NASA TECHNICAL NOTE

NASA TN D-7960

NASA TN D-7960

CONSPICUITY OF TARGET LIGHTS: THE INFLUENCE OF COLOR

Mary M. Connors

Ames Research Center
Moffett Field, Calif. 94035

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1975

1. Report No. NASA TN D-7960	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CONSPICUITY OF TARGET LIGHTS: THE INFLUENCE OF COLOR		5. Report Date November 1975
		6. Performing Organization Code
7. Author(s) Mary M. Connors		8. Performing Organization Report No. A-5791
9. Performing Organization Name and Address Ames Research Center Moffett Field, Calif. 94035		10. Work Unit No. 504-29-02
		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Note
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This study investigated the conspicuity, or attention-getting qualities of foveally-equated, colored lights, when seen against a star background. Subjects who were periodically engaged in a distracting cockpit task were required to search a large visual field and report the appearance of a target light as quickly as possible. Targets were red, yellow, white, green, and blue, and appeared either as steady or as flashing lights.

Results indicate that red targets were missed more frequently and responded to more slowly than lights of other hues. Yellow targets were acquired more slowly than white, green, or blue targets; responses to white targets were significantly slower than responses to green or blue targets. In general, flashing lights were superior to steady lights, but this was not found for all hues. For red, the 2 Hz flash was superior to all other flash rates and to the steady light, none of which differed significantly from each other. Over all hues, conspicuity was found to peak at 2-3 Hz.

Response time was found to be fastest, generally, for targets appearing at between 3° and 8° from the center of the visual field. However, this pattern was not repeated for every hue. Conspicuity response times suggest a complex relationship between hue and position in the visual field that is explained only partially by retinal sensitivity.

17. Key Words (Suggested by Author(s)) Target detection Conspicuity Collision avoidance	18. Distribution Statement Unclassified – Unlimited STAR Category 53		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 14	22. Price* $3.25

*For sale by the National Technical Information Service, Springfield, Virginia 22161

CONSPICUITY OF TARGET LIGHTS: THE INFLUENCE OF COLOR

Mary M. Connors

Ames Research Center

SUMMARY

This study investigated the conspicuity, or attention-getting qualities of foveally-equated, colored lights, when seen against a star background. Subjects who were periodically engaged in a distracting cockpit task were required to search a large visual field and report the appearance of a target light as quickly as possible. Targets were red, yellow, white, green, and blue, and appeared either as steady or as flashing lights.

Results indicate that red targets were missed more frequently and responded to more slowly than lights of other hues. Yellow targets were acquired more slowly than white, green, or blue targets; responses to white targets were significantly slower than responses to green or blue targets. In general, flashing lights were superior to steady lights, but this was not found for all hues. For red, the 2 Hz flash was superior to all other flash rates and to the steady light, none of which differed significantly from each other. Over all hues, conspicuity was found to peak at 2-3 Hz.

Response time was found to be fastest, generally, for targets appearing at between 3° and 8° from the center of the visual field. However, this pattern was not repeated for every hue. Conspicuity response times suggest a complex relationship between hue and position in the visual field that is explained only partially by retinal sensitivity.

INTRODUCTION

In selecting the colors for aviation lights, and particularly collision-avoidance lights, an important consideration is that the colors be visible at long distances. Red has been found to be a valuable hue from the standpoint of detection (ref. 1–3), correct hue determination (ref. 4), and lack of confusion with other colors (ref. 5). However, these findings relate to the case where the observer is either fixating a target or searching a defined and limited region within his field of view. In such cases, foveal vision is either required or implied. In considering the broader question of the conspicuity, or attention-getting qualities of a light, response to a target, when the observer is engaged in other tasks, may depend on a wide range of variables, only one of which is foveal luminance threshold.

The emphasis is the present study was on determining if the hue of the target light is instrumental in attracting an observer's attention when the observer is engaged in another task. A previous investigation from this laboratory (ref. 6) showed flashing white lights of low intensity to be superior to steady white lights, when seen against a star background with no significant differences associated with the flash frequency. Since most aircraft identification and/or anticollision coding systems involve colored lights, a further consideration was to determine if there are hue effects or interaction effects of hue and flash rate that influence the conspicuity threshold (as measured by probability of detection and reaction time). Nilsson and Nelson (ref. 7) have found that hue shifts result from intermittent stimulation, with the direction of the hue shift dependent on the stimulus wavelength and the magnitude of the hue shift dependent on both wavelength and flash rate. These findings present a theoretical basis for expecting a hue-flash rate interaction effect for the conspicuity threshold as well.

