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COLORS AND LEGIBILITY:

CAUTION AND WARNING DATA-PLATES

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HUMAN ENGINEERING LABORATORIES

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ABSTRACT

This study compared the legibility of black printing on a yellow background with the legibility of five color combinations often used for caution and warning plates. The plates were tested under three light levels: low red, low white, and high white. Results showed that black on yellow and white on black were significantly more legible than the other four color combinations in at least one of the light levels, as well as when data were pooled for all three light levels.

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INTRODUCTION

What color should a caution or warning plate be? MIL-P-00514C with Interim Amendment 2 states, "Type IX plates shall . . . have a black background, except that caution and warning plates shall have red letters and a black background" (6).

A survey of caution and warning plates on military equipment showed that this Military Specification was not being followed. It also revealed that some plates were more legible than others under certain illumination levels encountered in the military environment. Since legibility of caution and warning plates seemed so important, the Human Engineering Laboratories (HEL) decided to study how color affects legibility.

A literature survey yielded considerable information about the legibility of colored printing on a colored field under high ambient light levels. The highlights of this literature search on legibility are summarized below.

Brightness contrast is directly related to legibility: the more contrast there is between printed matter and background, the more legible the printed matter should be. Miyake, Dunlap, and Cureton (7) studied the legibility of colored numbers and words on colored paper, and found the most legible combinations were white on black, black on white, black on yellow, and black on green. The poorest combinations were black on red and red on black. They concluded that the brightness difference between the printed matter and background was the important determinant of legibility. In 1913 Luckiesh (4) studied the legibility of advertising posters. After comparing 13 color combinations, he found black on yellow was the most legible, red on white was third, black on white was sixth, white on red was eighth, and white on black was tenth. Using Luckiesh's study as a guide, Sumner (10) later ranked 42 color combinations by legibility. Black on yellow was third, black on white was 11th, red on white was 24th, black on red was 26th, white on black was 35th, and red on black was 39th. He also concluded that legibility depends on brightness differences between the color of lettering and the color of background. After asking his subjects to rank order the color combinations in order of preference, he found that affective preference for color combinations obeys the law of brightness-difference even more closely than legibility does.

TABLE 1

Color Combinations of Ink and Paper with Observed Color Effects (13)[a]

Trade Names	Observed Effect
Black jobbing on white	Black on light grayish white
Grass green on white	Dark green on light grayish white
Lustre blue on white	Dark blue on light grayish white
Black jobbing on yellow	Black on yellow (slight orange tinge)
Tulip red on yellow	Light red on yellow (slight orange tinge)
Tulip red on white	Light red on light grayish white
Grass green on red	Dark grayish green on red (dark tint)
Chromium orange on black	Dark lemon yellow on dark grayish black
Chromium orange on white	Light orange on light grayish white
Tulip red on green	Dark brown on dark green
Black jobbing on purple	Black on dark purple (violet)

[a]Trade names are given here as reported by Tinker, although it is recognized that several manufacturers may use the same term for products that vary somewhat.

Dark print on a light background is more legible than light print on a dark background. Starch (9) found his subjects read black letters on white paper 42 percent faster than white letters on dark gray paper. Paterson and Tinker (8) reported reading speed was 10.5 percent faster with black on white than with white on black; moreover, 77.7 percent of their subjects rated black on white more legible. Taylor (11) found that white print on black took longer to perceive and required more fixations than black on white.

Reading speed is directly proportional to brightness contrast between print and background. Tinker and Paterson (14) reached this conclusion after comparing 11 color combinations. They also concluded that the brightness contrast between print and background should be at least 60 percent to produce legible copy (the above number refers to page copy or books, not data plates where copy is kept to a minimum).

A printing ink's apparent color depends on the color of background it is printed on. Tinker (13) recorded colors 850 subjects perceived with their 11 combinations of ink and paper, as reproduced in Table 1.

When personnel must read white print on a dark background under low illumination, the white letters should have slightly thinner stroke widths than normal, because of a phenomenon known as irradiation. English and English (1) define irradiation as the apparent increase in the size when a relatively small, bright figure is seen against a darker background; that is, a white figure on a dark field appears larger than a black figure on a white field.

It must be emphasized that brightness contrast and color contrast are independent. Red and green have considerable color contrast, but they might have identical brightnesses (i.e., no brightness contrast at all). For instance, Federal Standard 595 (2) lists red #31136 as having 11 percent luminosity and green #34127 as also having 11 percent luminosity. They have no brightness contrast at all, yet their colors are totally different.

Most of the above findings, dealing with legibility at high ambient light levels, are difficult to apply to data plates, which must remain legible under low-white illumination and red illumination. It was necessary, therefore, to find out how low-white and red illumination affect the legibility of data plates and warning or caution plates.

