Brightness and Brightness Ratio as Factors in the Attention Value of Highway Signs

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By measuring the subjective reactions and eye movements of subjects looking at pairs of neutral gray chips varying in either brightness, brightness ratio, or brightness and brightness ratio, it was possible to assess the role of these parameters in attention value. Each variable controlled attention when unconfounded. When the two parameters varied simultaneously, brightness ratio predominated, but a high brightness enhanced the attention-getting value of high contrast. This was more evident in the negative than in the positive contrast direction. It is suggested that addition of a factor considering high relative brightness in combination with high relative brightness ratio would refine the Forbes et al models of highway sign attention value.

•IN a study conducted by Forbes (4), two types of attention value, as applied to highway signs, were indicated: (a) target value (characteristics that make a sign stand out in competition with other signs and distractions), and (b) priority value (qualities of a sign that result in one sign being read first, given equal target value). In the most recent work, the variables of position, brightness, size, and color in relation to sign target value were studied (7). Using, in part, a laboratory simulation technique, four simulated highway signs were simultaneously presented for 1 sec against a continually present highway scene. The subject was to indicate which of the presented signs was seen "best and quickest" by pushing the appropriate response button. To simulate the constant activity (visual and motor) involved in driving, the subject performed a secondary task. Highway sign presentations were randomly interspersed, while the secondary task was performed.

Of the four signs used, each was a different brightness of green; two were mounted over the highway, and one on each side of the road. The results showed that the overhead signs were picked first, and that the brightest sign was usually picked first for a night condition, whereas the darkest sign was usually picked first for a day condition. The same finding was replicated at a later date (5), but it was subsequently found that the brightness of the letters on the sign and the sign size modified the results of the first study (6).

A mathematical model that gave the closest approximation to the experimental data of the four experiments was based on the sign to background brightness ratio, with letter to sign brightness ratio added where appropriate. The summed ratios were then converted to percentages. This model is obviously based on brightness ratios and the assumption that brightness ratio was the factor controlling target value. In the experiments using blank signs, the brightness ratio model fitted well and appeared to account for the target value of each sign when more than one sign was present. A model based on the more commonly used percent contrast gave the next best fit. Because the brightness ratio model has the closest approximation to the actual data, it was hypothesized that brightness ratios, not absolute intensity, controlled the attention value of the simulated signs (7).

Other reasons for considering the mathematical model as a hypothesis arose from practical experimental limitations. It was not possible to delve into the study of any

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one factor of target value extensively; therefore, only four brightnesses were used. These were selected by inspection, and were unequally distributed along the brightness continuum. Also, and most importantly, the simulated signs were always presented against a fairly homogeneous background scene. This meant that whenever the four signs were of different brightnesses, the sign to background brightness ratios were also different. In short, stimulus brightness and sign to background brightness ratio were always confounded. The confounding of these two variables does not appear to be unique to the above experiments. The effect of stimulus intensity on learning (12); on response strength (10), and others; on binocular rivalry (3); and on attention value (1), and others have been studied, but background intensity remained invariant. This meant that stimulus intensity varied, but contrast also varied and was confounded.

In the area of perception, the work of Blackwell (2) on contrast thresholds and Jameson and Hurvich (11) on brightness matching at various contrast levels indicated that stimulus brightness and contrast interact in their effect on perception. From these studies and the work of Forbes et al, it would seem reasonable to generalize the idea of an interactive effect between contrast and stimulus brightness to their functioning as determiners of attention.

Measuring attention has been a problem. Motor responses allow the subject to make position responses; i.e., S uses only one of several available response indicators. The amount of judgment or logical decision-making involved in subjective responses is unknown. By monitoring eye movements these problems would be circumvented. There is an imperfect correlation between eye orientation and perceptual result; however, eye movements should reflect which stimulus is attended. Since the stimulus reported by the subject probably controls overt responding, this must be considered the primary measure of attention value.

