THE SUBJECTIVE BRIGHTNESS OF RETROREFLECTIVE SIGN COLORS

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16. Abstract

Previous research has provided evidence that the nighttime conspicuity of retroreflective signs depends to a significant degree on the color of the sign. The purpose of this study was to determine whether the color of retroreflective signing materials was a significant factor in their judged brightness.

A laboratory study was conducted in which subjects viewed pairs of sign panels side by side. One panel was set at a constant luminance, the other was adjustable. A full pair-comparison was run, using six standard sign colors (white, yellow, red, green, blue, and orange). The results show that the subjects judged red, green, blue, and orange about equal, and brighter (by a factor of about 1.5 to 2.5) than white and yellow.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In a recent investigation of nighttime sign conspicuity (Olson, 1988), it was noted that color seemed to have a significant effect on the distance at which subjects reported identifying test sign panels. In particular, sign panels in red, blue, green, and, to a lesser extent, orange, were identified at greater distances than yellow sign panels having comparable specific intensity per unit area (SIA). Possible explanations for this finding were explored. Information consistent with the field conspicuity data was found in the results of so-called heterochromatic brightness matching studies. These data show that perception of the brightness of colored surfaces is influenced by hue and saturation.

As a follow up to the field conspicuity experiment, a laboratory study was conducted in which subjects viewed panels of different colors side by side, judging which one appeared brighter, and by how much (i.e., 2:1, 3:1, etc.). The results of this test showed that the colors red, blue, and green were judged brighter relative to white and yellow than would be indicated based on photometric measures.

While the laboratory study made it clear that the phenomenon identified in the heterochoromatic brightness matching studies applied to retroreflective signing materials as well, the magnitude of the effect was not adequately addressed. The purpose of the study to be described in this paper was to better quantify the magnitude of the perceived differences.

METHOD

This was a laboratory study in which subjects were asked to match the brightness of two panels of different color. One panel, which was always on the subject's left, was set at 1 ft-L (3.43 cd/m^2). The other panel's luminance could be adjusted by the subject until he/she felt a brightness match had been obtained.

Independent Variables

Color. Six colors were used. They were white, yellow, blue, green, red, and orange. All panels were faced with type III retroreflective sheeting, manufactured by 3M. This material is also referred to as encapsulated lens sheeting. The trade name is High Intensity sheeting.

Subjects. A total of twenty-four subjects participated in the test. Twelve of these were young (i.e., 18-30), and twelve were older (i.e., 60-75). All were licensed drivers who volunteered for the test and were paid for their time.

Dependent Variable

The dependent variable was the luminance of the variable panel at the time the subject said it appeared to be equal in brightness to the constant panel.

Equipment and Test Arrangement

The test panels were one-foot square pieces of aluminum, faced with retroreflective sign material. They were supported on a table 25 feet from the subject, and viewed against a black velvet background. There was a separation of four inches between the panels.

The panels were illuminated by two 35mm slide projectors. Each projector was fitted with an aperture plate, just behind the normal plane of the slide, to restrict the illuminated area at the test panels to a circle, one-foot in diameter. Thus, what the subject saw were two circular illuminated areas side by side. The projectors were placed as close to the subject's viewing position as possible to minimize the observation angle.

The luminance produced by a given level of illumination depended on the panel color. The luminance of the constant panel on the subject's left was adjusted to 1 ft-L by varying an aperture on the front of the projector lens. The luminance of the variable panel was adjusted by a series of neutral density filters in the projector slide tray. A listing of the luminance levels achieved with each color by this process is given in Table 1.

Luminance measurements were made using a Model 1980-A Pritchard Photometer. This instrument was set at the subject's viewing position. Using the 1-degree probe, it was only necessary to pivot the photometer head slightly right or left to read the luminance values. When the subjects were making their judgments the probe was situated between the two panels, and subjects viewed the panels through the photometer optics. Viewing the panels through the photometer had the effect of reducing their luminance significantly. But the new level could not be measured.