A study was designed to compare the legibilities of various color combinations under the three lighting conditions. In a preliminary study, several subjects spent 15 minutes in a dark room to become essentially dark adapted. Then they looked at an array of data and warning plates placed in front of them. As the illumination level was slowly raised, the subjects read the plates as they became legible. It was interesting to note that black-on-white information plates were read long before the white-on-red or red-on-black warning plates. The study was repeated using red illumination, with the same results.

This preliminary study clearly showed that, although red is the accepted basic color for caution and warning plates, it does not give maximum legibility. Therefore we began searching for a color combination that would be legible under low-red, low-white, and high-white illumination. There must be a distinct color contrast between the caution plate and any surrounding surfaces, as well as clear differentiation from an information plate. To avoid training problems, the color should be one already associated with a cautionary situation. One obvious possibility is yellow, which is already used on highway caution signs, caution lights at dangerous intersections where a stop light is not warranted, and as floor paint to mark hazardous areas in industrial plants. The Army has used yellow and black on aircraft emergency controls for years. MIL-M-18012B (5) states that immediate-action controls shall have orange-yellow-and-black stripes or have a yellow-and-black-striped panel background. Since so many studies found black on yellow was a very legible color combination, we designed a study to compare black on yellow with various combinations of red, black, and white. Six color combinations were chosen for testing:

a. Black letters on a yellow field.

b. White letters on an international-orange field.

c. White letters on a red field.

d. Red letters on a black field.

e. Black letters on a red field.

f. White letters on a black field.

White lettering was chosen to represent the silvery lettering that results when colored backgrounds are printed on bare aluminum plates.

All six color combinations were tested under three illumination conditions: low-level red, low-level white, and high-level white.

METHOD AND PROCEDURE

Subjects

Ten male military personnel, ranging in age from 22 to 42, were used as subjects. All subjects demonstrated normal vision (20/20 corrected or uncorrected), as tested by the Bausch and Lomb Ortho-Rater, type 71-21-40.

Stimulus Materials

Ten five-letter words were selected at random from the Thorndike and Lorge (12) list of the 1000 most common words in printed English. The ten words were arranged randomly in two vertical columns of five words each, on six white practice cards and six colored test cards. Each card presented the ten words in a different order. Each word's position was balanced so the word appeared equally often in each of the two columns and in each part of the column.

The colored test cards were 3-x-5-inch color chips purchased from General Services Administration Business Service Center, Region 3, Washington, D. C. The specific colors chosen from Federal Standard 595 (2) are:

Black	#37038
Red	#31136
Yellow	#23655
Orange	#32246

The words were printed in 12-point Futura Demi-bold letters (Deca-dry transfer letters). Figure 1 lists the ten words used in the experiment and shows the arrangement and dimensions of the test cards.

Apparatus

A Harvard-type tachistoscope (modified Dodge tachistoscope) was used so subjects could view the actual plates. (Other types of apparatus seemed less suitable because subjects would have viewed projected images, rather than the actual plates.) In the high-white condition, all four lights within the tachistoscope were illuminated. During the low-white condition, only the two top lights were illuminated. In the red-light condition, the white lights were replaced with four red instrument-panel lights (FSN 6210-699-9458) used on an actual military vehicle.

