. 18) studied 24 retinal locations along each of four meridians: $\phi = 80^\circ - 260^\circ$, $90^\circ - 270^\circ$, $100^\circ - 280^\circ$, and $135^\circ - 315^\circ$. His results indicated a decrease in RT on the horizontal meridian where the density of rods plus cones is greatest, i.e., approximately $\theta = 18^\circ$ arc on the temporal side. His findings were compatible with those of others (refs. 11,12) in demonstrating a general trend of increasing RT with more peripherally imaged stimuli. Haines and Gilliland (ref. 17) investigated simple RT to white, photopic stimuli imaged at 72 locations in the full binocular visual field. They presented the findings in the form of a polar coordinate plot of iso-response time regions within each of which mean RT could be expected to be of approximately equal duration. These areas were almost twice as wide as they were high and tended to extend further to the right than to the left of the center of the visual field. Mean RT in the central area was 280 msec and greater than 360 msec at the limit of the visual field. Ushakova (ref. 14) reported a functional relationship between absolute visual light threshold and RT to

¹ A retinal meridian is the projection of a straight line in the frontal plane that passes through the center of the fovea.

suprathreshold white stimuli imaged across the horizontal meridian; an increase in threshold corresponded to an increase in RT. The effect of the stimulus' dominant wavelength on this finding has not yet been investigated in the peripheral retina.

Whereas all of the previously cited investigators used a white stimulus, other investigators have studied the relationship between RT and colored stimuli (refs. 19–21). Pollack (ref. 19) used six dominant wavelengths (412, 462, 505, 530, 589, and 657 nm), and each was tested at five luminance levels (2.6, 1.3, 0.0, -1.3, and -2.6 log mL) to determine whether wavelength had an effect on the *foveal* RT. Her subjects were binocularly light adapted to the same luminance as the test stimulus. Each subject was asked to fixate the center of a dark visual field and respond to a test light by releasing a RT key. Pollack's results indicated: (1) RT is inversely related to stimulus luminance and relatively little difference is due to dominant wavelength above -2.6 log mL (0.0023 ft-L) luminance; and (2) in general, for luminances in which there were RT differences due to wavelength, median RTs for each wavelength increased as the spectrum changed from blue to red. Bartlett *et al.* (ref. 20) found RTs to red stimuli to be significantly faster at the fovea than at $\theta = 12^\circ$ arc on the temporal retina. They also found that onset and offset RTs to blue and red stimuli decreased as luminance increased.

The relation between dark adaptation and changes in RT also reveals important information about the retinal mechanisms that underlie chromatic sensitivity. Hecht, Haig, and Chase (ref. 22) studied the course of dark adaptation for a violet and a red stimulus following several pre-adapting luminance levels. Their findings showed that, regardless of the pre-adapting luminance, the cone response curves were approximately the same. But the rod adaptation curves were of one of two types depending upon the pre-adapting luminance. Under low-pre-adapting luminances the rods exhibited a rapid adaptation. However, when the pre-adaptation luminance was very high there occurred a delay in the onset of adaptation which varied with the pre-adaptation luminance. Under the highest pre-adaptation luminance, the rod adaptation required as long as 13 minutes. Since rods and cones are known to be differentially sensitive to wavelengths and differ in distribution across the retina, it is strongly suggested that an interaction exists among wavelength, level of dark adaptation, and locus of retinal stimulation. The present investigation was designed to test this expectation.

Several investigators have studied color thresholds over large areas of the retina in both theoretical and applied contexts (refs. 23–25). No one, however, has yet investigated the color zones over the full visual field as measured by RT. In addition to its theoretical importance, this data would also be applicable in a variety of design situations such as helping locate warning lights on aircraft instrument panels or color coding for CRT displays. The present investigation served as a preliminary study of the effects of colored stimuli imaged across the horizontal meridian of the light and dark adapted retina.

METHOD

Subjects

Two of the authors served as subjects, D.N. (age 21 years) and M.D. (age 27 years). Both possessed normal monocular and binocular visual field limits and 20:20 near and distance acuity

(near acuity corrected for subject M.D.). Subject D.N. possessed normal color perception as measured by the Ishihara Isochromatic plates, while M.D. evidenced a slight red-green deficiency in both eyes (plate no. 6 missed). Neither subject had any other known visual dysfunctions. Both were dominant right eye. Each served as the experimenter for the other; both were highly motivated throughout the experiment. Neither subject was permitted to inspect any data until the study was completed.

