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Color and Shape Recognition of Reflectorized Targets Under Automobile Low-Beam Illumination at Night

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Two independent studies were conducted to determine the distances at which the color and the outside shape of reflectorized targets were recognized at night under automobile low-beam illumination. The targets were flat plates presented in one of three outside shapes and covered with retroreflective sheeting using one of six colors. All flat plates were prepared in such a way that they had the same area and close to the same specific intensity per unit area. In Study 1, the color recognition distances and the shape recognition distances were determined. In Study 2, the only color recognition distances investigated were for square targets that had the same area and specific intensity per unit area as used in Study 1. Summary measures for recognition distances and confusion matrices were obtained to examine the effects of color and shape. The results of Study 1 indicate that the recognition distances for highly saturated colors are about twice the recognition distances for outside shapes. The statistical analysis results of both studies show that the recognition distances for highly saturated colors are significantly different and that some colors have longer recognition distances than others. In addition, on the basis of a statistical analysis, the results of Study 1 indicate that the recognition distances for the shapes are not significantly different. It may be concluded that the highly saturated colors are superior stimuli when earliest possible recognition of a reflectorized target under automobile low-beam illumination at night is important.

Color and outside shape have always been regarded as important stimulus dimensions in considering the proper recognition of reflectorized targets such as retroreflective traffic signs during daytime and nighttime. As stated in a FHWA manual (1): "standardized colors and shapes are specified so that the several classes of traffic signs can be promptly recognized. Simplicity and uniformity in design, position and application are important." In addition, the manual stipulates design criteria for signs using retroreflective materials and mandates that reflectorized signs show the same shape and color by both day and night.

Research to determine the detection distance of retroreflective targets at night has been carried out by Zwahlen (2–4). Research to determine the nighttime recognition of white reflectorized warning plates as a function of outside shape and target brightness, as well as a function of full area reflectorization and borders-only reflectorization for different target brightness levels, has been conducted by Zwahlen et al. (5,6). The results of the study by Zwahlen et al. (6) indicate that increasing target brightness has either no effect or only a small detrimental effect on the correct outside-shape recognition distances for the full reflectorization and the borders-only reflectorization. Targets with only the borders reflectorized were recognized from farther away than targets that were fully reflectorized. As Kantowitz and Sorkin discuss (7), detection requires only a go/no go decision—a stimulus is either present or absent. In contrast, recognition requires that the subject identifies not only whether a signal is present or absent, but, if it is present, what signal occurred. Studies investigating how well outside shape, symbols, and color can communicate abstract concepts or messages have been reported in literature by authors including Jones (8) and Saenz and Riche (9). For example, Jones studied the symbolic representation of two abstract concepts used in road signs—type of message and prohibition—and found that the use of two coding variables, color and outside shape, was unnecessary in most cases; the shape of the sign alone proved to be enough to convey these concepts. Jones stated,

> The effect of removing the usual colour cues from the road sign did not affect their capacity to communicate the two abstract concepts of message type and prohibition to any great extent. The shape of the sign alone, in the case of message containing orders and warnings, enables them to be clearly differentiated. Only in the case of messages intended to convey information did removal of the usual colour cue (blue) lead to a significant loss of interpretability. To distinguish information type messages from others, therefore, some additional cue (although not necessarily colour) appears to be necessary.

In these types of studies, the researchers were primarily interested in how well an abstract concept or message can be communicated by the outside shape, symbol, or color against a selected background condition. The researchers used experimental conditions in which the stimulus dimensions—such as the color and outside shape—were well within the recognition capabilities of the subjects (suprathreshold levels).

The present studies did not investigate how well the meaning of a particular shape, color, or shape-color combination was communicated; they were designed to assess whether one of the two stimuli (color or outside shape) can be recognized from farther away than the other and thus be superior in terms of recognition distance. The overall objective was to determine the distances at which the color of a reflectorized flat plate can be recognized. Another major objective of the first study was to determine the distances at which the outside shape of a reflectorized flat plate of a specific color can be recognized.

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METHOD

Subjects

In Study 1, a group of seven subjects was used. The average age of the subjects was 21 years, and the visual acuity for distance ranged from 20/17 to 20/22. In Study 2, a group of six subjects was used. The average age of the subjects was 23.3 years, and the visual acuity for distance ranged from 20/17 to 20/25. No major color deficiencies were found in any of the subjects. Visual acuity and color capability were tested by using the Bausch & Lomb Vision Tester. All subjects showed normal contrast sensitivity over the examined spatial frequency range as determined by the Vistech Contrast Sensitivity Test.