APPARATUS

The apparatus and much of the calibration techniques and experimental procedures used were the same as those described in another report (ref. 6). Basically, the subject sat on a platform in the center of a large, blackened room, and faced a wall 9.14 m away on which were mounted 50 point sources of light of varying intensities that simulated a star background. In addition, 20 point source "targets" appeared at fixed locations among the "stars." The subject's primary task (*target task*) was to respond to the appearance of each of these targets by depressing a button in the center of his response panel. (For a further description of the experimental facility, see ref. 6.) While searching for target lights, the subject was simultaneously engaged in an *auxiliary task*. His instructions for the *auxiliary task* were to sum four numbers which appeared simultaneously on a visual readout and to respond by pressing a dimly-lit indicator with his left index finger if the numbers sum to 19 or less; by pressing a similar indicator with his right index finger is they sum to more than 19. The *auxiliary task* was mounted 40.64 cm in front of and diagonally below the subject's line of sight, and simulated the primary features of a cockpit task.

PROCEDURE

The subject was shown both steady target lights and flashing target lights of several hues (red, green, blue, yellow and white). A description of the chromatic characteristics of these lights is given in table 1. Calculations were made to determine the neutral tint filters necessary to foveally match the several hues in apparent intensity. These filters were used as gross measures of equality of intensity. Subsequently, several subjects were run in series of brightness matching exercises in which all hues were cross compared, for foveal match. An average of the judgments, which varied little among observers, was used as a final intensity-match setting for the various hues. The intensity at the observer's station was the equivalent of (and visually matched to) a target of approximately 0.034 ml.

Subjects were ten color-normal college students. The subject dark-adapted for 10 to 15 min at the beginning of each session. Using binocular vision throughout, he performed the *auxiliary task* which commenced at 10-sec intervals, while at the same time searching for the target lights which appeared amidst the star background at temporal intervals varying randomly in one-second steps from 8 to 24 sec. He received no instructions on how to search the background and was free to develop his own technique. Each subject received several days of training in order to stabilize his responses. The subject did not know the relative priority of each task, and was instructed to respond to both tasks as quickly and as accurately as possible.

The *auxiliary task* appeared for 3 sec; the subject could respond within this period or up to 1.5 sec after the display extinguished. The primary, or *target task* appeared for a total of 3 sec after which the subject had an additional 2 sec to respond. For the primary, *target task*, the subject was instructed to respond to all lights, whether steady or flashing, and of any hue, which appeared in the star background.

Each subject viewed each combination of hue (5), flash rate (5), and light position (20), twice (one replication), for a total of 1000 presentations per subject. The on/off duty cycle was 0.5/0.5 and the total exposure duration, including off periods, was 3 sec throughout. Flash rates were 1 Hz, 2 Hz, 3 Hz, and 4 Hz along with a steady light condition whose total energy was twice that of the flashing lights (since the steady light was "on" for the entire stimulus duration).

Each subject was given a total of 100 trials in each experimental session. A session consisted of five runs; in each run each of the 20 target lights was presented. Ordering of light position was randomized without replacement within runs. All other variables were randomized within a replication (i.e., five experimental sessions). The replicated data were randomized in a similar fashion so that the subject never viewed the same light presentation orderings more than once. Responses to the *auxiliary task* were tabulated as "correct," "incorrect," or "no response." Responses to the *target task* were tallied as "detected" or "missed," and reaction time to detected lights were measured to within 1 msec accuracy.

The purpose of the *auxiliary* arithmetic task was to engage the observer sufficiently, so that he would be distracted from the primary *target task*. To this end, the *auxiliary task* was set so that the subjects could maintain a high, but not perfect, performance rate. After training, performance scores on this task ranged consistently between approximately 80 percent and 90 percent for all subjects.