Experimental Design

This investigation can be characterized as a $4 \times 2 \times 5 \times 18$ factorial design, within subjects, having the following variables: 4 *Stimulus Colors* (yellow, red, green, and blue); 2 *Orders* of adaptation level [light adaptation followed by dark adaptation (LA-DA) and dark adaptation followed by light adaptation (DA-LA)]; 5 *Blocks* (of 250 stimulus presentations each, two blocks following dark adaptation and three following light adaptation) constituted a session; and 18 *Stimulus Positions* (from 80° arc left of fixation to 90° arc right of fixation in 10° arc increments along the horizontal retinal meridian). There were 10,000 presentations of color stimuli per subject during the course of the experiment.

Procedure

Each subject was given one training session of approximately 30 minutes each day for a total of eight days. This was found to be sufficient to yield stable, asymptotic mean RT and small, consistent standard deviations (approximately 15 msec) at each retinal location. All training was performed using only white RT stimuli imaged across the $\phi = 90^\circ - 270^\circ$ arc (horizontal) meridian under conditions of dark adaptation. At the end of the training period, 1,250 RT trials were presented per subject to obtain baseline data for white stimuli under the DA-LA adaptation order.

Each subject then served in eight experimental sessions. Two sessions were administered per color (presentation order for both subjects was yellow, red, blue, and green), one for each of the two adaptation orders (DA-LA and LA-DA). The presentation order of the adaptation level variable was counterbalanced across subjects. The sequential order of events for each adaptation period is shown in table 1.

In order to help insure *spatial* uncertainty regarding which of the 18 stimulus positions would occur on a given trial, a random stimulus order was programmed within blocks of 120 trials.² The 120 RT trials were randomized but with the constraints that there had to be three presentations of each stimulus position in the first 54 and the second 54 trials and that a given stimulus position could not appear more than twice in succession.

In order to help insure *temporal* uncertainty regarding when a stimulus was going to appear, the intertrial interval was varied randomly in five steps, and the percentages of occurrences in each block of 120 trials are shown in parentheses: 1.8 sec (30.2%); 2.2 sec (26.5%); 2.4 sec (24.5%); 2.8 sec (13.2%); and 3.2 sec (5.6%). The mean intertrial interval was 2.19 sec, for a total of 26.5 trials per minute.

²The same random stimulus sequence was initiated at the beginning of each first block of LA and DA. Thus, the stimulus sequence was identical for the first block of DA and LA.

TABLE 1.— SEQUENTIAL ORDER OF TESTING EVENTS

(a) Dark adaptation-light adaptation (DA-LA) protocol

DA			LA					
5 min red goggles	5 min total darkness	19 min total darkness 2 blocks of 250 trials each	5 min break	5 min red goggles	5 min total darkness	2 min LA	3 min full LA	28½ min total darkness 3 blocks of 250 trials each

(b) Light adaptation-dark adaptation (LA-DA) protocol

LA				DA				
5 min red goggles	5 min total darkness	2 min LA	3 min full LA	28½ min total darkness 3 blocks of 250 trials each	5 min break	5 min red goggles	5 min total darkness	19 min total darkness 2 blocks of 250 trials each

Note: The primary intent of this design was to control for fatigue and other temporal order effects which might occur during testing.

The subject was either dark- or light-adapted before testing began. For dark adaptation the subject wore red goggles (Kodak No. 29 filter) for five minutes and then remained in total darkness for at least another five minutes. The white light adaptation procedure also began with the same procedure as outlined for dark adaptation but was immediately followed by almost full visual field light adaptation to approximately $3.73 \log \text{mL}$. The subject was positioned beneath the large, concave, diffuse surface illustrated in figure 1.³ A first surface mirror reflected light from the primary light source through the diffuser to the subject's eyes.



Fig. 1.— Photograph of subject beneath response time test apparatus with light adapting (concave) surface present.

Each subject was instructed to relax his accommodation, since the diffused surface was closer than his near point. In the final three minutes of this procedure, the subject attempted to maintain fixation within an area of approximately $\pm 5^\circ$ arc from the center. Immediately after the light adaptation period was completed the subject was moved from beneath the light adapting apparatus to beneath the RT perimeter. This required only about 10 seconds, after which the LA source was extinguished. RT testing was begun no longer than 2 seconds after light or dark adaptation was complete.

