ANALYSIS of CERTAIN VARIABLES RELATED to SIGN LEGIBILITY

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THE RECENT development of high-speed urban freeways has increased the need for destination signs of maximum legibility. One factor thought to influence legibility is the letter-background arrangement, with the usual alternatives being black letters on a white background and white letters on a black background. A survey of the literature revealed nine published studies in which the legibilities of these two combinations were systematically compared.1/ The results of these studies throw little light on the problem as it relates to highway destination signs.

All but one of the studies were conducted in the laboratory with illumination levels ranging from 1 to 100 foot-candles. Since outdoor daylight may range as high as 10,000 foot-candles, results obtained in lower illumination levels may not be directly applicable to the usual daylight situation. However, if the results are considered only in terms of the low levels of illumination, the problem still remains unresolved because of the inconclusive and contradictory results obtained. Furthermore, the earlier experiments were, in general, based on the principle that all variables but one should be held constant. Therefore, it was assumed that the relationship between letter-background arrangement and legibility was independent of other factors. The failure to assume interaction between several relevant variables may be responsible in part for the contradictory nature of the findings.

As a result of the survey and analysis of the experimental literature related to the subject, it was decided that an investigation should be made in a field situation to attempt to determine whether or not outdoor, daylight letter legibility varies with letter-background arrangement, and in turn how this letter-background legibility is influenced by spacing between letters and rows.

CONSTRUCTION OF THE TEST SIGNS

Letter-background Arrangement. Using the Bureau of Public Roads Standard Alphabet for Highway Signs, 1945, as a model, 3-in.-high Series E (stroke width approximately one sixth of letter height) rounded capital letters were carefully drawn and then contact photographed. Contact prints were made from the negative and from a paper positive on white, semimat (G-81 contact) photographic paper.

The letters B, C, D, E, F, O, P, and R were used for the experiment. These particular letters, which appear in the American Optical Company Snellen Chart for visual acuity, were considered appropriate for this experiment.

1/ - Details of these nine studies are presented in the annotated bibliography starting on page 55.

From the black and white letter reproductions, 40 random groups of eight letters were then chosen so that for each "randomly" selected group of eight black letters there was an identical group of eight white letters. However, the order of appearance of the letters was not the same for both the black and the white card of a particular pair. In addition, all of the eight different letters used did not necessarily appear on any single card, since the selection method resulted in some letters appearing more than once in a specific group. Thus, there were 20 matched pairs of letter groups.

Spacing. The matched pairs of letter groups were then fastened on black or white mat boards, 20 by 30 in. Eight letters appeared on each board in two rows of four letters each. Ten of the 20 paired groups were placed on the boards so that there was 1½ in. (half the letter height) between each of the letters in a row of four, and 2 in. between the two rows. The other ten pairs were spaced 4 in. between letters (1 1/3 of the letter height) and 4 in. between the two rows.

The experimental material, therefore, consisted of 20 black signs and 20 white signs. Half of the black and half of the white signs contained eight closely[2] spaced letters; the other halves contained eight widely spaced letters. This gave a matching of pairs in which each member of the pair had the same spacing.

PLACEMENT OF THE SIGNS

Several problems arose in determining the most adequate distance of the signs from the subject for best observation purposes. Undoubtedly the viewing range is important, for if the signs are placed at distances such that the subject can read either none of the letters or all of them, no legibility differences resulting from the black and the white letters can be expected. It is also not known whether the effect being studied remains constant over the range between these extremes, or manifests itself differentially for different degrees of difficulty, i.e., different distances.

The problem of cooperation on the part of the subject became an important factor since the experiment involved a restricted routine task taking approximately ½ hr. of the subject's time. If cooperation was to continue throughout the observation period, the task should permit a reasonable number of successes.

In a preliminary study an attempt was made to find a single range composed of five equally spaced distances, so that none of the subjects would read less than half of the letters correctly and none would get more than 80 percent correct. A single range containing observation distances meeting these requirements was not found. However, it was possible to establish two separate ranges. When the subjects with better visual acuity were tested on the distant range and the subjects with poorer visual acuity were tested on the close range, each range was found to be satisfactory for its appropriate group of subjects. The distant range consisted of five equally spaced positions between 295 and 355 ft. The close range consisted of five equally spaced positions between 220 and 280 ft.

2/ - Actually, these closely spaced letters were as far apart for their height as those on any highway destination sign.