RESULTS

The purpose of the *auxiliary task* was to distract the subject; data concerning performance on this task are not presented. For the *target task*, analyses of variance were performed on the detection data (number of targets correctly detected) and on the reaction time data. All main and double interaction effects were analyzed by Duncan's Method of Multiple Comparisons (ref. 8); the results of these comparisons are shown in tables 2 to 4. A continuous line below levels of a variable indicates that the levels sharing this line do not differ significantly from each other for that measure and experimental condition. The numbers in parentheses are the mean reaction times in msec for the condition indicated. A dash between levels indicates an insignificant difference; a comma between levels indicates an identical detection rate or mean reaction time. With few exceptions, the detection and reaction time data show the same trends, with the reaction-time data showing greater sensitivity in distinguishing among conditions. Although these detection and reaction-time data are not totally independent (since failure to detect a target resulted in tabulation of a reaction time of 5 sec, the maximum time allowed), a further analysis of the reaction time data, which excluded readings where the subject failed to respond, showed the same orderings of colors and of flash rates as are shown in table 2. This means that a stimulus condition that results in a light being frequently missed will also result in a long reaction time when it is detected.

Hue

Table 2 indicates that, for the conditions of this experiment, the red light was responded to, over all conditions, significantly fewer times, and slower than other hues. Reaction time to yellow was significantly slower than reaction time to white, green, or blue, with white significantly slower than blue.

Flash Rate

Table 2 indicates that reaction time to a steady light was significantly slower than to any of the flashing lights, with the 4-Hz and 1-Hz rates inferior overall to the 2-Hz rate. The detection data show the same trends.

Hue vs. Flash Rate

The ordering of the various hues by performance level seems to be little affected by the flash rate used (table 3). Although at 2 Hz the differences between yellow, white, and green targets is obscured, the blue light retains its detection advantage while the red light continues to require longer reaction times. Table 4 shows that when flash rates are ordered for the various hues, some relationships emerge that differ from those seen in the overall data. For blue and green targets, for instance, no detection-rate or reaction-time differences can be attributed with high statistical probability to the differences between flashing and steady lights, or to differences among flash rates. For white light, the reaction time to a steady light is significantly slower than to flashing lights, while for yellow and red, the 2-Hz flash rate results in significantly faster reaction times than other flash rates or a steady light. The flash rate orderings for red are particularly interesting since the steady light does not even occupy a position towards the low performance end on the flash-rate dimension. Only the 2-Hz flash rate improves both detection and reaction time to red.

Position in the Visual Field

The influence of position of the target in the visual field on reaction time, averaged over conditions, is shown in figure 1. A curve has been fitted visually, in this figure and in figure 2, to aid the reader. Figure 1 shows the relationship between light position and subject response time that was suggested for white light in an earlier study (ref. 6). Reaction time has a distorted U-shape relationship to distance from the center of the visual field; that is, it is high for the light that is directly aligned with the subject's horizontal line of sight, drops to a minimum for those lights adjacent to the center of the visual field (approximately 3° to 8° from center), and rises again for lights in the extremes of the field of view.

Position in the Visual Field vs. Hue

A hue analysis of the relationship noted between position in the visual field and reaction time (fig. 2) reveals that the overall data are dominated by two general trends: (1) a relatively long response time (found for all hues except red and blue) for the center light; and (2) the tendency for longer reaction times (particularly for red and yellow stimuli) to lights at the extremes of the visual field. For the yellow stimuli, the central light and lights at the extremes of the visual field result in significantly slower reaction times than lights appearing in the rest of the visual field. For red, reaction times to lights at the extremes of the visual field were significantly slower than reaction times to lights at other positions. For white, the central light results in a significantly poorer reaction time performance than lights at other positions. Light position does not result in differences that reach statistical significance for the green or blue stimuli.

Position in the Visual Field vs. Flash Rate

Although the analysis of variance showed the interaction of light position and flash rate to be a significant effect,[1] there is no evidence that flash rate affected various light positions in a consistently different manner. The general pattern is that described in figure 1.