Experimental Design, Site, and Apparatus

In Study 1, the independent variables were color and outside shape. The colors were red, orange, yellow, green, blue, and white (six levels), and the outside shapes were a circle, a square, and a diamond (three levels; see Figure 1). The dependent variables were the distance at which the subject made a color recognition decision and the correctness of that decision and the distance at which the subject made an outside-shape recognition decision and the correctness of that decision. The randomized block design was used in the experiment. There were two kinds of blocks: color recognition blocks and shape recognition blocks. Each block had 18 conditions: 6 colors × 3 shapes. Within each block each color-shape recognition condition appeared in a unique random order exactly once. For each subject there were two color recognition blocks and two shape recognition blocks, and the number of observations was 72: 6 colors × 3 shapes × 2 recognition types × 2 replications. The order of the color and shape recognition blocks was randomized and approximately balanced for the seven subjects.

In Study 2, the independent variable was the color of square targets, which had the same six levels as were used in Study 1. The dependent variable was the distance at which the subject made a color recognition decision and the correctness of that decision. The targets used in Study 2 were the same six square targets as used in Study 1. The randomized block design was also used in Study 2. The six colors were randomized within each block, and each color appeared in a unique random order exactly once. For each subject there were 10 blocks and 60 observations.

All reflectorized color targets used in the two studies had the same area (36 in.²) and close to the same specific intensity per unit area (28.2 cd/fc/ft² at 0.2 degrees observation angle

and −4 degrees entrance angle). All the targets used 3M high-intensity encapsulated lens retroreflective sheeting material, which provides highly saturated colors (desirable) under nighttime automobile beam illumination and also meets the daytime requirements for colors used on traffic signs as specified by FHWA (1).

The daytime 45/0.2-degree OBS Y,x,y tristimulus values for ILL D_{65} were 3.35, 0.6645, 0.3169 for red; 18.03, 0.5498, 0.4027 for orange; 16.39, 0.5332, 0.4626 for yellow; 6.46, 0.1340, 0.4503 for green; 3.24, 0.1413, 0.1391 for blue; and 31.41, 0.3106, 0.3311 for white. The nighttime 0.33-degree OBS, Beta 1 = −5 degrees, Beta 2 = 0 degrees, Rot Ang. = 0 degrees, for CIE 1931 2-degree std. obs., std. Illuminant A, the X, Y, Z tristimulus values were 106.09, 50.33, 0.32 (chromaticity, CIE 1976, $u' = 0.4923$, $v' = 0.5255$) for red; 140.99, 93.41, 1.91 ($u' = 0.3643$, $v' = 0.5431$) for orange; 201.75, 160.69, 1.06 ($u' = 0.3086$, $v' = 0.5530$) for yellow; 11.91, 43.33, 16.78 ($u' = 0.0669$, $v' = 0.5476$) for green; 11.43, 22.77, 38.57 ($u' = 0.0975$, $v' = 0.4372$) for blue; and 253.81, 237.77, 62.66 ($u' = 0.2533$, $v' = 0.5339$) for white. The same specific intensity per unit area for the different color targets was obtained by using the blue target, which had the lowest specific intensity per unit area as the standard (e.g., 28.2 cd/fc/ft²). All other color targets were then covered with thin, black, equally spaced self-adhesive stripes in such a way that the overall specific intensity per unit area of a color target was close to 28.2 cd/fc/ft². Figure 2 illustrates how the square targets were covered and provides dimensions and photometric values. The grating pattern was made fine enough so that it produced a spatial frequency (greater than 50 cycles/degree) that was beyond the recognition capability of the human visual system for any contrast value for the recognition distance range of interest.

Both studies were conducted using the same unused concrete airport runway (75 ft wide and 1,500 ft long) at the outskirts of Athens, Ohio. Figure 3 illustrates the setup of the site. A two-lane state highway with moderate traffic runs parallel to the runway about 200 ft away. A number of luminaires, a few illuminated advertising signs, and other light sources were within the subjects' field of view, mainly in the left half of the visual field. The dark background surrounding the target had a luminance value range from 0.02 to 0.05 fL. In Study 1, a 1987 Pontiac Grand Am with properly aimed 4652 low beams was used. In Study 2, a 1979 Chrysler New Yorker with properly aimed 4652 low beams was used. During the experiment, the car engines were kept idling.