PROBLEM

The present study attempts to evaluate the effect on attention value of (a) brightness, when brightness ratio is held constant; (b) brightness ratio, when brightness is held constant; and (c) stimulus brightness and brightness ratio, when both are varied simultaneously. Specifically it is hypothesized that: (1) if stimulus brightness is held constant (B = K), the highest brightness ratio will be reported as being seen "best and quickest"; (2) if brightness ratio is held constant (R = K), the highest brightness stimulus will be reported as being seen "best and quickest"; and (3) if brightness ratio and stimulus brightness are varied simultaneously (B ≠ K and R ≠ K), brightness ratio will determine which stimulus is reported as seen "best and quickest."

The present study further attempts to determine if an interaction between brightness and contrast, such as found by Blackwell (2) at threshold levels, will also be found at supra-threshold levels, with regard to attention value. The hypothesis is: (4) higher relative brightness will enhance the attention value of any brightness ratio. The study also attempts to evaluate the relation between a primary and several alternative types of attention-value measures. It is further hypothesized that: (5) eye movement measures will be highly correlated with, and will give essentially the same results as, subjective responses, which are considered the primary measure of attention value. All hypotheses were tested for both positive (stimulus lighter than background) and negative (stimulus darker than background) contrast directions.

METHOD

Basically the hypotheses were tested by showing Ss Munsell chips against Munsell cards in a paired comparison design. Various combinations of stimulus and background brightness were used to achieve the conditions of stimulus brightness constant (B = K), brightness ratio constant (R = K), and both varied together (B ≠ K, R ≠ K). Eye movements and subject responses were recorded. The study was conducted in two phases: the first used chip-card brightnesses resulting in a positive contrast direction (C-pos), and the second tested negative contrast direction (C-neg). Each phase used different Ss, but the same method.

Experimental Design

A paired comparisons design was used. In the first condition, brightness was held constant (B = K), and pairs of chip-card combinations in which only the brightness ratio varied were used. In the next condition, the brightness ratio was held constant (R = K), and pairs of chip-card combinations in which only the brightness varied were used. Both conditions were tested over three levels of the variable being held constant; e.g., B_1 was tested versus B_2 at each of three different brightness ratio levels. The B = K and R = K regimes were considered control conditions, since they would indicate the attention value of one variable with the other variable held constant.

The third condition was considered the experimental condition, since stimulus brightness ratio varied together ($B \neq K$, $R \neq K$). In no pair were either the two chip brightnesses or the two brightness ratios the same.

Conditions B = K and R = K were presented in counterbalanced order to the same 10 Ss. Ten different Ss saw the $B \neq K$, $R \neq K$ condition. Each S saw 18 pairs of stimuli with the order of the pairs and left-right positions within the pairs randomized.

Stimuli

The stimulus configuration consisted of two ⅝- by ⅞-in. (136 minutes of arc subtended at the eye) neutral gray, matte finish, Munsell chips seen against two 3- by 5-in. Munsell background cards. This configuration included a flat, black metal edge (1 in. wide) that held the cards in place.

The card brightnesses of the C-pos phase were in the middle-to-high mesopic range (0.15 to 1 ft-L) and were well within the luminance range (0.1 to 1 ft-L) defined for night driving (13). The values for the negative contrast direction ranged from 0.52 to 3.6 ft-L and were representative of twilight driving conditions.

Subjects

College students from introductory psychology classes volunteered and were give- extra credit for participating in the experiment. Ten Ss were used for the control group and 10 for the experimental group. This arrangement was repeated for the second contrast direction with 20 different Ss.

Apparatus

A polymetric Products eye movement recorder was used to present the stimulus and record Ss eye fixations. Type 47 (ASA 3000) Polaroid film was used and exposure time was 4 ± 1 sec. The variation in exposure was needed to compensate for individual differences among subjects. The same light illuminating the stimuli served as a constant adaptation light for S; the brightness of the adapting field was 0.24 ft-L. This and all other brightness measurements were made with a Prichard Photometer. Two push buttons on a black box located on the table by the eye movement recorder activated a Lafayette event recorder. By pushing the appropriate (left or right) button, S indicated which of the stimuli he saw best and quickest.

Procedure

The room lights were off, and a minimum of 5 min was allowed for S to become adapted to the experimental lighting. During this time the optical system was aligned and focused, and S was given instructions. The stimuli were then presented in a paired comparison design. After all trials were finished, S was questioned about his general state of rest and specifically how his eyes felt before participating in the experiment. He was also asked for comments about the stimuli.