DISCUSSION

In attempting to equate various hues on an intensity dimension, some arbitrary standards must be adopted. Since vision at the receptor level is a dual function, equating on the brightness dimension for one set of receptors means that the complementary set of receptors is not equated. This presents no problem if the stimuli can be directed to particular portions of the retina, since, in this case, the receptor distribution can be predicted. However, in measuring a complex and dynamic function such as the conspicuity of targets during free visual search, it is not known where on the retina the light is imaged initially. This area may, and likely does, differ from trial to trial. In the present experiment, the lights were foveally equated, a condition that is closer to the aeronautical situation than is peripheral matching. Equating for foveal luminance gives a brightness advantage to those lights at the shorter wavelengths if, and when, detection is initiated peripherally, since blues and greens that appeared to be the same intensity as reds and yellows with foveal, cone vision would appear brighter than reds and yellows seen with peripheral, rod vision. The findings of this study as measured by detection rate and reaction time, are in the direction of what would be expected from the luminance relationships of the various hues if imaged peripherally. The conspicuity ordering of hues, from highest to lowest, measured both by the probability of detection and by the speed of reaction, is: blue – white – green – yellow – red. This indicates that under these viewing conditions, an observer who is given no search instructions, begins his search in the middle of the visual field, and makes at least some of his responses from information initiated through peripheral vision. Enoch has found similar patterns for locating targets in highly complex photographs and maps (ref. 9).

It is required only that aeronautical lights reach a stated minimum liminance (rather than being specifically equated as they were in this study). However, it is reasonable to assume that in actual operation, red lights, which are commonly used as beacons in nighttime flying, tend to be missed until they are acquired by foveal, or near-foveal vision. Lights of other hues, which have a higher potential for being acquired peripherally, would be more likely to be detected earlier. Of course,

---

[1] The F ratios for the light position-flash rate interaction were by far the smallest of the main and double interactive ratios, reaching 2.1 for the detection data and 2.3 for the reaction-time data.

this does not take into account the influence of such environmental factors as target detection against a complex background, backscatter, etc. It should be remembered, also, that we are speaking here of conspicuity. This is not the same as other kinds of requirements such as color recognition or color identification, all of which must be considered in establishing specifications for aircraft lighting.

Since the data for red and yellow targets suggest that the subjects begin their free visual search by fixating close to the center of the field of view, (detecting lights at the extremes of the visual fiels only when they fall on or near the fovea), it is somewhat surprising that the blue central light has a relatively short reaction time that is approximately the same as that elicited by blue targets far removed from the central position. Assuming luminosity factors play a dominant role, one might expect an inverse relationship between the angular separation from the center of the visual field and reaction time for the blue stimuli. The reaction times for blue targets in this study are of about the same magnitude as those to white targets used in an earlier study (ref. 6) which were 0.5 $\log_{10}$ unit brighter. If it is assumed that the variations in reaction time with position in the visual field for blue targets are merely chance variations, as they appear to be for green, and as the statistical tests suggest, it may be that an irreducible reaction time for this task has been reached, so that further increases in apparent intensity (as in viewing the blue light peripherally) do not contribute to lowered reaction time. If this is true, the present conditions would be expected to obscure a decreased reaction time with increased angular separation from the central position for short wavelength hues, a finding which might occur with dimmer or briefer stimuli. Or, it may be that the relationship between luminance and retinal position suggested by the data of the longer wavelengths (red, yellow) is only one aspect of a more complex visual sensitivity pattern that mediates conspicuity, particularly at shorter wavelengths (blue). In any event, the relationship between the angular distance of the targets from the center of the visual field and reaction time is similar to what would be predicted from luminosity factors for stimuli of longer wavelengths, but not for those of shorter wavelength.

Perhaps the most interesting findings are those related to flash rate effects and the relationship of flash rate and hue. It seems clear that, in general, a steady light is a poor enhancer of conspicuity when seen against a star background; and a steady white light is particularly inconsistent with rapid response. It seems equally clear that conspicuity generally peaks at from 2 to 3 Hz. For both probability of detection and reaction time, and for all colors, a steady light is either the same as, or inferior to other flash rates; while a 2 Hz light is either the same as, or superior to, steady lights and other flash rates.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., 94035, October 14, 1974

REFERENCES

1. Malone, F. L.; Sexton, Mary S.; and Farnsworth, D.: The Detectability of Yellows, Yellow-Reds, and Reds, in Air-Sea Rescue, Res. Lab. Rep., no. 182, 1951, pp. 177–185.