SIGN PRESENTATION

Each range contained five distances, and since there were 40 signs in all, eight signs, or four matched pairs, were shown at each distance. The letters on two of the matched pairs were closely spaced and those on the other two were widely spaced. Thus, any differences between white letters and black letters at a particular distance would not be due to differences in letter difficulty.

To exclude the possibility of presentation order affecting the results, a different random order of the 20 pairs of signs was used for each subject. Both members of a matched pair appeared at the same distance; and at each of the five distances, half of the signs were closely spaced and half were widely spaced. The order of appearance of the five distances was randomized for each subject.

SELECTION OF SUBJECTS

Subjects were initially screened for visual acuity of 20/40 or better on the Keystone Industrial Telebinocular No. 46A. For further refinement of measurement of the visual acuity levels of each subject a large-scale eye chart was constructed using the same letters (both black and white) as those used in the experiment. This was scaled on the basis of the results of preliminary measurements. There were 28 letters on this chart. If a prospective subject could read 19 or more of the letters at a distance of 280 ft., he was assigned the more distant range in the experiment; if he read 11 to 19 letters, he was assigned the closer distance; and if he was unable to read 11 letters, he was not used in the experiment.

All of the subjects were volunteers from enrolled students at the University of California, Los Angeles, Summer Sessions of 1951.

FIELD LAYOUT

A large, flat area which had just been leveled for construction purposes was chosen as the experimental site. An apparatus consisting of an exposure shutter was placed at one end of the field and a movable sign holder at the other. The two ranges on which the signs were to be shown were marked off on the field.

The shutter-like apparatus was painted olive drab, and the background against which the signs were shown was the light brown of recently turned earth.

EXPERIMENTAL PROCEDURE

One experimenter and one subject sat behind the shutter device. Another experimenter stood beside the sign holder, which had been moved to the first position at which this subject was to see the signs. A decision was made as to whether the close or distant range was to be used on the basis of the prior acuity measurements.

A number of small cards had been prepared showing random sign orders

and distance orders. Before the subject's arrival, the 40 signs had been stacked according to one of these cards. All 40 signs were placed in the sign holder so that when one was removed the next one in order was revealed.

The subject was told what letters were being used (B, C, D, E, F, O, P, R) and was handed a small card on which these letters were shown.3/ The shutter was then opened and the subject instructed to read the letters at a rate which suited him, and to say "blank" when a letter was completely unrecognizable. The experimenter at the shutter recorded the letters as the subject read them. When the subject finished with a sign, the experimenter signalled the man at the sign holder to remove the observed sign, thus revealing the next one.

When all eight signs at a particular distance had been read, the shutter was closed, the sign holder moved to a new position, and the shutter reopened. This procedure was continued until the subject had seen eight cards at each of five positions.

No instructions were given as to rest periods or means of reducing eye strain. The subjects were free to view the signs in whatever manner they chose. Nor were they told the exact nature of the experiment; however, this was obvious to most of them after a few of the signs had been shown.

STATISTICAL TREATMENT OF RESULTS

The results consist of four scores for each subject. These scores are the number of letters correctly identified for each of the four different kinds of signs. Since there were ten signs of each kind and eight letters on a sign, the maximum possible number of correct letters is 80.4/ Thus, in Table 1, for subject 1, the score 36 means that Subject 1 correctly identified 36 of the 80 closely spaced white letters on a black background.

With two experimental variables and two degrees or qualities of each, a two-by-two factorial analysis of variance with replication was selected as an appropriate analytic design. Since each subject experienced all four experimental conditions, the number of replications is equal to the number of subjects.

From the subject totals (Column 6, Table 1) it is apparent that a fairly wide range of visual acuity was sampled. However, if the subjects are grouped with respect to visual acuity, it is possible to examine one more factor, since it is not known whether the relationships between letter-

3/ - This was due to finding, through preliminary measurements, that the subjects tended to make consistent errors due to erroneous first judgments. For example, if it happened that the subject's first sign was seen at such a distance that he misread the R, calling it an N, he would continue to make this error even at closer distances. It appeared that this was due to careless reading, since if urged to study the letter carefully at the closer distances, the subject would correct the error.

4/ - Each of these four scores actually represents sums of correct letters for all five distances even though distance is orthogonal to letter-background arrangement and spacing. Distance was not analyzed as a separate factor, because the wide individual differences in visual acuity render it relatively meaningless.