Experimental Procedure

In both studies the stationary car was positioned so that the center of the front of the car was exactly above the centerline of the runway and the longitudinal centerline of the car formed a 3-degree angle to the left of the runway centerline. A darkly clothed experimenter rode a dark bicycle toward the car at approximately 10 mph, 6.25 ft to the right of the runway centerline (from the subject's point of view) (see Figure 3). The reflectorized target was attached to the front of the bicycle in such a way that the target surface was vertical and the center of the target was 25 in. above the ground. The subject would fixate on the target approaching the car with
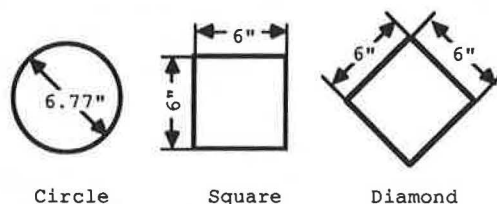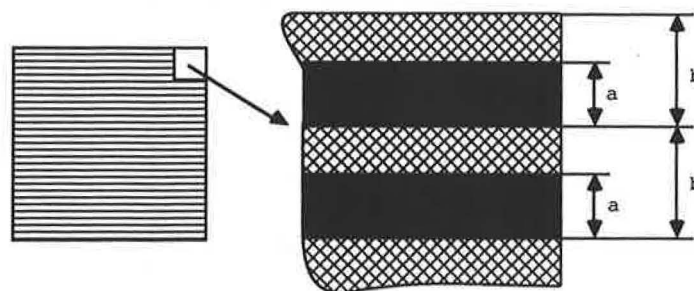

FIGURE 1 Dimensions of reflective targets.

Color	Avg. SIA (cd/fc/sq.ft)	Width (in.)		Cycles/deg. at 200'dist.
		a	b	
White	346.6	0.5	0.544	77
Yellow	256.2	0.5	0.562	75
Orange	118.5	0.25	0.328	128
Red	72.8	0.125	0.204	205
Green	54.5	0.125	0.259	162

Targets were covered by black self-adhesive stripes
to obtain an equivalent overall average SIA of 28.2
cd/fc/sq.ft as was measured for the blue color

FIGURE 2 Target covering patterns, dimensions, and photometric values (SIA = specific intensity per unit area).

the low beams on. When the subject recognized the color or the outside shape of the approaching target, he or she would turn on the high beams of the car temporarily. The experimenter riding the bicycle would then drop a small sandbag. The distance from the front of the car to the sandbag was recorded as the recognition distance. The subject would also call out the color or shape of the target to an experimenter in the car, and the subject's response would be recorded. The bicycle rider would return to the starting position with the sandbag and be outfitted with another target for the next run as soon as the distance was measured.

RESULTS

Figure 4 shows the recognition distances for the six colors and the three outside shapes obtained from Study 1. From Figure 4 it can be observed that for all the color and shape conditions, the average color recognition distances consistently are considerably longer than the average outside-shape recognition distances. An analysis of variance (ANOVA) test using a .05 significance level showed that the color recognition distances were significantly different (longer) than the outside-shape recognition distances. This appears to be true for the standard deviations also. The overall average color recognition distance is 719.1 ft, but the overall average outside-shape recognition distance is only 356.4 ft (color recognition distance 2.02 times longer than outside-shape recognition distance, or 3.4 min of visual angle versus 6.8 min of visual angle for a 8.5 in. target dimension).

Figure 5 shows an overall comparison between color and outside-shape recognition distances obtained in Study 1. The average color recognition distance appears to be about twice the average shape recognition distance. The overall average standard deviation of the color recognition distances (215.8 ft) was 1.84 times larger than the overall average of standard deviation of the shape recognition distances (117.2 ft). The ANOVA tests (using a .05 significance level) further indicated that in Study 1 there was a significant difference in the color recognition distances. A Newman-Kuels test (using a .05 significance level) showed that the color recognition distances for red are significantly different when compared with the color recognition distances for greens; this was the only statistically significant difference among all color pair comparisons. The ANOVA for the shape recognition distances obtained in Study 1 showed that neither the color nor the outside shape produced statistically significant differences in the outside-shape recognition distances. The confusion matrices for the color recognition and for the outside-shape recognition tasks obtained in Study 1 are given in Tables 1 and 2. The confusion matrices and the values for the information transmitted show that the percentage of stimulus information transmitted in the color recognition task (73.3 percent) is higher than that for the shape recognition task (58.4 percent).