2. Malone, Florence L.: A Preliminary Field Evaluation of the Relative Detectability of Colors for Air-Sea Rescue. Med. Res. Lab. Rep., no. 237, 1953, pp. 1–9.

3. Connors, Mary M.: Luminance Requirements for Hue Identification in Small Targets. J. Opt. Soc. Amer., vol. 58, no. 2, Feb. 1968, pp. 258–263.

4. Connors, Mary M.: Luminance Requirements for Hue Identification in Small Targets. J. Opt. Soc. Amer., vol., 59, no. 1, Jan. 1969, pp. 91–97.

5. Connors, Mary M.: Luminance Requirements for Hue Perception and Identification for a Range of Exposure Durations. J. Opt. Soc. Amer., vol. 60, no. 7, July 1970, pp. 958–965.

6. Connors, Mary M.: Conspicuity of Target Lights. The Influence of Flash Rate and Brightness. NASA TN D-7961, 1975 (to be published).

7. Nilsson, T. H.; and Nelson, T. M.: Hue Shifts Produced by Intermittent Stimulation. Vision Research, vol. 11, July 1971, pp. 697–712.

8. Duncan, D. B.: Multiple Range and Multiple F Tests. Biometrics, vol. 11, no. 1, March 1955, pp. 1–42.

9. Enoch, J. M.: Natural Tendencies in Visual Search of a Complex Display. In Visual Search Techniques – Proceedings of a Symposium Sponsored by the Armed Forces – NRC Committee on Vision. Washington, D.C., April 7–8, 1959.

TABLE 1.– DESCRIPTION OF HUES OF TARGET LIGHTS

Hue	Wratten filter no.	Dominant λ	Excitation purity, %
Red	29	630.7	100
Green	60	532.3	75
Blue	47	465.9	96
Yellow	16	588.3	99

TABLE 2.– COLOR AND FLASH RATE ORDERINGS

	Detection	Reaction time				
Color	Red Yellow - White - Green - Blue	Red (2352)	Yellow (1376)	White - (1061)	Green - (1003)	Blue (812)
Flash rate, Hz	Steady 4–1–3–2	Steady (1446)	(1342)	(1305)	(1271)	(1200)
	Low ← Performance → High					

TABLE 3.– COLOR ORDERINGS BY FLASH RATE

Flash rate, Hz	Measures					
	Detection	Reaction time				
Steady	Red Yellow White - Green - Blue	Red (2232)	Yellow (1771)	White (1263)	Green - (1034)	Blue (932)
1	Red Yellow - Green - White, Blue	Red (2335)	Yellow (1280)	White - (1027)	Green (1018)	Blue (863)
2	Red White - Yellow - Green - Blue	Red (2074)	Yellow - (1105)	White - (1021)	Green - (962)	Blue (840)
3	Red Yellow - Green - White - Blue	Red (2267)	Yellow (1034)	White - (977)	Green - (937)	Blue (871)
4	Red Yellow - Green - White - Blue	Red (2353)	Yellow (1420)	Green - (1061)	White (1019)	Blue (856)
	Low◄——— Performance ———►High					

TABLE 4.– FLASH RATE ORDERINGS BY COLOR

Hue	Measures					
	Detection	Reaction time				
White	Steady - 2, 4 - 3 - 1	Steady (1263)	1 - (1027)	2 - (1021)	4 - (1019)	3 (977)
Blue	Steady - 4 - 1 - 3 - 2	Steady - (932)	3 - (871)	1 - (863)	4 - (856)	2 (840)
Green	4 - Steady - 1 - 3 - 2	4 - (1061)	Steady - (1034)	1 - (1018)	2 - (961)	3 (937)
Yellow	Steady - 4 - 3 - 1 - 2	Steady (1771)	4 - (1420)	3 - (1304)	1 (1280)	2 (1105)
Red	1, 4 - Steady - 3 - 2	4 - (2353)	1 - (2335)	3 - (2267)	Steady (2232)	2 (2074)
	Low◄——— Performance ———►High					