Scoring and Analysis

Four dependent variables were used in this experiment.

1. The Ss choice of which stimulus of the pair was seen best and quickest was scored in the usual paired comparison fashion (case V) described by Guilford (9). That

is, raw scores were placed in matrix form, transformed into the percentage that each stimulus was chosen over every other stimulus, transformed into normal deviates, and scale estimates for each stimulus made.

2. The chip fixated first for each trial was noted, and paired comparison scale values were determined in the same manner as noted above.

3. Duration, or the amount of time fixated on each chip, was crudely measured, and these measurements were transformed into percents that were also scaled in paired comparison fashion.

4. The number of fixations were counted for each chip and entered in a paired comparison matrix. The raw data were transformed into percents and scaled according to the paired comparison method.

RESULTS

The results from the two phases of the study are discussed together for each dependent variable. The dependent variables themselves are then discussed.

Subjective Reactions

The results showed that for the subjective reaction measure of attention value (Fig. 1a), scale values increased as brightness ratio increased when brightness was constant (B = K). Scale value increased as brightness increased (Fig. 2) when brightness ratio was constant (R = K); and contrast was the predominant determinant of attention value (Figs. 3a and 4a) when brightness and brightness ratio were varied simultaneously (B ≠ K, R ≠ K). Chip brightness affected subjective reactions more at higher brightness ratios than at lower ratios, especially in the C-negative phase.

Chip Fixated First

Generally the middle brightness ratio was fixated first in the B = K condition (Fig.), while the highest or lowest chip brightness was fixated first in the R = K condition (Fig. 2b). In other words, the R = K results were almost the reverse of the B = K findings. On the other hand, results for the B ≠ K, R ≠ K condition were very similar to the subjective reaction data, with brightness ratio being the predominant factor and high chip brightness enhancing attention value at the higher brightness ratios (Figs. 3b and 4b).

Time on Each Chip

For the C-pos phase (Fig. 1c), the middle brightness ratio was generally fixated for the greatest duration. For the C-neg phase, lowest brightness ratio was generally fixated the longest. The two phases generally gave different results. When the chip was lighter than the card, the middle brightness ratio was fixated longest, but in the reverse condition, the highest brightness ratio was fixated longest.

R = K data for the C-pos phase (Fig. 2c) show that the highest and lowest chip brightnesses were fixated the longest at the lower brightness ratio levels. In the C-neg phase, the highest brightness was fixated longest at all ratio levels. Figures 3c and 4c show that the general form of the response patterns in the B ≠ K, R ≠ K condition was different for the two phases. In the C-pos phase, the highest scale values were given to the middle brightness ratio, while C-neg scale values generally increased as contrast increased and gave results very similar to subjective reaction results.

Number of Fixations

As shown in Figure 1d, the highest brightness ratio received the greatest proportion of fixations in the B = K condition. The differences were very small in the C-neg phase. The R = K conditions showed a somewhat reverse pattern with the results taking a "V" shape (Fig. 2d). B ≠ K, R ≠ K results were similar to the subjective reactions results, but the differences were greatly attenuated (Figs. 3d and 4d).

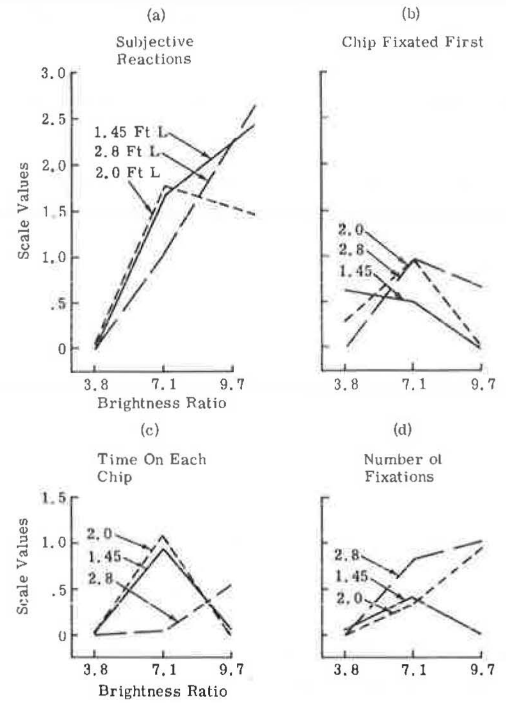

Figure 1. B = K condition paired comparison scale values plotted for each dependent variable; C-positive phase.