Figure 6 shows the recognition distances for the correct color recognition decisions obtained in Study 2 (square target) along with the averaged (all three outside shapes combined) color recognition distances obtained in Study 1. An ANOVA test using a .05 significance level showed that the recognition distances for different colors were also significantly different
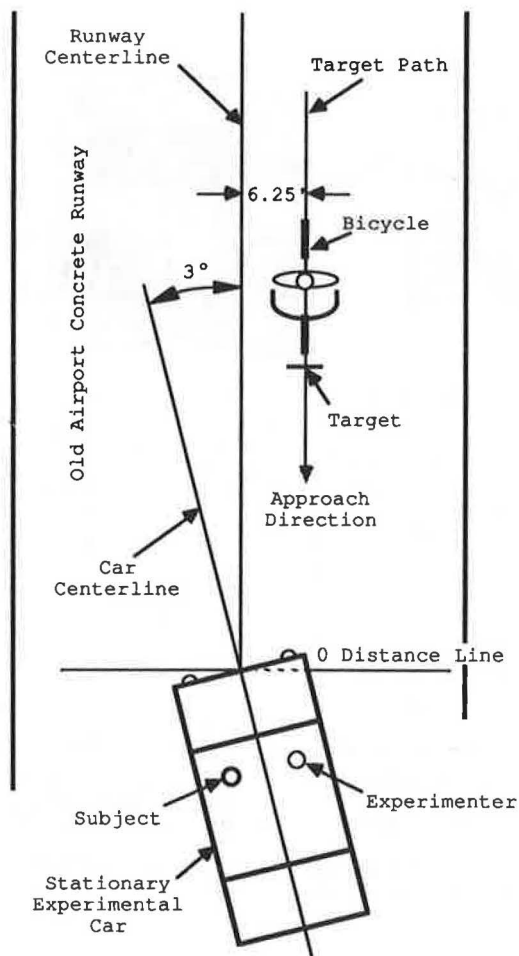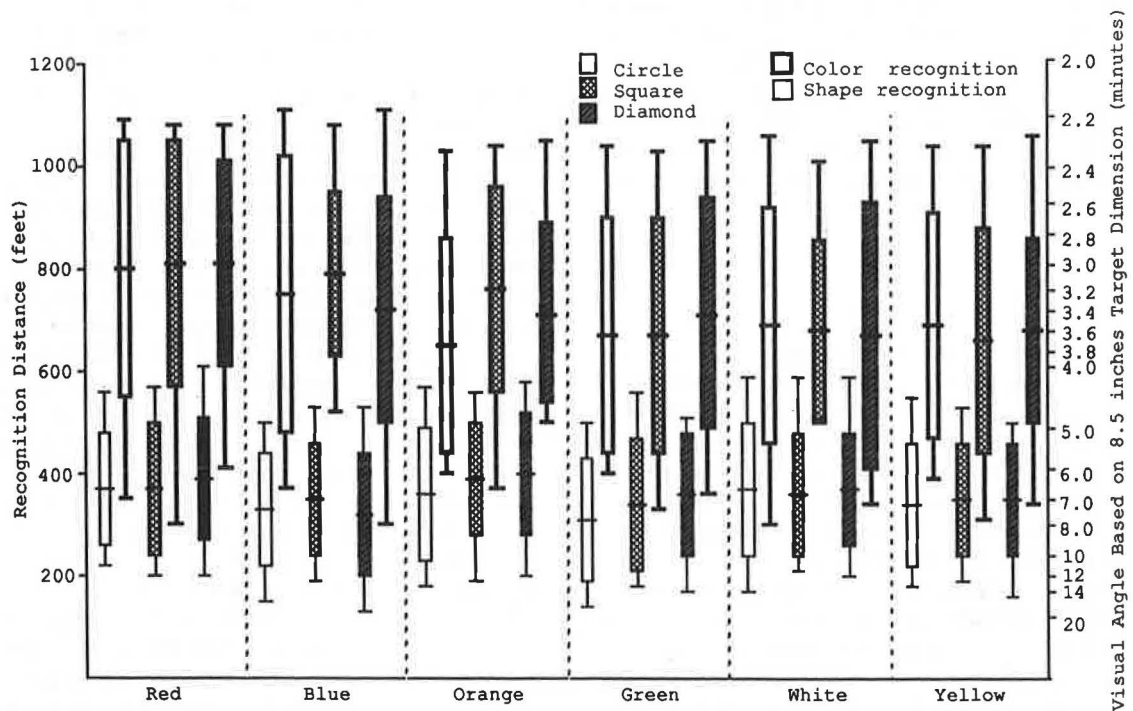
FIGURE 3 Experimental site.