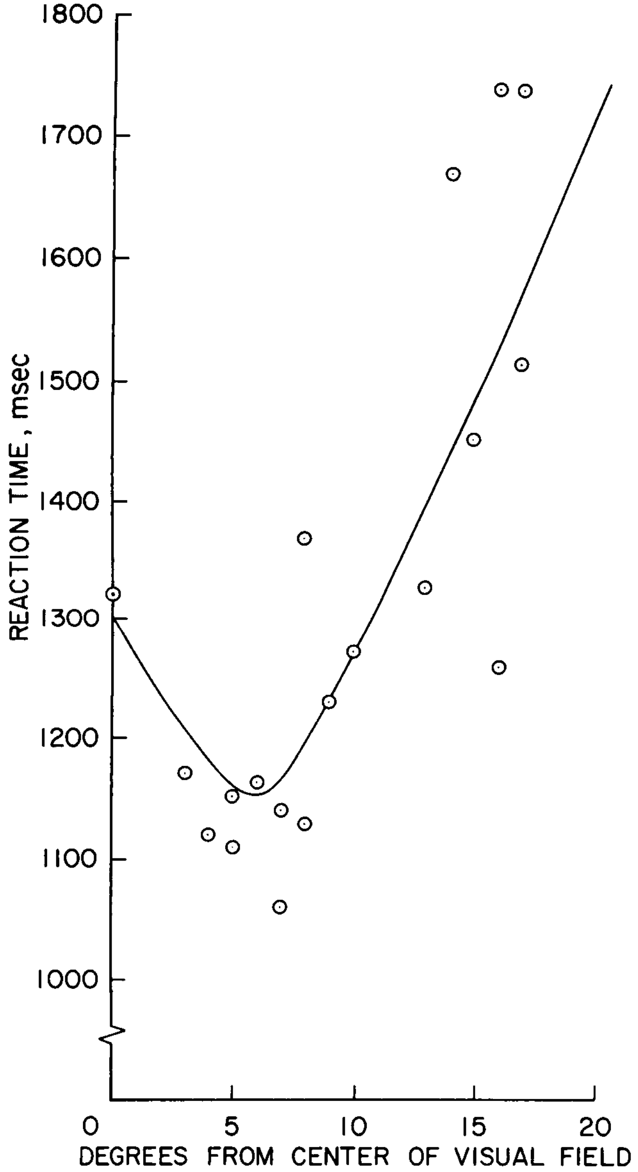
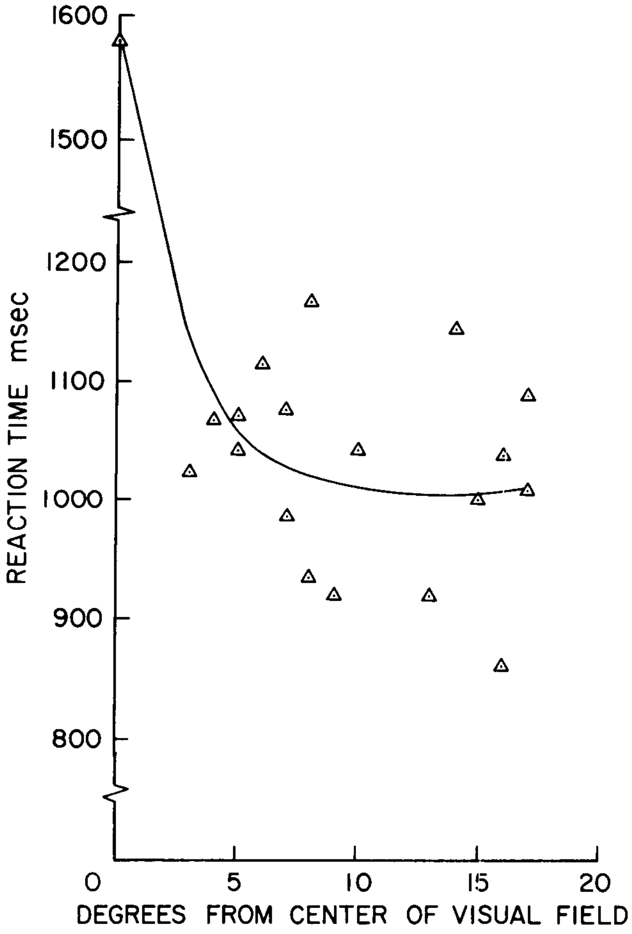