TABLE 1. Listing of luminance values (cd/m/m) obtained on variable panel with different neutral density slides.

slide	panel colors					
number	white	yellow	orange	green	red	blue
1	1.28	0.97	0.45	0.29	0.30	0.15
2	2.16	1.62	0.73	0.49	0.48	0.25
3	3.01	2.23	1.01	0.69	0.67	0.35
4	3.57	2.74	1.25	0.76	0.82	0.37
5	4.71	3.47	1.57	1.09	1.03	0.56
6	6.77	5.02	2.20	1.57	1.39	0.80
7	9.12	6.73	2.94	2.14	1.85	1.09
8	14.20	10.40	4.56	3.37	2.87	1.72
9	23.00	16.80	7.20	5.50	4.54	2.81
10	27.30	20.00	8.58	6.54	5.38	3.35
11	33.60	24.00	10.50	8.12	6.59	4.19
12	40.30	29.40	12.60	9.70	7.87	5.02
13	67.90	48.90	21.50	16.70	14.03	8.76
14			127.30	99.20	82.50	52.50

Procedure

A full pair-comparison procedure was used. With six panels, this made 15 pairs. The pairs were administered in a random order, with the right-left placement counterbalanced from subject to subject. When the subject entered the laboratory the room lights were extinguished and the test procedure explained. At the start of each trial the luminance of the variable panel was set at either maximum or minimum by the experimenter, and the control was handed to the subject. The subject looked into the eyepiece of the photometer and adjusted the luminance of the variable panel up or down as required until it appeared the same brightness as the constant panel. The control was then returned to the experimenter, who read the slide number and set the control to the extreme setting opposite to the previous trial. Four replications were run on each pair by each subject. Time required to complete the test ranged from about one to two hours.

RESULTS

Figures 1 through 6 illustrate the basic results of the study. Each figure is for one reference color (i.e., the constant-luminance panel on the subject's left) and shows how many times brighter (or dimmer) the variable panels on the subject's right were set on average when subjects judged them equal in brightness to the reference panel. Data are separated by age group. Each data point in these figures is the mean of 24 trials (six subjects, four replications).

There are three main points that should be noted in Figures 1 through 6. First, and most important based on the primary purpose of the study, there are large differences in the subjective brightness of the colors. Specifically, white and yellow had to be set at much higher luminance values to achieve a match against the other four colors. Blue, orange, green, and red generally differed little among themselves. Second, there is a suggestion of age-related differences involving red and blue, but only as reference colors, and only against white and yellow. This can be seen in Figures 5 and 6. Only the blue-white comparison shown in Figure 6 proved to be significant ($p < 0.05$), however. There is no hint of such a difference when the colors were viewed opposite (i.e., with white or yellow as the reference), as shown in Figures 1 and 2. The third point is the large difference in performance as a function of which color was the reference and which the variable. In general, subjects acted as though the reference panel was much brighter (or the variable panel was much dimmer) than was actually the case. This finding caused much concern and led to a series of follow-up tests designed to find an explanation, or at least rule out error in the test set up.

The judgment bias associated with panel position or designation was quite large. As an example, when the yellow panel was the reference at 1 ft-L, the young subjects set the white panel at an average of 2.37 ft-L. With the situation reversed, the young subjects set the yellow panel at an average of 1.58 ft-L, rather than the 0.42 ft-L that would be expected based on the results of the first match. The older subjects showed the same bias, the corresponding values being 2.40 and 1.15, respectively. Of course, these comparisons do involve different groups of subjects. That is, six of each age group saw this combination with the white panel on the left, the other six saw it with the white panel on the right. However, the results are reasonably consistent from pair to pair, raising the possibility that it was induced by something about the experimental set up.

A number of tests were conducted. First, the experimenters ran themselves as subjects on a few comparisons, and produced the same biased results, even though they knew what the bias was. Next, data were collected with the constant panel on the right, but the bias simply flipped to the right side. The projectors were then reversed, so that the one that had provided the constant 1 ft-L now provided the variable luminance and vice-versa, all to no effect.