During all RT testing, the subject was instructed to maintain fixation upon a dimly illuminated broken cross which surrounded the 0° arc (foveal) stimulus. He adjusted the luminance of the yellow-green fixation cross by means of a variac-controlled projector so that the cross was just above his photopic threshold throughout testing.

³In figure 1 the subject is shown positioned under the RT testing apparatus. All testing was performed in the supine orientation.

The subject was instructed to respond as quickly as possible to the onset of a stimulus by pressing a button with the thumb of his right hand. Response time was recorded to the nearest five msec. If he did not respond, the intertrial interval was recorded and labeled as a "no response."

Apparatus

The apparatus has been described in detail elsewhere (ref. 9). Briefly, a research RT perimeter was used which consisted of an aluminum half circle channel (0.61 m radius) upon which the 18 individual stimuli were rigidly aligned, 10° arc apart from 80° arc left to 90° arc right of the line of sight. An 8 mm (0° 45' arc) diameter, diffuse, acrylic, molded hemispheric plastic lens was located at each stimulus position. This lens received light from the exit end of a fiber optic bundle (DuPont CROFON, 64 Fiber, 1610X), and transmitted it as a diverging cone of light toward the eyes. The perimeter is shown in figure 1.

The source for all stimuli was a fluorescent flash tube with 1 μsec rise time. Each stimulus remained on for 50 msec per trial. The white test stimuli were set to 0.107 mL (0.1 ft-L) luminance, as measured with a Pritchard Spectra Photometer and 6 min arc diameter aperture.

In order to determine RT to colored stimuli the following Kodak gelatin filters were placed over the fluorescent flash tube: (1) yellow, Wratten No. 16, with a peak transmittance at 582.7 nm and transmittance of 57.7%; (2) red, Wratten No. 29, with a peak transmittance at 631.6 nm and a transmittance of 6.3%; (3) green, Wratten No. 60, with a peak transmittance at 525.7 nm and a transmittance of 26.1%; and (4) blue, Wratten No. 47 with a peak transmittance at 463.7 nm and a transmittance of 2.8%. The luminances of these colored stimuli were approximately equated by inserting neutral density filters between the flash source and the color filter. Table 2 presents the results of the photometric matching procedure. The red, green, and blue stimuli were approximately 0.5 log and the yellow approximately 0.9 log above the absolute forced choice light threshold of each subject.

TABLE 2.— COLOR FILTER PHOTOMETRIC MATCHING RESULTS

	Color filter			
	Yellow	Red	Green	Blue
N.D. filter added (\log_{10})	1.0	0.3	1.0	0.0
Resultant luminance: (ml)	0.070	0.027	0.033	0.027
(ft-L)	0.065	0.025	0.031	0.025

To help mask auditory cues generated by the sequencing equipment, the subject wore padded earphones over which white noise was inserted at a comfortable volume from a Grason-Stadler, Model 455C noise generator with a low pass frequency of 25 kHz.

RESULTS

Mean RTs for each *Color* (yellow, red, green or blue), *Adaptation Order* (DA-LA or LA-DA), *Block*, and *Stimulus Position* (80° arc left to 90° arc right) were computed for each session, within subjects. These means excluded “early response” (less than 75 msec) and “no response” (NR) trials. In addition, extremely long RTs (over 750 msec) were dropped, but when two or more such long RTs occurred at any given *Stimulus Position* within blocks, the long RTs were retained. The dropped responses were coded as NRs in subsequent analyses. Because some *Stimulus Positions* had all NRs, a mean RT of 500 msec was assigned in order that an analysis of variance might be performed.⁴ The mean RT data for the dark adapted condition are presented in figures 2 and 3, where stimulus position is plotted on the abscissa and mean RT on the ordinate.