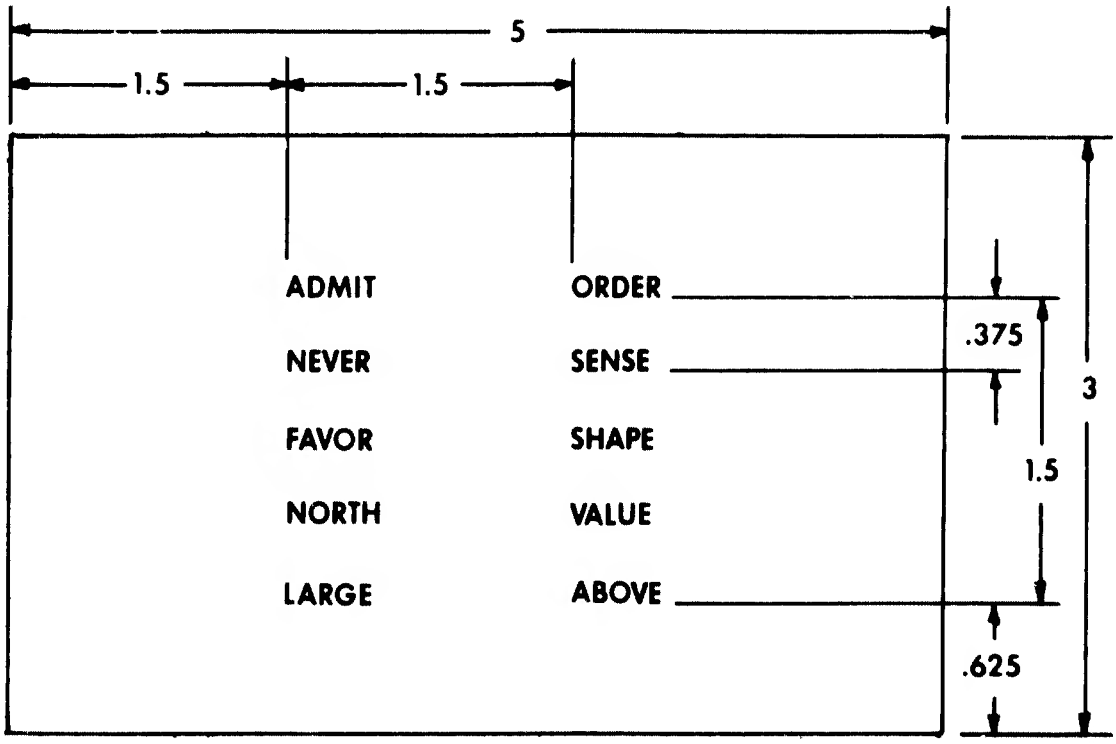

Fig. 1. ARRANGEMENT AND DIMENSIONS (INCHES) OF TEST CARDS

Light levels were measured under all test conditions with a Spectra Spot-Brightness meter (model SB 1 1/2) by measuring the reflectance of a white card in the tachistoscope. These reflectances are:

a. High-white illumination -- 6.0 foot-Lamberts.

b. Low-white illumination -- 1.0 foot-Lambert.

c. Low-red illumination -- 0.1 foot-Lambert.

The red lamps were operated with 20 volts direct current from a locally made power supply. The white lamps were powered by two 400-volt power supplies that are part of the Harvard tachistoscope set.

A Hunter timer (model 100-C, series D) was used with the tachistoscope.

The test apparatus served several purposes: (a) it illuminated an adapting field before and after exposing the test plate, (b) it illuminated the test plate at the same intensity as the adapting field for a controlled period of time, and (c) it controlled illumination level and color of both the adapting field and the test plate.

The experimenter felt all subjects' eyes should be focused at the same spot on the adapting field, to eliminate the variable time it would take to fixate on the first word. Therefore the adapting field had a white cross placed so that a subject fixating on it would fixate on the first letter of the first word in the left column when the test plate was exposed.

A pilot study showed that subjects read about six to eight words on the test plates in high-white light with an exposure of 1.75 seconds. To keep subjects from reading all the words on a card, an exposure time of 1.75 seconds was used with all three light levels. With a constant exposure time, changes in reading speed could be attributed to varying light level and color.

To balance learning and fatigue effects, both the test cards and the three lighting conditions were presented to the subjects in random orders.

Procedure

After taking an eye examination, the subject sat behind the tachistoscope and adjusted his chair to a comfortable height. The following instructions were read to each subject:

> I want you to look into the machine and focus your eyes at the intersection of the white lines. In time, a card with two vertical columns of words will appear. You will read the words out loud starting at the upper left and reading across the columns. In other words, read the top word on the left column, then the top word on the right column, the second word on the left column, the second word on the right column, etc. Are there any questions?

All questions were answered by repeating the applicable portion of the instructions. Subjects with questions were told, "You will get the 'hang' of it when I give you these practice cards." If the subject did not ask questions, he was told, "I am going to give you these practice cards to acquaint you with the task." Because of the nature of the task, all subjects learned rapidly and went on to the main portion of the experiment after one exposure to each of the six practice cards.

There was a 15-minute break after the practice session and between each of the three portions of the experiment. This break was necessary in going from a high light level to a low light level, because it allowed the subjects to spend 15 minutes in total darkness and become essentially dark adapted. To keep the time between conditions constant, the subjects also took a 15-minute break when going from low light level to high light level.

RESULTS

The raw data were treated with analyses of variance, using the 0.01 level as the criterion of significance, as described by Garrett (3). Table 2 summarizing the analyses of variance, shows significant F ratios for each illumination condition. Since all the F ratios were significant, the rank-ordered mean scores for each condition of illumination and overall were examined with t tests to determine which color combinations were significant. Table 3 shows the results of these tests.

Results from the three conditions were treated both separately and as a unit. The raw data showed black print on yellow was more legible than the other color combinations under all three lighting conditions; however, not all of these differences reached significance. When the mean responses of the three conditions were averaged, black on yellow was significantly more legible than black on red, white on orange, white on red, and red on black. White on black was significantly more legible than all the other combinations except black on yellow. There was no significant difference between black on yellow and white on black.