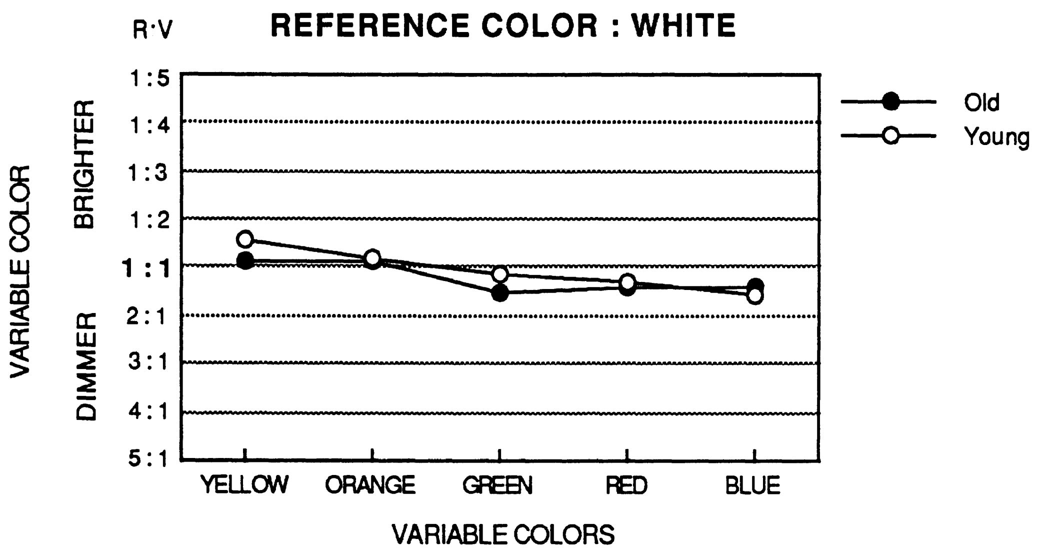

FIGURE 1. Luminance ratio of variable colors to reference color when subjects judged them equal in brightness.

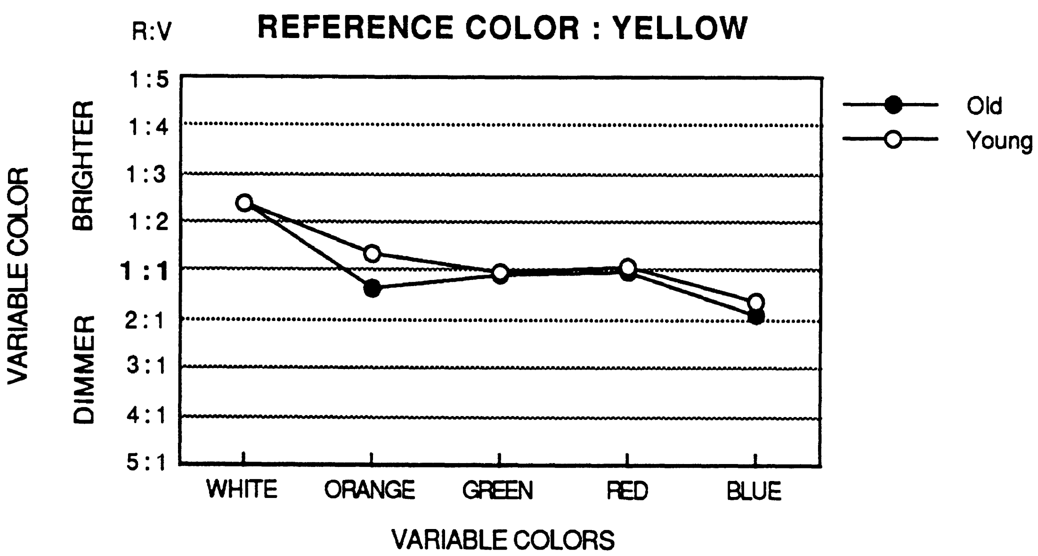

FIGURE 2. Luminance ratio of variable colors to reference color when subjects judged them equal in brightness.