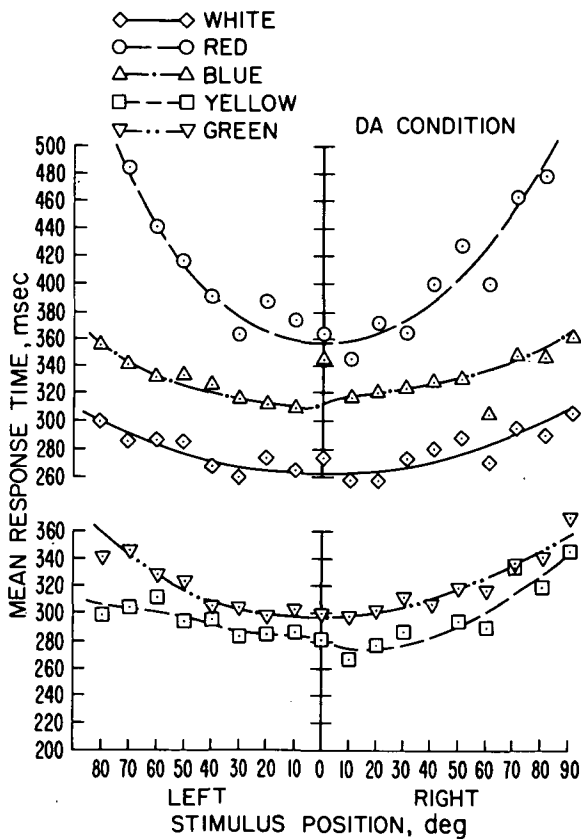


Fig. 2.— Grand mean RT results for subject D.N.

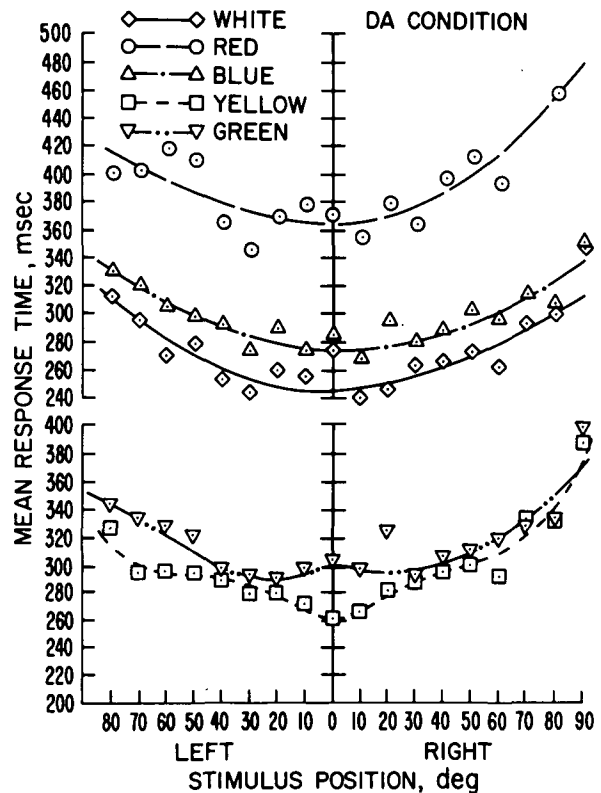


Fig. 3.— Grand mean RT results for subject M.D.

The results of an analysis of variance (ref. 26) of the above variables is presented in table 3. It showed a significant main effect of *Color*. Response time to yellow stimuli was, on the whole, faster than to blue or green stimuli (which were about equal) while RTs were longest to red stimuli. The

⁴This was considered to be a reasonable value since it was a longer RT than is ordinarily associated with valid RT responses; it accords with the idea that a “no response” falls at the end of the continuum of increasing RTs but was not so large a value as to create significant statistical effects merely because of its magnitude compared to the other valid means used in the analysis.

TABLE 3.— ANALYSIS OF VARIANCE SUMMARY

Source	df	SS	MS	F	p
Color (C)	3	3.811	1.270	76.9	<0.005
Block (B)	4	0.254	0.063	19.6	<0.01
Stimulus position (P)	17	1.380	0.081	166.3	<0.001
Order (O)	1	0.001	0.001	0.2	
(C) × (B)	12	0.079	0.006	2.5	
(C) × (P)	51	0.522	0.010	3.6	<0.001
(C) × (O)	3	0.039	0.013	1.7	
(B) × (P)	68	0.146	0.002	1.4	
(B) × (O)	4	0.014	0.003	1.8	
(P) × (O)	17	0.071	0.004	1.7	
(C) × (B) × (P)	204	0.496	0.002	1.2	<0.05
(C) × (B) × (O)	12	0.037	0.003	1.0	
(B) × (P) × (O)	68	0.110	0.001	0.8	
(C) × (P) × (O)	51	0.134	0.002	0.7	
(C) × (B) × (P) × (O)	204	0.300	0.001	0.6	
Mean	1	175.030	175.030		

fact that the yellow stimuli were approximately 0.4 log brighter than the other three stimulus colors probably accounts for this finding.