FIGURE 4   Averages, standard deviations, and maximum and minimum values of color and shape recognition distances, Study 1 ($n = 14$).
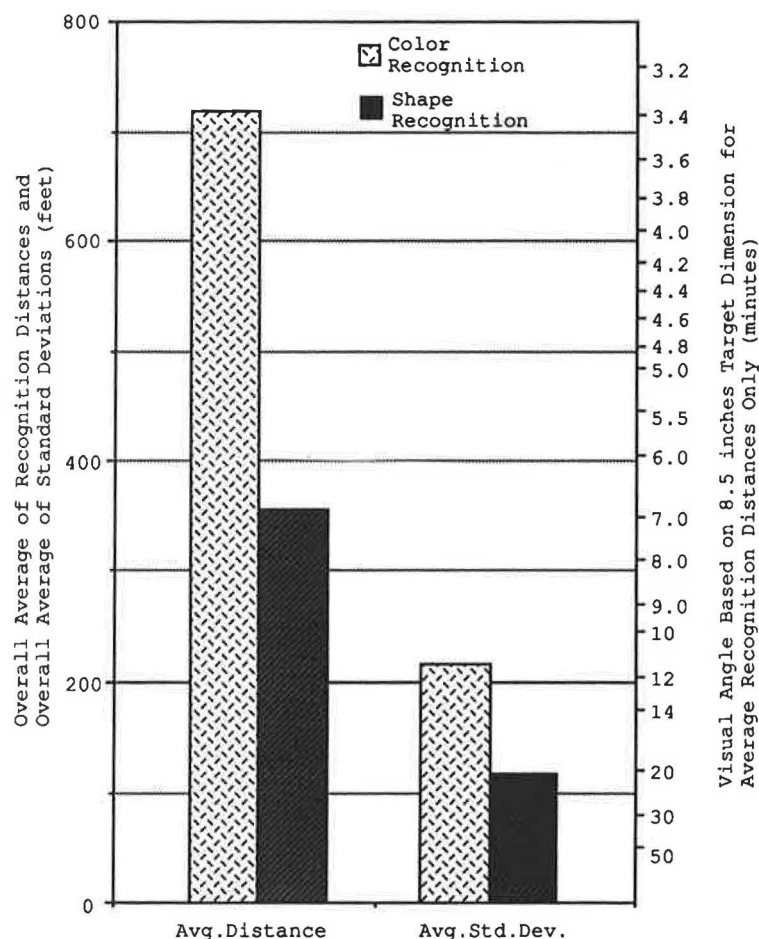
FIGURE 5   Comparison between color and shape recognition distances
(overall average and overall standard deviation), Study 1.

in Study 2. The overall average recognition distance (using distances associated with correct recognition decisions only) was 659.5 ft, which is slightly shorter (8.3 percent) than the average color recognition distance obtained in Study 1 (719.2 ft). The difference between the averages obtained in the two studies could be partly because two different groups of subjects and two different cars were used, or because of slight differences in car heading angles and eye-headlamp dimensions, or because the average color recognition distances in Study 1 included some recognition distances for which incorrect recognition decisions were made. The results of the Newman-Kuels test for Study 2 are shown in Table 3 and indicate that the recognition distances for red and orange are significantly different (longer) than those for all the other colors. A confusion matrix based on the results of Study 2 for correct and incorrect responses is given in Table 4. The percentage of the color stimulus information transmitted in Study 2 is 84.5 percent.

DISCUSSION OF RESULTS AND CONCLUSIONS

The results suggest that, for subjects with normal color vision capabilities, the highly saturated colors used in this study are

TABLE 1   CONFUSION MATRIX FOR SHAPE RECOGNITION, STUDY 1

	Responses			
Stimuli	Circle	Square	Diamond	Σ
Circle	74	3	7	82
Square	6	73	5	82
Diamond	9	2	73	82
Σ	89	78	85	252

$H(S) = 1.585$ bits $H(R) = 1.583$ bits

$H(S,R) = 2.242$ bits $T(S:R) = 0.926$ bits

Percentage of stimulus information transmitted =
58.4%

better stimuli than outside shapes when earliest possible recognition of a reflectorized target under automobile low-beam illumination at night is important (near threshold conditions). Furthermore, the results show that one cannot automatically count on simultaneous color and shape stimulus redundancy, especially when long recognition distances are involved (near

TABLE 2   CONFUSION MATRIX FOR COLOR RECOGNITION, STUDY 1

			Responses				
Stimuli	Red	White	Orange	Blue	Green	Yellow	Σ
Red	39		3				42
White		39	1			2	42
Orange	2		36			4	42
Blue				34	8		42
Green				9	33		42
Yellow		8	4			30	42
Σ	41	47	44	43	41	36	252

$H(S) = 2.585$ bits $H(R) = 2.58$ bits

$H(S,R) = 3.27$ bits $T(S:R) = 1.896$ bits

Percentage of stimulus information transmitted = 73.3%.