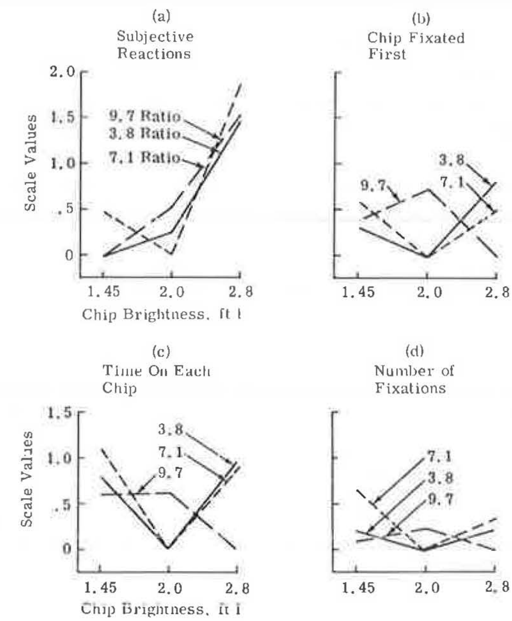

Figure 2. R = K condition paired comparison scale values plotted for each dependent variable; C-positive phase.

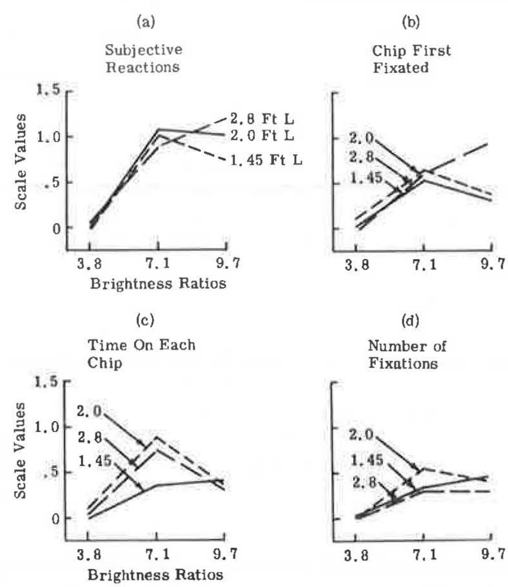

Figure 3. B≠K, R≠K condition paired comparison scale values plotted for each dependent variable; C-positive phase.

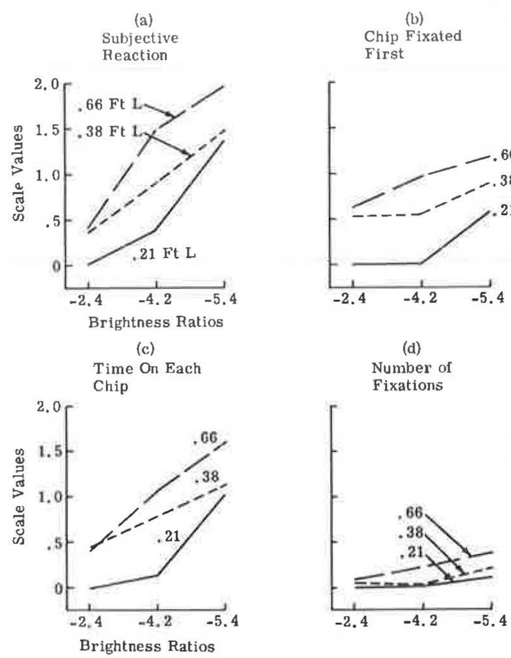

Figure 4. B≠K, R≠K condition paired comparison scale values plotted for each dependent variable; C-negative phase.

Relation Between Measures

Spearman rank order correlations were performed between all combinations of the measures. A mean correlation of 41.5 existed between all four dependent measures. A moderate (mean R = 0.56) relation was found between the subjective reactions andthe eye movement measures. Eye movement measures correlated from 0.83 to 0.92 among themselves.