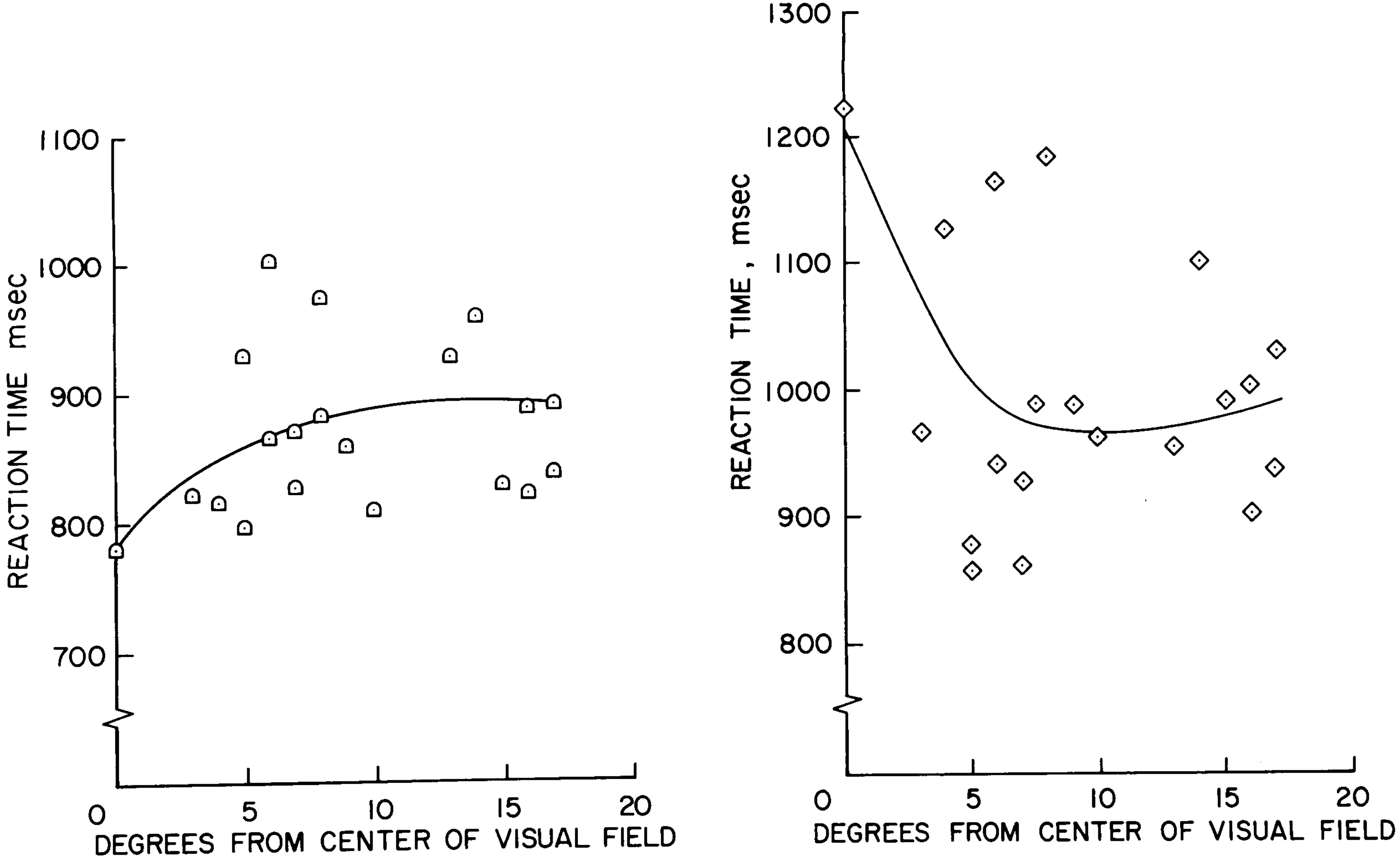