The *Block* main effect was also significant, in large part because of the difference between the DA blocks and the LA blocks; RT following DA was shorter by about 20 msec than RT following LA. In addition, mean RT decreased greatly (by about 23 msec) between the first and second blocks following LA.

Stimulus Position also yielded a highly significant main effect. Mean RT tended to be longer in the periphery than in the fovea. Also both the *Color* by *Stimulus Position* interaction and the *Color* by *Stimulus Position* by *Block* interaction were significant, which supports the idea that the significant *Color* by *Stimulus Position* effect is dependent upon the state of light or dark adaptation. The *Stimulus Position* by *Block* interaction approached the $p = 0.05$ level of confidence.

Another analysis of variance was performed that excluded all *Stimulus Positions* where there were no RTs obtained (namely, $\theta = 50^\circ$ to 80° arc left; 20° arc right; and 70° to 90° arc right). The results of this analysis are not presented because of their close similarity to the first analysis of variance presented above. The correspondence between these two analyses supports the belief that, as the independent variables cause an increase in RT, they are operating along a continuum which will ultimately terminate in a "no response," i.e., a theoretically infinite RT.

One of the purposes of using the present experimental design was to study the effect of the early stages of dark adaptation following prior light adaptation upon peripheral visual RT. This necessitated an analysis of variance to compare the beginning of DA testing with the beginning of

LA testing; this variable will be called *Adaptation Level*.⁵ The first six minutes of each testing period were divided into three two-minute-long *Segments* for this analysis. Each *Segment* contained three stimulus presentations at each *Stimulus Position*, within *Color*. Mean RTs were determined for each subject, *Color*, *Adaptation Order*, *Adaptation Level*, and *Stimulus Position* for each *Segment*.

The results of this analysis, presented in table 4, supported the belief that a finer temporal breakdown of the effect of dark adaptation would be warranted. The effect of *Color* was significant, as were the effects of *Adaptation Level*, *Stimulus Position*, *Color* by *Stimulus Position*, *Adaptation Level* by *Stimulus Position*, and *Color* by *Adaptation Level* by *Stimulus Position*. In addition, the *Segment* by *Stimulus Position* interaction was significant because of a decrease in mean RT of approximately 30 msec within 30° arc on both sides of the fovea during the third two-minute-long *Segment* relative to the first two, two-minute-long *Segments*. The significant *Color*

TABLE 4.— ANALYSIS OF VARIANCE SUMMARY FOR THE EARLY STAGES
OF DARK ADAPTATION UPON RT

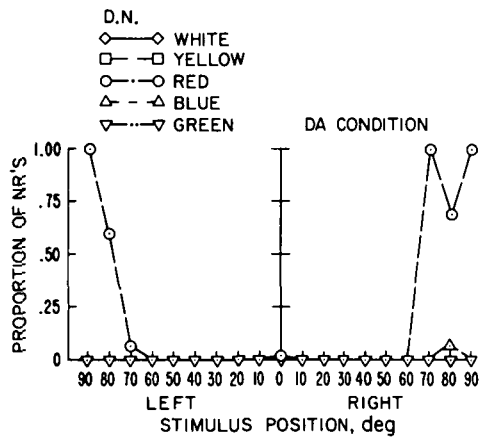
Source	df	SS	MS	F	P
Color (C)	3	4.358	1.452	32.140	<0.01
Adaptation level (A)	1	1.613	1.613	372.783	<0.05
Adaptation order (O)	1	0.0001	0.0001	0.0008	
Subjects (S)	1	0.311	0.311		
Segment (B)	2	0.740	0.370	2.162	
Stimulus position (P)	17	1.245	0.732	28.661	<0.001
(C) × (A)	3	0.106	0.035	7.322	
(C) × (O)	3	0.357	0.119	2.712	
(C) × (S)	3	0.135	0.045		
(C) × (B)	6	0.015	0.002	1.147	
(C) × (P)	51	0.569	0.011	5.124	<0.001
(A) × (O)	1	0.003	0.003	0.861	
(A) × (S)	1	0.004	0.004		
(A) × (B)	2	0.116	0.058	16.082	
(A) × (P)	17	0.150	0.008	2.818	<0.025
(O) × (S)	1	0.114	0.114		
(O) × (B)	2	0.001	0.0005	0.598	
(O) × (P)	17	0.019	0.001	0.287	
(S) × (B)	2	0.034	0.017		
(S) × (P)	17	0.043	0.002		
(B) × (P)	34	0.099	0.002	2.164	<0.025
(C) × (A) × (P)	51	0.354	0.006	3.203	<0.001
(C) × (B) × (P)	102	0.167	0.001	1.701	<0.025
(A) × (B) × (P)	34	0.101	0.002	2.422	<0.01

Note: None of the remaining three, four, or five-way interactions was statistically significant.