TABLE 3   RESULTS OF NEWMAN-KUELS TEST, STUDY 2 (0.05 SIGNIFICANCE LEVEL)

	Blue	Green	Yellow	White	Orange
Red	S	S	S	S	S
Orange	S	S	S	S	
White	NS	NS	NS		
Yellow	NS	NS			
Green	NS				

S = Significantly different.
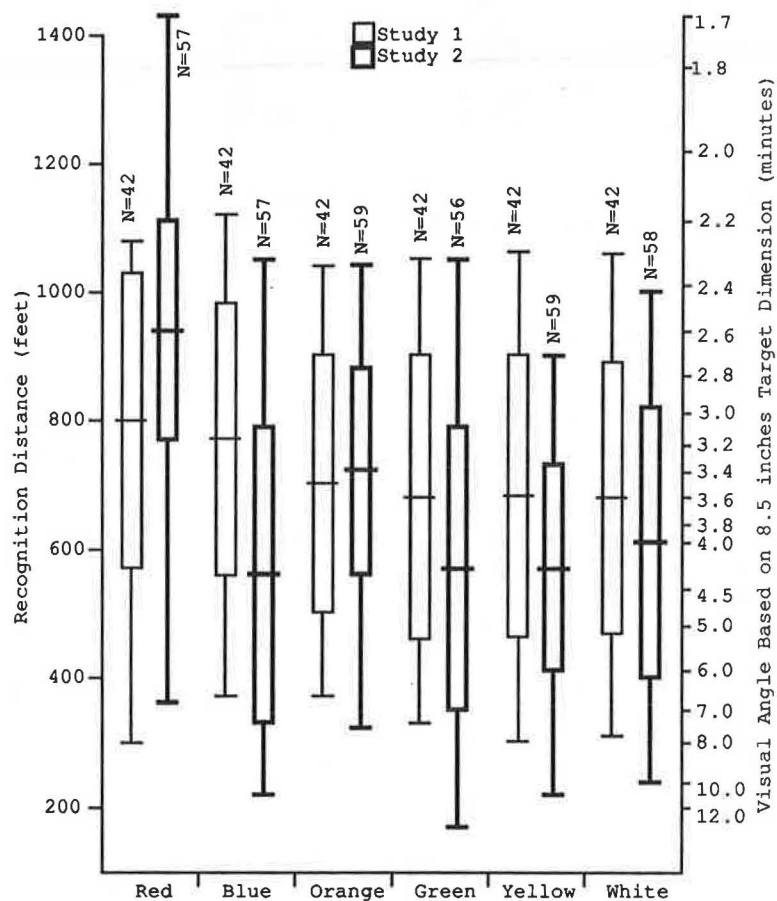
NS = Not Significantly different.

FIGURE 6   Averages, standard deviations, and maximum and minimum values of correct color recognition distances, Study 2, and averages, standard deviations, and maximum and minimum values for averaged color recognition distances, Study 1.

TABLE 4 CONFUSION MATRIX FOR COLOR RECOGNITION, STUDY 2

	Responses						
Stimuli	Red	Blue	Yellow	White	Orange	Green	Σ
Red	58						58
Blue		53				7	60
Yellow			55	4	1		60
White			3	57			60
Orange	2				58		60
Green		17				45	62
Σ	60	70	58	61	59	52	360

$H(S) = 2.585$ *bits* $H(R) = 2.58$ *bits*

$H(S,R) = 2.979$ *bits* $T(S:R) = 2.185$ *bits*

Percentage of stimulus information transmitted =

84.5%.

threshold conditions). A highly saturated color, in addition to the outside-shape stimulus of a retroreflective target, appears to increase the average recognition distance by a factor of 2. To maximize color recognition and minimize confusion for individuals with normal color vision capabilities, a highly saturated red color of the retroreflective target is recommended.

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