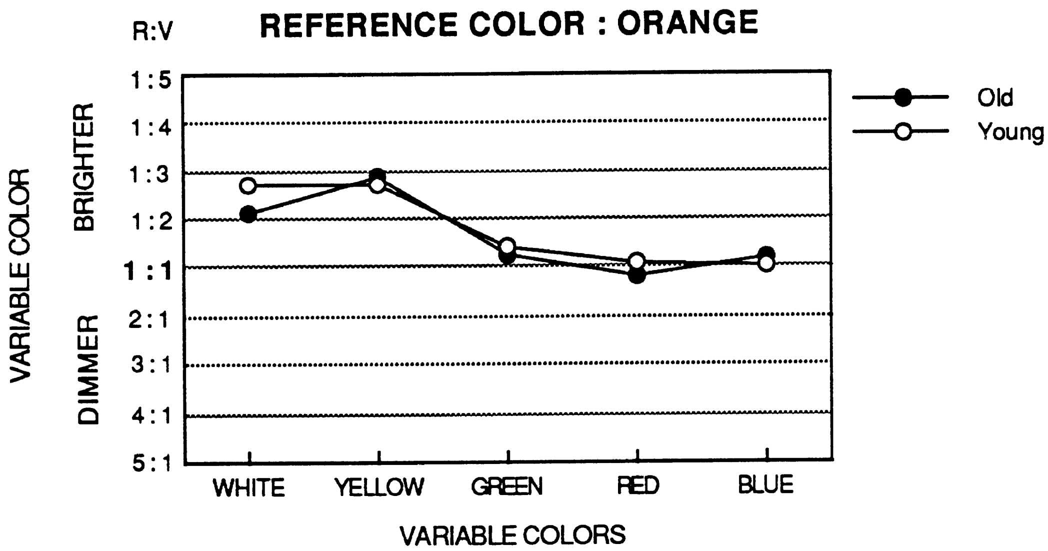

FIGURE 3. Luminance ratio of variable colors to reference color when subjects judged them equal in brightness.

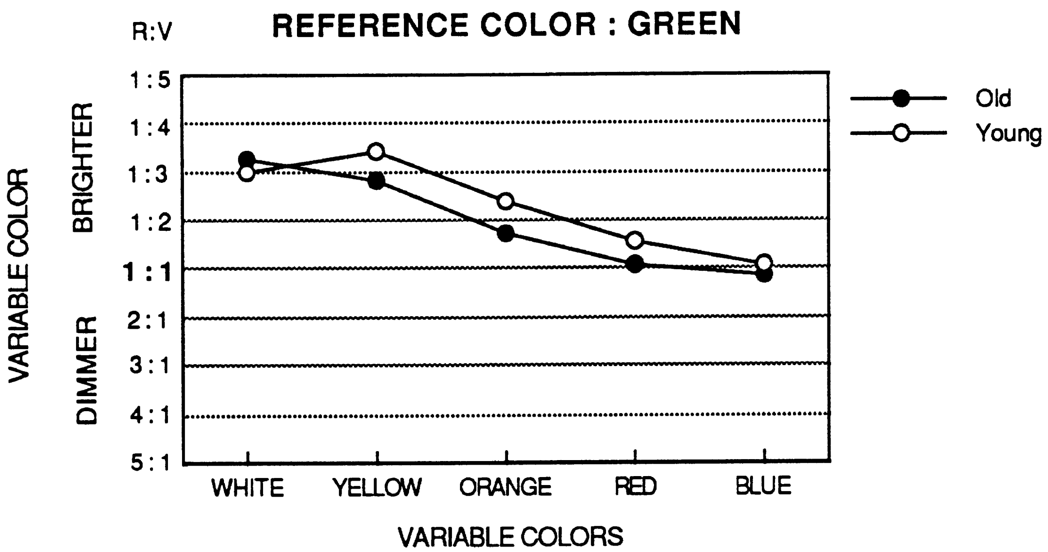

FIGURE 4. Luminance ratio of variable colors to reference color when subjects judged them equal in brightness.