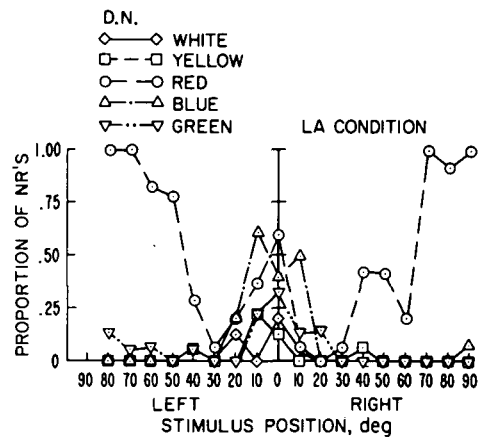
⁵The term *Adaptation Level*, as a variable name, will refer to the retinal processes that underlie visual sensitivity changes.

by *Segment* by *Stimulus Position* interaction indicated that this effect varies with the color of the stimulus; inspection of the data shows that it is primarily due to blue and green. The significant *Adaptation Level* by *Segment* by *Stimulus Position* interaction indicated that the effect varies according to whether the retina has been previously light or dark adapted and is the result of the light adaptation condition.

In view of the importance of “no responses” in many applied situations, the present “NR” data were also analyzed for each independent variable. The proportion of NRs that occurred at each *Stimulus Position* for the first *Block* following DA and for the first *Block* following LA for the DA-LA adaptation order sessions is shown in figures 4 and 5 for subjects DN and MD, respectively.

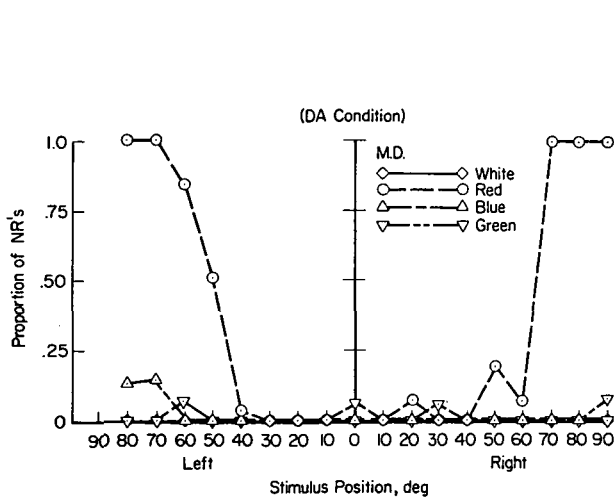


(a) Late stage of dark adaptation (DA)

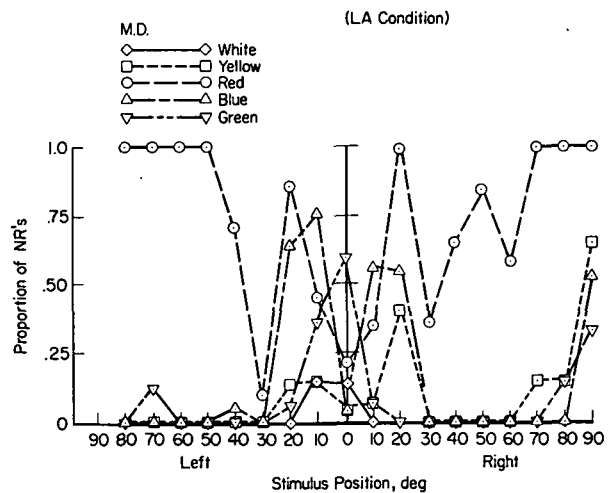


(b) Early stage of dark adaptation (LA)

Fig. 4.— Proportion of no responses by stimulus position for subject D.N.



(a) Late stage of dark adaptation (DA)



(b) Early stage of dark adaptation (LA)

Fig. 5.— Proportion of no responses by stimulus position for subject M.D.

In general, there was a greater likelihood of “no responses” following light adaptation than following dark adaptation, particularly within the parafoveal region, i.e., within about 30° arc on either side of the fovea. The four colors elicited quite different spatial patterns of occurrence of “no response,” and red stimuli were missed, particularly in the periphery, much more frequently than were stimuli of any other color.