An examination of scale values reveals a rather interesting pattern. Subjective reaction results took the same form in both the B = K and R = K conditions. However B = K eye movement results were almost exactly opposite the R = K response patterns. Since this occurred when one or the other independent variable was constant, it would be very interesting to see how the two opposing eye movement patterns were resolved when both variables were varying. Comparison of the data revealed that the three measures showed a pattern similar to the B = K condition, while there was little or no similarity between the eye movement characteristics of the R = K and B ≠ K, R ≠ K conditions. The different eye movement response patterns noted above were also present in the C-neg phase, but were not as consistent.

DISCUSSION

Considerations Pertinent to the Hypotheses

For the B = K condition, the results for both phases strongly confirmed the hypothesis (the highest brightness would have the highest scale values). It should be noted that in a paired comparison design such as this only the lowest ratio was never the highest in any configuration. Therefore, the middle brightness ratio could be the lowest presented in some pairs and highest in other pairs.

The second hypothesis (the highest brightness will be seen best and quickest) was strongly confirmed for both phases. Again the middle value in the scale of ratios was responded to somewhat differently than the highest and lowest ratio. This further emphasized the relevancy of judgment and scaling principles for attention value phenomena.

Support for the third hypothesis (brightness ratio will be dominant over intensity in determining which chip is seen best and quickest) was very strong in the C-pos phase of the study, with less unequivocal support from the C-neg phase. In the C-pos phase, comparison of the control conditions with the experimental condition (B ≠ K, R ≠ K) showed that while scale values increase as brightness increased in the R = K condition, there was little increase in scale value as a function of brightness in the B ≠ K, R ≠ K condition. The only differences in scale values were between the brightness ratios; therefore, brightness ratio was the controlling factor in determining attention value.

The less clear-cut evidence shown during the C-neg phase was due to a brightness effect that was different for the various brightness ratios. In short, a high ratio resulted in high scale values regardless of chip brightness, but stimulus brightness resulted in high scale values only in combination with higher brightness ratios, thereby indicating that brightness ratio was the controlling factor.

The above discussion is relevant not only to the third, but also to the fourth hypothesis (higher brightness will enhance the attention value of any brightness ratio). Support for this hypothesis came primarily from the C-neg phase results. While it was apparent that brightness ratio was the predominant variable, attention value, as measured by subjective reactions, did increase as chip brightness increased for a given brightness ratio. The effect was most pronounced for the two highest brightness ratios. C-pos phase support of hypothesis 4 was very slight. Only at the highest brightness ratio was there an evident increase in scale value related to a brightness increase.

Three possible reasons for the difference in results between the B ≠ K, R ≠ K condition for the two phases are (a) the brightness ranges sampled in the two phases were not identical, (b) the relation between the three brightnesses used in each phase was not the same, and (c) there was a systematic relationship between the card and chip brightness when brightness ratio changed. An analysis of the card brightnesses negated this possibility.

The fifth hypothesis (subjective reactions and eye movement measures will be highly related) was partially supported. The amount of correlation varied as a function of stimulus condition. For the B = K condition, there were low to medium correlations for all measures in each phase. For the R = K condition, subjective reactions and eye movement measures had medium (0.50) correlations, and the three eye movement measures were highly correlated (0.80). In the B ≠ K, R ≠ K condition, correlations were medium to high for the C-pos phase and high for the C-neg phase.

The above pattern of correlations may be an indication that eye movements are related to subjective reactions as a function of the number of parameters varying within the stimulus configuration. As more stimulus dimensions (e.g., brightness and contrast) vary concomitantly, the more eye movements concur with subjective reactions.