TABLE 1

	Close Spacing		Wide Spacing		
Subject	white letters	black letters	white letters	black letters	Subject's Total for all letters
1	36	43	61	58	198
2	26	41	49	56	172
3	28	33	51	42	154
4	38	43	66	66	213
5	42	52	63	67	224
6	34	36	55	54	179
7	56	68	72	69	265
8	36	32	51	64	183
9	37	47	61	63	208
10	19	22	60	47	148
11	28	45	55	61	189
12	45	47	70	68	230
13	20	29	35	34	118
14	25	28	50	38	141
15	27	24	52	45	148
16	31	30	59	46	166
17	55	56	64	68	243
18	23	40	46	50	159
19	57	57	70	71	255
20	40	43	57	57	197
21	49	52	62	59	222
22	40	51	60	61	212
23	32	36	57	63	188
24	40	49	58	63	210
25	47	40	54	54	195
26	34	38	55	53	180
27	54	39	72	67	232
28	22	26	46	44	138
sums	1021	1147	1611	1588	
means	36.5	41.0	57.5	56.7	

Combined Means

white letters on black background	94.0
black letters on white background	97.7
close spacing	77.4
wide spacing	114.2

background arrangement, spacing, and letter legibility are independent of visual acuity (or reciprocally, independent of the difficulty of the task). The grouping was accomplished by ranking the subjects with respect to total correct letters and dividing the 28 subjects into four groups of seven, as shown in Table 2. Thus, the analysis of variance design is a two-by-two-by-four analysis with replication.

The calculations for the two-by-two-by-four analysis were accomplished in the usual manner[5] with the results shown in Table 3.

One of the assumptions of analysis of variance is that the variables being dealt with are distributed normally. A chi-square goodness-of-fit test was made and the distribution was found not to differ significantly from a normal distribution with the same mean and variance.

Another assumption made when using analysis of variance to test the significance of the differences between means is that the variances are homogeneous. This assumption was tested using Bartlett's method[6] and found to hold. The uncorrected value for chi squared with three degrees of freedom was 2.21. The probability of obtaining this value, or a larger one, is greater than .50.

INTERPRETATION OF RESULTS

Spacing. In Table 3 it is seen that a highly significant F was obtained for the difference between the close and wide spacings. The means shown in Table 1 reveal that the widely spaced letters were much more legible than those closely spaced. A possible explanation in terms of fixation shifts is as follows.

Due to head movements, eye movements, and instability in the visual mechanism, the image of an object shifts about slightly on the retina, even though the observer may try to keep his head and eyes still. When there is wide spacing between two objects, the only effect of this shifting is a slight blurring of the edges of the objects. If the spacing between them becomes sufficiently small, the net result of the shifting is a superposition of adjacent letter parts which could decrease letter legibility.

Interaction Between Letter-Background Arrangement and Spacing. The highly significant F obtained for the interaction of the two variables means that the legibility of the two letter-background arrangements is not independent of the letter spacing. Black letters on white background is the most legible arrangement when the letters are closely spaced, but this is not true when the letters are widely spaced. It may even be that white letters are superior when wide spacing is involved. A possible explanation may be found in the phenomena of irradiation and the fixation fluctuation mentioned above.

5/ - Edwards, Allen L., Experimental Design in Psychological Research, Rinehart and Co., Inc., 1950, pp. 237-260.

6/ - Eisenhart, C; Hastay, M. W.; Wallis, W. A., Techniques of Statistical Analysis, McGraw-Hill Book Co., 1947, pp. 387-388.

TABLE 2

Visual Acuity	Close Spacing		Wide Spacing		Subject's Total for all letters
	White Letters	Black Letters	White Letters	Black Letters	
Group I	56	68	72	69	265
	57	57	70	71	255
	55	56	64	68	243
	54	39	72	67	232
	45	47	70	68	230
	42	52	63	67	224
	49	52	62	59	222
Group II	38	43	66	66	213
	40	51	60	61	212
	40	49	58	63	210
	37	47	61	63	208
	36	43	61	58	198
	40	43	57	57	197
	47	40	54	54	195
Group III	28	45	55	61	189
	32	36	57	63	188
	36	32	51	64	183
	34	38	55	53	180
	34	36	55	54	179
	26	41	49	56	172
	31	30	59	46	166
Group IV	23	40	46	50	159
	28	33	51	42	154
	19	22	60	47	148
	27	24	52	45	148
	25	28	50	38	141
	22	26	46	44	138
	20	29	35	34	118

TABLE 3

ANALYSIS OF VARIANCE

Source of Variation	df	S S	M S	F	P
within	96	2617.58	27.27		
black and white	1	94.73	94.73	3.47	grearer than .05
spacing	1	9490.72	9490.72	348.03	less than .001
visual acuity	3	8451.53	2817.18	103.31	less than .001
black and white by spacing	1	198.22	198.22	7.27	less than .01
black and white by visual acuity	3	74.66	24.89	. . .	
spacing by visual acuity	3	147.53	49.18	1.80	greater than .10
black and white by spacing by visual acuity	3	84.03	28.01	. . .	
Total	111	21159.00			

Column Heading Legend

df = degrees of freedom.