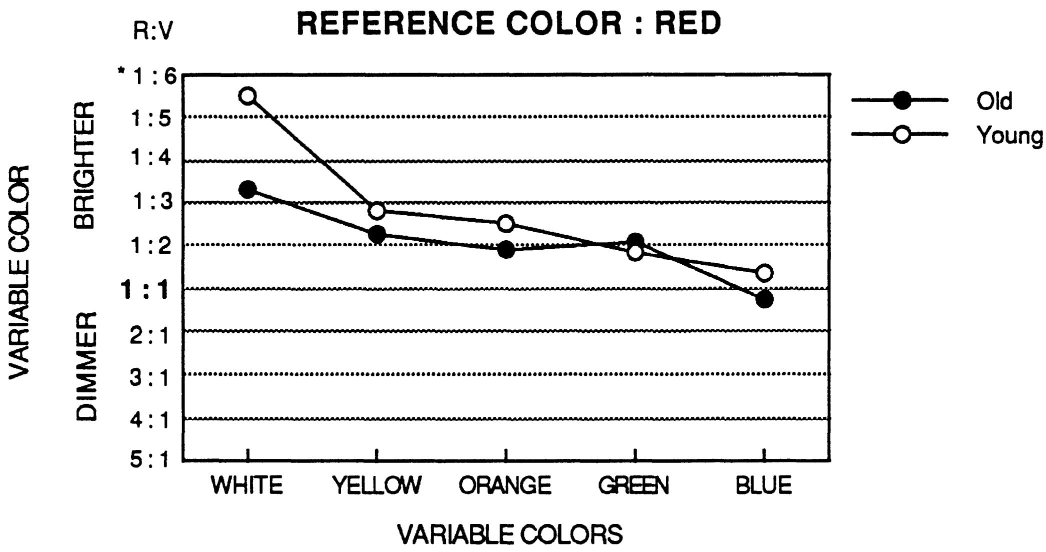

FIGURE 5. Luminance ratio of variable colors to reference color when subjects judged them equal in brightness.

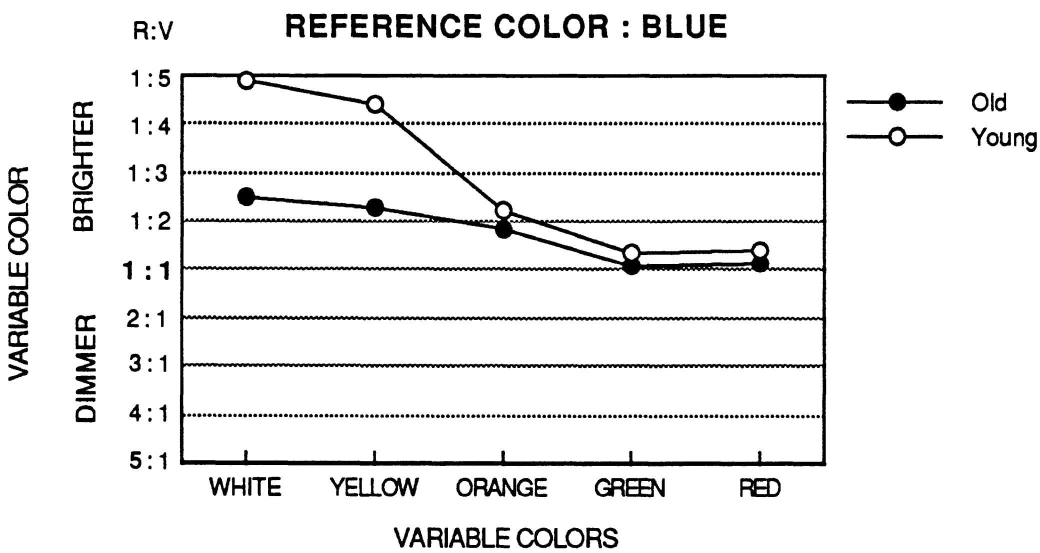

FIGURE 6. Luminance ratio of variable colors to reference color when subjects judged them equal in brightness.