Application of the Results

The model developed by Forbes et al (7) was not intended to be applied to repeated paired comparison measures. A rough idea of how the model works for these data can be obtained by selecting stimuli from each phase and calculating the expected proportions. Four, chip-background card configurations from each phase were chosen because they were analogous to the brightness and contrast relations of the simulated signs used for day and night backgrounds in the Forbes project. The relative number of times a stimulus was selected as best and quickest was the observed value, and the theoretical percent was calculated by using both the brightness ratio and percent contrast models. In Figures 5 and 6 the proportion of each of the selected chips picked as being seen best and quickest was plotted versus the brightness and brightness ratio characteristics of the two chips being compared. The physical characteristics of each selected chip and card were then used in the two theoretical models and plotted in the same fashion. It is quite apparent that the brightness ratio model provides a closer fit to the observed data than the percent contrast model. This verifies the Forbes et al (7) finding.

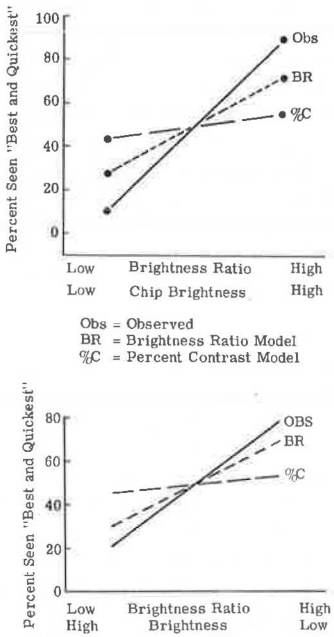

Figure 5. Comparison of results observed experimentally and theoretical results calculated from brightness ratio and contrast models; C-positive phase.

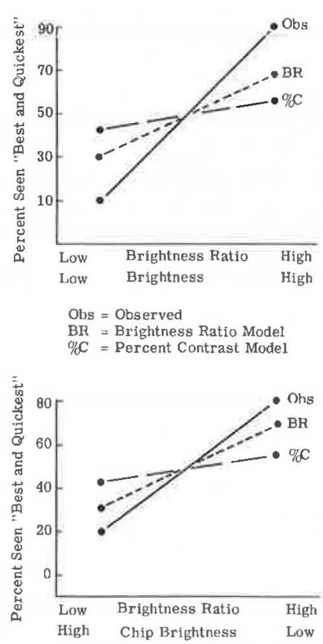

Figure 6. Comparison of results observed experimentally and theoretical results calculated from brightness ratio and contrast models; C-negative phase.

In both phases it was observed that whenever high chip brightness and brightness ratio were together there was a 20 percent difference between the experimental and theoretical results. However, when low chip brightness was associated with high brightness ratio, the difference between experimental and theoretical results was only 10 percentage points. Since the theoretical model does not take into account chip brightness, the calculated values reflect only brightness ratio. The larger discrepancy between observed and calculated values in the presence of high brightnesses reflects the interaction or enhancement effect of higher brightnesses on high brightness ratios.

The above demonstration leads to an alternative explanation for the consistent finding of Forbes, Pain, Joyce, and Fry (7); namely, that calculated values were roughly 10 percentage points below observed values. This differential was attributed to the repeated measures technique utilized; however, the present study makes it evident that the effect of high brightness in combination with contrast could also account for the discrepancy.

In general, there appears to be evidence that a brightness factor used in a model for predicting attention-gaining characteristics would add considerable refinement to the model. While this study does not permit a precise empirical determination of the quantitative value of such a factor, there were indications that a higher brightness enhances a high brightness ratio by roughly 10 percent.

CONCLUSIONS

Either brightness or brightness ratio, when present as the only variable, has equivalent attention-gaining value. For each, the attention value increased in a rapidly accelerating manner as the variable is increased. When brightness and brightness ratio are present together, brightness ratio receives more attention. However, a high relative brightness enhances the attention-gaining effect of brightness ratios. This was more evident for the negative contrast direction (background brightness levels in the night driving-twilight range) than for the positive contrast direction (night driving background brightness levels).

Generally, the subjective reaction measure was most consistent. The three eye movement measures were highly correlated with each other, but not with the subjective reaction measure. As the number of dimensions varying concomitantly increased, the correlation between eye movement and subjective reaction measures became quite high.

The Forbes et al models for predicting traffic sign attention value were successfully applied to data from different methodology and subjects. The brightness ratio model gave a closer fit to empirical results than a percent contrast model. It is suggested that the addition of a factor giving consideration to high relative brightness when in combination with high relative brightness ratio (contrast) would refine the models.

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