S S = sum of squared deviations from the mean.

M S = mean sum of squared deviations.

F = F ratio

P = probability of obtaining an F as great or greater.

A bright object on a dark background appears to be wider than a similarly sized dark object on a bright background. Though the underlying casual factors are not agreed upon7/, this phenomenon has long been known and is called irradiation. Such irradiation was easily observed in the case of our letters. The white ones appeared to be considerably wider than the black ones. Conversely it may be that the black letters were affected in an opposite manner, and seemed narrower due to the irradiation of the white areas surrounding them.

The overall effect of this irradiation is an increase in the apparent stroke width of the white letters and therefore a decrease in the apparent spacing between letters. The stroke width of the black letters appears to either remain constant or actually decrease, thereby increasing the apparent spacing between the letters. Thus, even with constant distances between letters, the apparent spacing is decreased for the white letters and possibly increased for the black letters. It follows that the white letters would be expected to suffer more interference due to fixation shifts and therefore to be less legible.

As spacing increases in magnitude, it eventually becomes so great that interletter interference does not occur, or at least is not the limiting factor affecting the legibility. For widely spaced letters then, an increase in the apparent stroke width of the white letters would not necessarily decrease legibility. In fact, if the letters were viewed at such a distance that the stroke widths became the limiting factor, the white letters might be expected to be more legible than the black letters, due to their greater apparent stroke width.

It will be remembered that letter-stroke width remained constant during the experiment. Therefore, the results, strictly speaking, are limited to this stroke width. However, if this explanation of the results is valid, it would seem quite possible to predict what the effects of varying stroke width would be.

For the closely spaced letters we would expect an increase in legibility with a decrease in stroke width for both black and white letters. This would be due to effectively increasing spacing and, therefore, decreasing the interference between the letters which is caused by fixation fluctuations. Eventually a point would be reached where further decrease in stroke width would decrease legibility. It is at this point that stroke width itself becomes the limiting factor in legibility. However, we would expect this maximally legible stroke width to be smaller for white letters than for black letters, due to irradiation.

With the closely spaced letters, fixation fluctuations and irradiation are thought to be of considerable importance, as these may be the cause of interference between the letters. In the case of the widely spaced letters, however, consideration must be given to the overall shape, size of crucial distances between letter parts, knowledge of what letters are being presented, and other factors somewhat more complex. The manner in which these factors interact with irradiation and fixation fluctuation will depend on

7/ - Bartley, S. Howard, Vision, D. Van Nostrand Co., Inc., 1941, p. 235 ff.

many additional factors including the design of the letter itself. For these reasons, any general inferences with respect to the widely spaced letters on the basis of this one experiment would be unwarranted.

Visual Acuity or Difficulty of the Visual Task. It is interesting to note that there were no significant interactions involving the variable of visual acuity. Hence, the other relationships investigated in this experiment appear to be reasonably independent of visual acuity or the difficulty of the task for the general conditions of this experiment.

Letter-Background Arrangement as a Main Effect. A sizable F was obtained for letter-background arrangement as a main effect. The means in Table 1 indicate that black letters on white were better than the opposite arrangement. If the spacings used had been selected randomly, this effect might be interpreted to mean that, in general, black letters on white are superior to white letters on black. Actually, no such interpretation should be made, since the spacings were not chosen at random and the significance of this effect is due entirely to the result of close spacing.

SUMMARY

Black letters on a white background and white letters on a black background were compared with respect to legibility. Both closely spaced and widely spaced signs were used. The subjects were divided into four levels of visual acuity, on the basis of the results. The results indicated that the widely spaced letters were more legible than those closely spaced, and that the legibility of the black-white arrangement as compared with the white-black arrangement was dependent on the letter spacing. This interaction was discussed in terms of irradiation and fixation fluctuations, and these concepts were then used to infer the effects of decreasing stroke width. These inferences were limited to the closely spaced letters.

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