Figure 1.– Reaction time (in msec) as a function of degrees from center of visual field averaged over color and flash rate.



(a) White

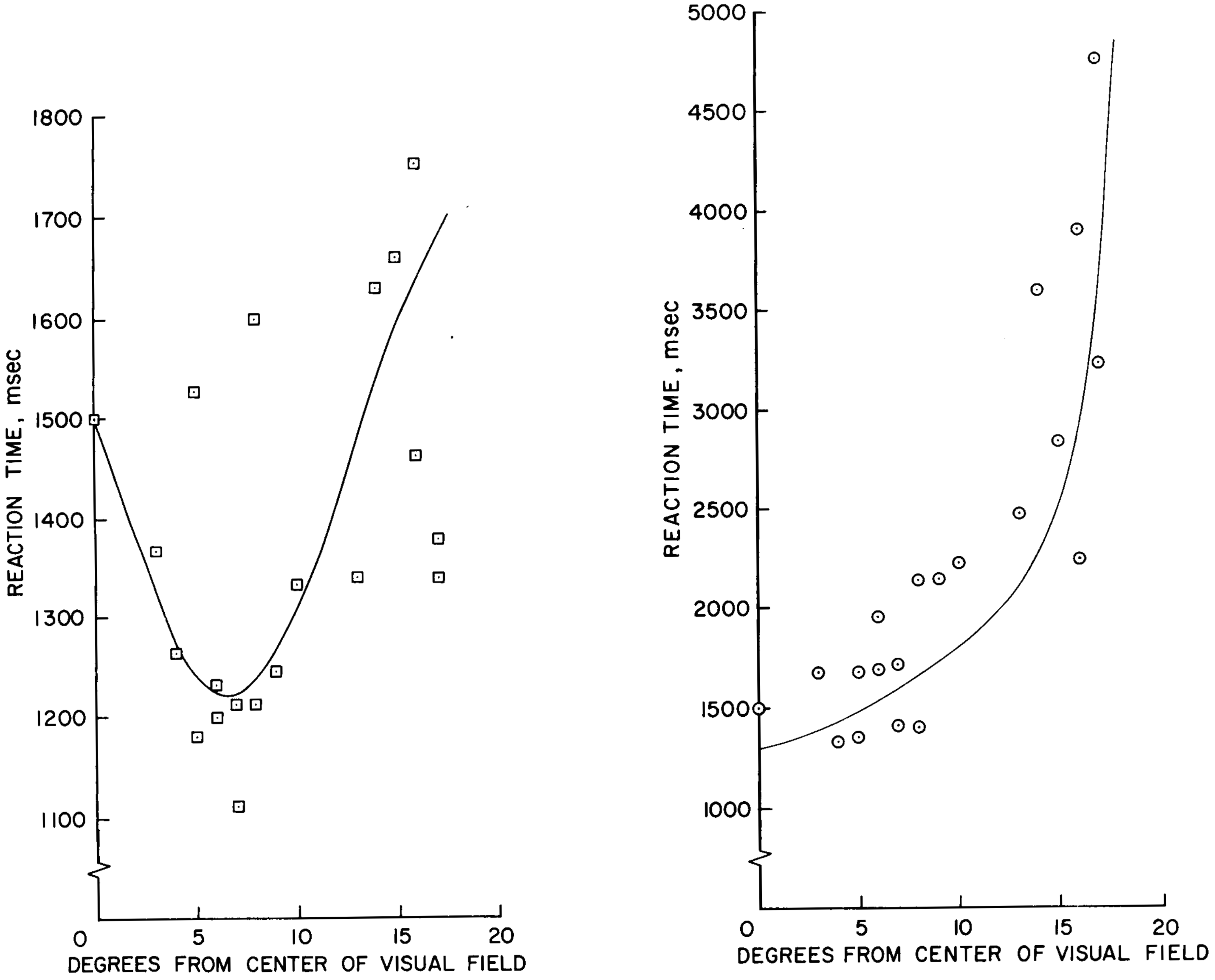
Figure 2.– Reaction time (in msec) as a function of degrees from center of visual field for individual colors.



(b) Blue.

(c) Green.

Figure 2.– Continued.



(d) Yellow.

(e) Red.

Figure 2.– Concluded.

NASA-Langley, 1975 A-5791