If the subject bias is not attributable to the test set up or equipment, then it must be associated with the test procedure. One can take the means of the data to gain a (presumably) unbiased estimate of the effect of interest, but the question remains whether, even then, the results might not be simply an artifact of the test methodology. To address this issue a limited amount of data were collected using a method in which one experimenter set the luminance of the two panels at the same or different levels (one or the other was always set at 1 ft-L) and the other two experimenters judged the pair the same or different, and, if different, indicated which one was brighter. This test produced no apparent bias, but did show the expected color differences. For example, if a red and yellow panel were viewed when both were set at 1 ft-L, the tendency was to say the red panel was brighter.

In Figures 7 through 12 means have been taken of the data for the two age groups, balancing out the directional or reference bias. Although the figures are redundant in that each data point is effectively presented twice, it is easier to make the comparisons of interest this way. In these mean data, the basic trends are more clearly shown. For example, Figure 7 shows that all colors were seen as brighter than white. The magnitude of the difference depends on the color, running about 1.5:1 for yellow and orange, but ranging from 2:1 to nearly 4:1 for red, green and blue, at least for the young subjects.

Yellow, as shown in Figure 8, is seen as brighter than only white. The other colors were perceived as being about twice as bright as yellow, except for the younger subjects with blue.

The four remaining figures in the set (i.e., Figures 9 through 12) show that orange, red, blue, and green are seen as roughly equivalent, although the latter three may have a slight edge on orange.

Table 2 provides overall means of the test data. Each cell in this table is the mean of 96 data points (24 subjects, four replications).

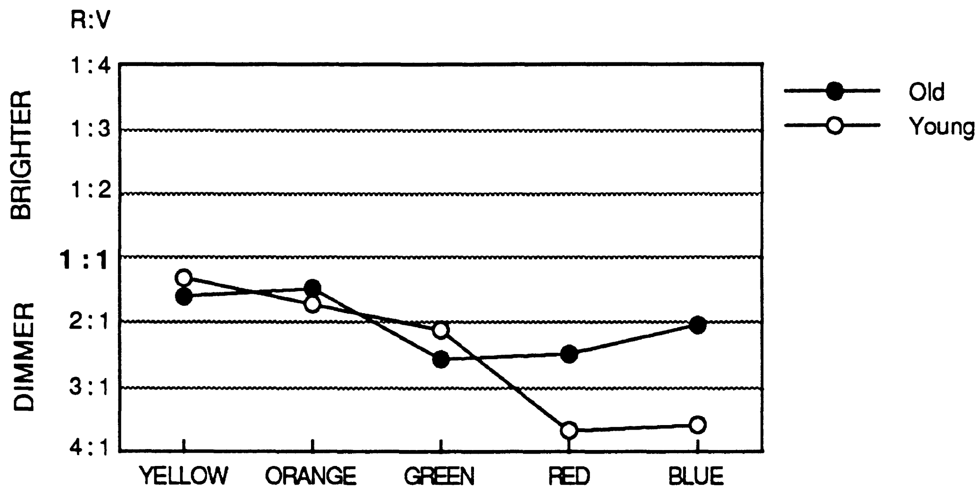

FIGURE 7. Luminance ratio of other colors to **WHITE** when subjects judged them equal in brightness. These data are averages with **WHITE** as both a reference and variable color.