Under the low-red condition, white on orange and white on red were completely illegible. The subjects could not read any of the words on the cards in the time allotted. Under the low-white condition, the subjects were again unable to read any of the words printed in black on a red card, and their scores for red printed on black were significantly lower than for the other four combinations. Under the high-white condition, black on red was significantly less legible than all the other combinations except white on orange.

TABLE 2

Analyses of Variance

Illumination	Source of Variation	df	Sum of Squares	Mean Square (Variance)	F
Low Red	Among Conditions	5	1385.89	277.18	54.9***
	Within Conditions	54	272.70	5.05	
	Total	59	1658.59		
Low White	Among Conditions	5	2561.74	512.35	8.85***
	Within Conditions	54	312.60	5.79	
	Total	59	2874.34		
High White	Among Conditions	5	134.40	26.89	3.48**
	Within Conditions	54	417.00	7.72	
	Total	59	551.40		
Overall	Among Conditions	5	4478.74	895.75	29.9***
	Within Conditions	54	1620.20	30.00	
	Total	59	6098.94		

*** Significant beyond .001
** Significant beyond .01

TABLE 3

Summary of t-Tests Comparing Mean Scores[a]

Illumination	Color Combinations					
	White on Orange	White on Red	Red on Black	Black on Red	White on Black	Black on Yellow
Low Red	0	.1	8.3	8.8	9.8	12.5
	Black on Red	Red on Black	White on Orange	White on Red	White on Black	Black on Yellow
Low White	0	9.9	15.6	17.1	18.0	18.4
	Black on Red	White on Orange	Red on Black	White on Red	White on Black	Black on Yellow
High White	18.8	21.5	22.2	22.8	22.8	23.3
	Black on Red	White on Orange	White on Red	Red on Black	White on Black	Black on Yellow
Overall	27.6	37.1	40.0	40.4	49.9	54.2

[a]Means differ significantly ($p < .01$) unless underscored by the same line.

DISCUSSION

If caution or warning plates must be legible under all three lighting conditions, this experiment conclusively shows which combinations should be used. As mentioned in the Results section, white on orange and white on red are not legible under red illumination and, therefore, should not be used on caution or warning plates. Similarly, black on red is not acceptable under the low-white condition. Since red on black was significantly less legible than all combinations except black on red under the low-white condition, it, too, should be eliminated. This leaves only black on yellow and white on black.

Black on yellow was not only legible under all three conditions, but it was significantly more legible than all other combinations except white on black when the scores of the three test conditions were averaged.

These findings generally support the results reviewed in the Introduction. Black on yellow and white on black gave the greatest brightness contrast and were the most legible. The finding that subjects read more words with black on yellow and white on black, supports the theory that reading speed is proportional to brightness contrast between print and background.

Black on white was used only on the practice cards, and subjects' scores were not analyzed. This color combination was discarded because, if used on a metal plate, it would mean black letters on an aluminum background. In evaluating equipment, we have found that even matte aluminum plates reflect too much light, producing glare that seems to degrade legibility.

Since white on black was as legible as black on yellow, it should be adequate as a color combination for information plates. When both are applied to an olive-drab surface, the caution plate's yellow background should be quite noticeable. Not only are the colors quite different, but the olive-drab surface and the yellow plate have a 50 percent difference in brightness contrast.

SUMMARY AND CONCLUSIONS

Because color combinations for caution and warning plates have not been standardized, HEL evaluated various combinations that have been used on Army materiel. Since legibility was deemed to be the most important factor in a good caution or warning plate, literature on legibility was reviewed. Previous studies showed that black letters on a yellow background were very legible, so a stuuy was designed to compare black letters on yellow with other color combinations that are used:

Black on yellow
White on international orange
White on red
White on black
Red on black
Black on red

Ten military personnel read words printed in these color combinations and shown in a tachistoscope under three lighting conditions: high white, low white, and red. The plate's legibility depended heavily on the level and color of light. Red illumination severely degraded the legibility of plates when the letters or background were red, and even more so with an orange background. Results showed black on yellow and white on black to be significantly more legible than the other combinations.

It is, therefore, recommended that Amendment 2, MIL-P-00514C (6), paragraph 3.2.2.1, be changed to read:

> 3.2.2.1 When specified (see 6.2), type IX plates shall be made of anodized photographic aluminum (sensitized), grade A or grade B. Type IX plates shall also have a black background, except that caution and warning plates shall have black (Federal Standard 595 #37038) letters with a yellow (Federal Standard 595 #23655) background.

Any other caution and warning plates not covered by this Military Specification should also use black letters on a yellow background.

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