DISCUSSION

The present data confirm the belief that stimulus color, level of retinal adaptation, and the angular displacement of colored stimuli from the line of sight significantly affect simple RT. The most important findings of the present investigation are: (1) RT to yellow stimuli is, on the average, faster than RT to blue or green stimuli,⁶ which are, in turn, faster than RT to red stimuli; (2) RT is generally slower with increased angular displacement of the stimulus' image from the fovea, although the general form of the distribution of RT values varies with color; (3) RT to red stimuli, in particular, increases rapidly in the peripheral visual field, as does the proportion of “no responses”; and (4) the state of light adaptation of the retina affects not only the mean RT but also the incidence of “no responses.”

The results of the present investigation bear some similarity to the findings of a previous study that used colored luminous stimuli. Pollack (ref. 19), comparing wavelengths ranging from 412 nm blue to 657 nm red, found longest RTs to red and shortest to blue stimuli. Pollack found no appreciable RT differences for different colors at luminances greater than $-2.6 \log \text{ mL}$ (0.00232 ft-L); in the present investigation differences of mean RT elicited by red, green, and blue stimuli were found to occur at luminances of approximately $-1.57 \log \text{ mL}$ (0.025 ft-L). This difference may be attributable, at least in part, to the size difference between the stimuli used in the two studies, to different retinal adaptation levels, and to the fact that her stimulus presentation was solely to the fovea.

The present findings regarding the different RT distributions across the horizontal retinal meridian for different colored stimuli suggest the importance of performing a more complete mapping of the zones within the *full* visual field that mediate RT to colored stimuli. Such data would be particularly useful to engineering designers in a number of fields.

The present data may have a number of practical applications, especially in helping to optimize the colors and locations of luminous controls and displays on instrument panels. These findings suggest that the placement of flashed, colored indicators would have a highly significant influence upon RT to such displays. Also, the luminance of these indicators must be carefully chosen so as to reduce to an acceptable minimum the number of “no responses.” The NR data presented in figures 4(a) and 5(a) for red, green, and blue stimuli show that luminances of approximately 0.5 log above absolute threshold (during the dark adapted condition), will produce a relatively small proportion of “no responses” within about 40° arc from the fovea. However, the proportion of “no responses” rises rapidly beyond this position in the visual field for red stimuli.

The “no response” data presented in figures 4(b) and 5(b) for RT testing just after prior light adaptation show the effect of the loss of retinal sensitivity upon the “no responses.” The marked

⁶It should be noted that the yellow effect might be partly attributable to a slightly higher luminance of the stimuli.

increase in "no responses" further emphasizes the importance of selecting the luminance level of visual indicators so that they will be visible over the entire range of ambient luminances present.

Bartz (ref. 1) has presented findings which suggest that increases in RT of the kind found in the present investigation might represent only one component of an even larger increase in RT caused by locating the stimuli in less than optimal positions in the visual field. This results from the fact that it not only takes longer to move the eyes to fixate a peripheral stimulus, but it also takes longer to respond appropriately to the stimulus once the eyes have moved. It is likely that a pilot, for instance, would have to shift his visual fixation to, and then respond appropriately to, a peripheral visual stimulus; these additional delays could become highly significant in an aircraft travelling at 130 knots (approximately 33.5 m per 500 msec). Even more importantly color and retinal image position are, in conjunction with luminance level, stimulus attributes that determine whether a light will be detected at all. Since this is the case, the consequences for the use of luminous warning indicators are clear. Further work is needed to define the limits of perceptibility of colored RT stimuli.

It must be noted that the present results were obtained under almost optimal viewing conditions: the subject was lying in a relaxed position, attending only to the task at hand, and he knew that a stimulus would appear at least every 3.2 sec along the horizontal meridian. Previous RT research has shown that RT is lengthened by various environmental stressors (ref. 15) which suggests that even longer RTs than those reported here might be expected under such conditions.

Since the results of the present study showed significant differences in the distribution of RTs to colored stimuli across the horizontal meridian, another investigation should be conducted in which RT data are obtained for colored stimuli imaged along other meridians. These data would yield a graphic representation of color RT zones for the full visual field similar to the RT data of Haines and Gilliland (ref. 17) for white stimuli. Such an investigation would provide useful information regarding the maximally effective placement of colored indicators.

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