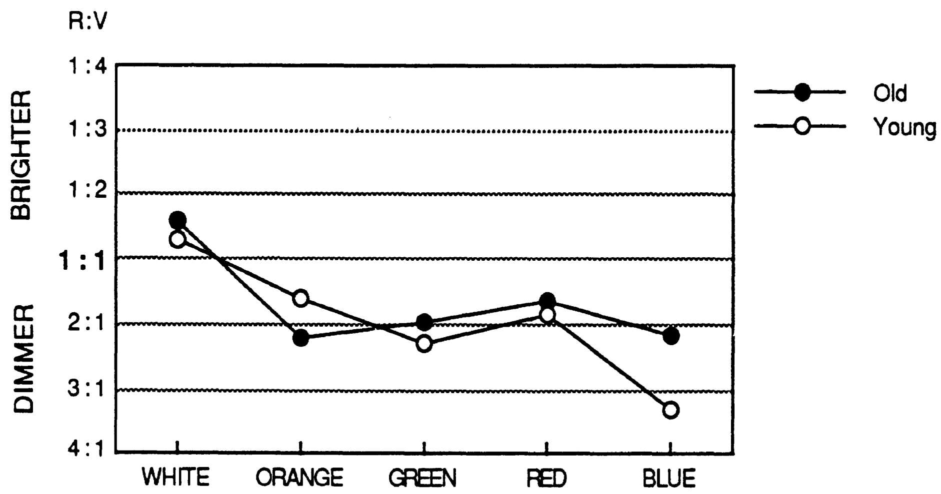

FIGURE 8. Luminance ratio of other colors to **YELLOW** when subjects judged them equal in brightness. These data are averages with **YELLOW** as both a reference and variable color.

FIGURE 9. Luminance ratio of other colors to **ORANGE** when subjects judged them equal in brightness. These data are averages with **ORANGE** as both a reference and variable color.

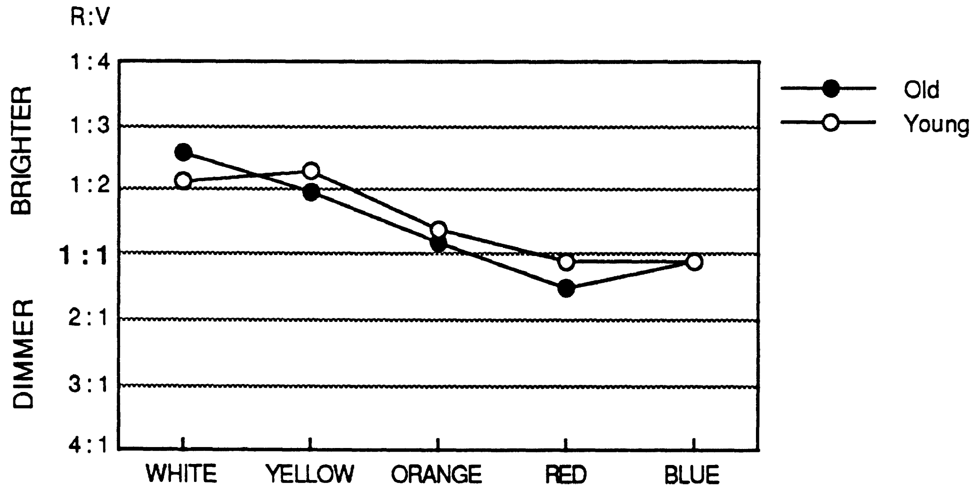

FIGURE 10. Luminance ratio of other colors to **GREEN** when subjects judged them equal in brightness. These data are averages with **GREEN** as both a reference and variable color.

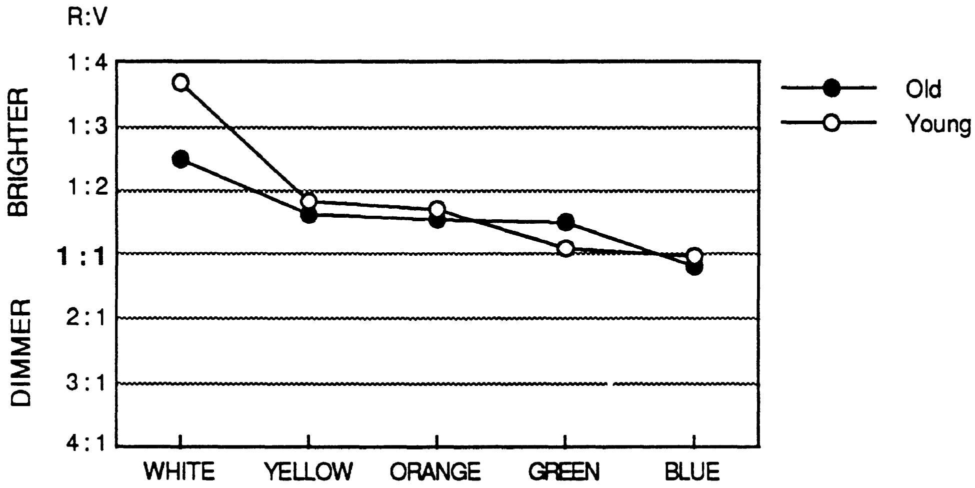

FIGURE 11. Luminance ratio of other colors to **RED** when subjects judged them equal in brightness. These data are averages with **RED** as both a reference and variable color.

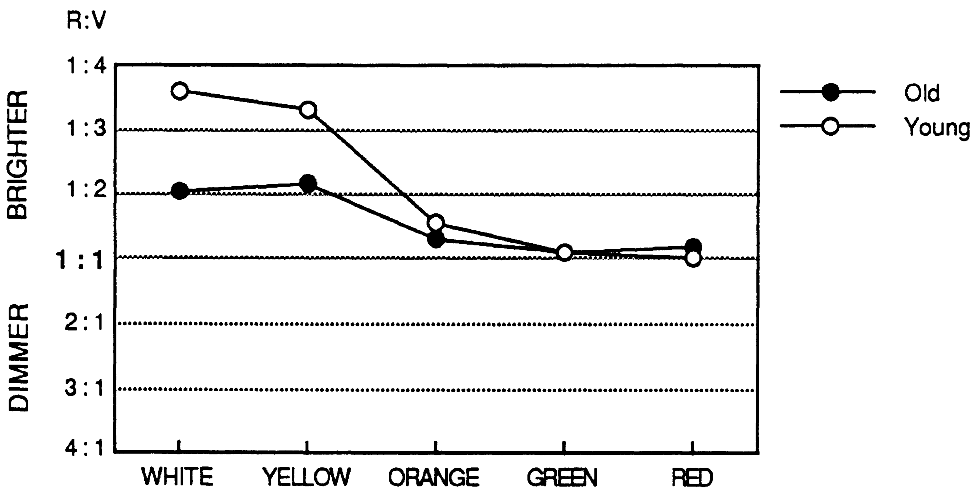

FIGURE 12. Luminance ratio of other colors to **BLUE** when subjects judged them equal in brightness. These data are averages with **BLUE** as both a reference and variable color.

TABLE 2. Overall means: Luminance of variable panel divided by luminance of reference panel.

(1) Older Subjects

REFERENCE COLOR		WHITE	YELLOW	ORANGE	GREEN	RED	BLUE
	WHITE	-					
	YELLOW	1.58	-				
	ORANGE	1.48	2.21	-			
	GREEN	2.57	1.97	1.20	-		
	RED	2.51	1.64	1.57	1.50	-	
	BLUE	2.04	2.15	1.31	1.11	1.19	-

VARIABLE COLOR

(2) Younger Subjects

REFERENCE COLOR		WHITE	YELLOW	ORANGE	GREEN	RED	BLUE
	WHITE	-					
	YELLOW	1.31	-				
	ORANGE	1.72	1.60	-			
	GREEN	2.11	2.27	1.41	-		
	RED	3.69	1.83	1.70	1.11	-	
	BLUE	3.57	3.33	1.57	1.12	1.04	-

VARIABLE COLOR

DISCUSSION

The results of this investigation are consistent with the findings of the field study of sign conspicuity in that the colors red, blue, green, and orange are seen as brighter than yellow and white. In the context of highway signing this means that these colors would have greater brightness than would be suggested by their SIA values. Consequently, their conspicuity relative to white and yellow should be greater than indicated by the difference in SIA values.

As was discussed in the field conspicuity report, there are potential explanations other than perceived brightness for the differences that were found. This issue should be explored further, using a methodology that more adequately approximates the problems associated with detecting signs in a driving environment.

REFERENCE

Olson, P. L. Minimum Requirements for Adequate Nighttime Conspicuity of HIghway Signs. Ann Arbor. The University of Michigan Transportation Research Institute. Report Number: UMTRI-88-8. February, 1988.