REACTION TIMES TO BODY-COLOR BRAKE LAMPS

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Report No. UMTRI-92-15
May 1992

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-92-15		

4. Title and Subtitle REACTION TIMES TO BODY-COLOR BRAKE LAMPS	5. Report Date May 1992
	6. Performing Organization Code 302753
7. Author(s) Chandra, D., Sivak, M., Flannagan, M. J., Sato, T., and Traube, E. C.	8. Performing Organization Report No. UMTRI-92-15
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute Ann Arbor, Michigan 48109-2150 U.S.A.	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes Bosch, Carello Lighting, Donnelly, Ford (Plastic and Trim Products Division), GE Lighting, GM (Inland Fisher Guide Division), GTE Products, Ichikoh Industries, Koito Manufacturing, Philips Lighting, Stanley Electric, and 3M.

16. Abstract

Body-color brake lamps are lamps that in their off state match the body color of a car. When energized, all body-color lamps, as well as conventional lamps, appear bright red. The speed of response to a body-color brake lamp may differ from the speed of response to a conventional lamp for two possible reasons. The first is that the difference between off- and on-state luminances varies primarily with off-state luminance. When the difference is larger than for the conventional lamp, the increased luminance contrast may speed reaction time. The other reason that responses for the two types of lamps may differ is the greater chromaticity contrast that body-color lamps have between their on and off states.

This study separately evaluated the effects of luminance contrast and chromaticity contrast for body-color brake lamps. One set of chromatically neutral lamps of varying lightness (from black to white) was tested, along with a set of chromatically varied lamps of equal lightness, and a conventional lamp. The lamps were run pair-wise in a dual-task paradigm where one task involved simple compensatory tracking, and the other task was to respond to the onset of either of the two brake lamps. Reaction times were recorded.

The primary findings are statistically significant effects of both luminance contrast and chromaticity contrast on reaction time to brake lamps. Neither of these effects is large; the difference between fastest and slowest mean reaction times was 33 msec. The effect of luminance contrast is such that lamps that are light in their off state yield slower reaction times. Performance with the lightest lamp in this study was slightly worse than performance with the conventional lamp. None of the chromatic lamps degraded performance relative to the conventional lamp. The pattern of responses to the chromatic lamps suggests that for all lamps that are different from red in their off state, the effect of chromaticity contrast will be to speed up reaction time slightly compared to the conventional lamp.

17. Key Words	18. Distribution Statement
brake lamps, stop lamps, body-color lamps, high-contrast lamps, luminance contrast, chromaticity contrast, reaction time, color, contrast	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	17	

ACKNOWLEDGEMENTS

Appreciation is extended to the current members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research:

Bosch
Carello Lighting
Donnelly
Ford (Plastic and Trim Products Division)
GE Lighting
GM (Inland Fisher Guide Division)
GTE Products
Ichikoh Industries
Koito Manufacturing
Philips Lighting
Stanley Electric
3M

Special thanks go to Stanley Electric for constructing the test lamps, and to Dennis Battle, Gabriel Helmers, and D. Alfred Owens for assisting with various aspects of this study.

CONTENTS

INTRODUCTION

When a brake lamp is energized, its luminance increases; this is perceived primarily as an increase in the lamp's brightness. With a conventional brake lamp, this luminance contrast is the only significant change, but with new body-color brake lamps there is also a change in chromaticity. In its off state, a body-color brake lamp matches the chromaticity of the car body. Such a lamp is constructed by placing a grating of narrow body-color stripes in front of the conventional brake lamp fixture. Because body-color lamps appear red in the on state just as conventional lamps do, their chromaticity changes (from body color to red) when they are energized.

This study was conducted in order to compare driver reaction times to the onset of body-color lamps with reaction time to a conventional lamp. Reaction time to the onset of a lamp is a simple, but relevant, measure of driver performance. This study was a follow-up to the one performed by Sivak, Flannagan, and Gellatly (1991). In that work, a lamp that was black in its off state was compared with a conventional lamp. The black lamp was labeled the "high contrast" lamp, since its luminance contrast was greater than that of the conventional lamp. Sivak et al. predicted that reaction times to the high contrast lamp would be faster than those to the conventional. The results showed that there was indeed a small but reliable difference between reaction times to the lamps in the expected direction. The magnitude of the difference was 19 msec, which corresponds to a savings of 0.5 m of stopping distance at an initial speed of 100 km/hr. That study, however, could not dissociate the effects of the increased luminance contrast from the effect of the chromaticity contrast between (off-state) black to (on-state) red.

The present study tested eight body-color lamps. Of these, one set of four chromatically neutral lamps varied in lightness (from black to white) and the other set of four varied in chromaticity so that the effects of these two factors could be analyzed separately. The four lamps that varied in chromaticity were matched in lightness (strictly speaking, Munsell value) with one of the chromatically neutral lamps. A conventional lamp was also included in the study to provide a baseline for comparison. As in the previous study (Sivak et al., 1991), the experimental setup simulated bright sunlight shining on the brake lamps—a relatively demanding real-world scenario for detecting the onset of the brake lamps.

METHOD

Tasks

Subjects performed two concurrent tasks. One task was to press a response button when either of two brake lamps was energized. The lamp turned off as soon as a response was made, so the subject received immediate feedback. The other task was to control a compensatory tracking task designed to approximate the perceptual and motor workload of driving. The tracking task was a dynamic simulated road scene on a computer-driven monitor. The subject's task was to keep the road centered on the monitor. At the end of each block of trials, if requested, subjects were told their mean reaction time for that block.

Equipment

Schematic diagrams of the experimental setup and subject's view are shown in Figures 1 and 2. The subject sat 4 m from the 58.4 cm (23 in) television monitor that displayed the tracking task. Subjects turned a knob with their left hand to control the driving task. They used their right index finger to press a response button when either brake lamp was energized. Eye position was kept constant across subjects by having them place their chins in a chin rest at a fixed position.

The brake lamps were positioned to either side of the tracking task monitor such that the visual angle from the center of either lamp to the center of the monitor was 7.9°. The distance between the lamps and the subject's eye position was 3.69 m. A stiff, light-weight black board (2.1 m x 0.9 m) with an aperture the size of the television screen (48 cm x 38 cm) was placed between the monitor and brake lamps to provide a uniform background for the lamps. The lamps were mounted on black stand-alone brackets in front of this board.

Photoflood lamps were placed on each side of the table to illuminate the face of the brake lamps at 36,000 lux, a level chosen to simulate bright sunlight. The color temperature of the photoflood lamps was 3200K. Overhead fluorescent lights were also on throughout the experiment. In order to prevent the reflection of these lights from appearing on the television monitor, a baffle made of the same black board used for the screen was constructed and positioned appropriately. The resulting nonuniform background illumination was measured at two locations. On the black board immediately above the monitor, the luminance was 11.8 cd/m^2, while on the gray wall above the center of the board the luminance was 138.1 cd/m^2.

Two computers were used for the study, one to control the onset and offset of the brake lamps and another to control the tracking task. The computer that controlled the lamps also randomized the sequence of lamp presentations, controlled the timing, and collected the button-press responses. Hardware internal to this computer allowed reaction times to be recorded with millisecond accuracy. Data from the tracking task were not stored.

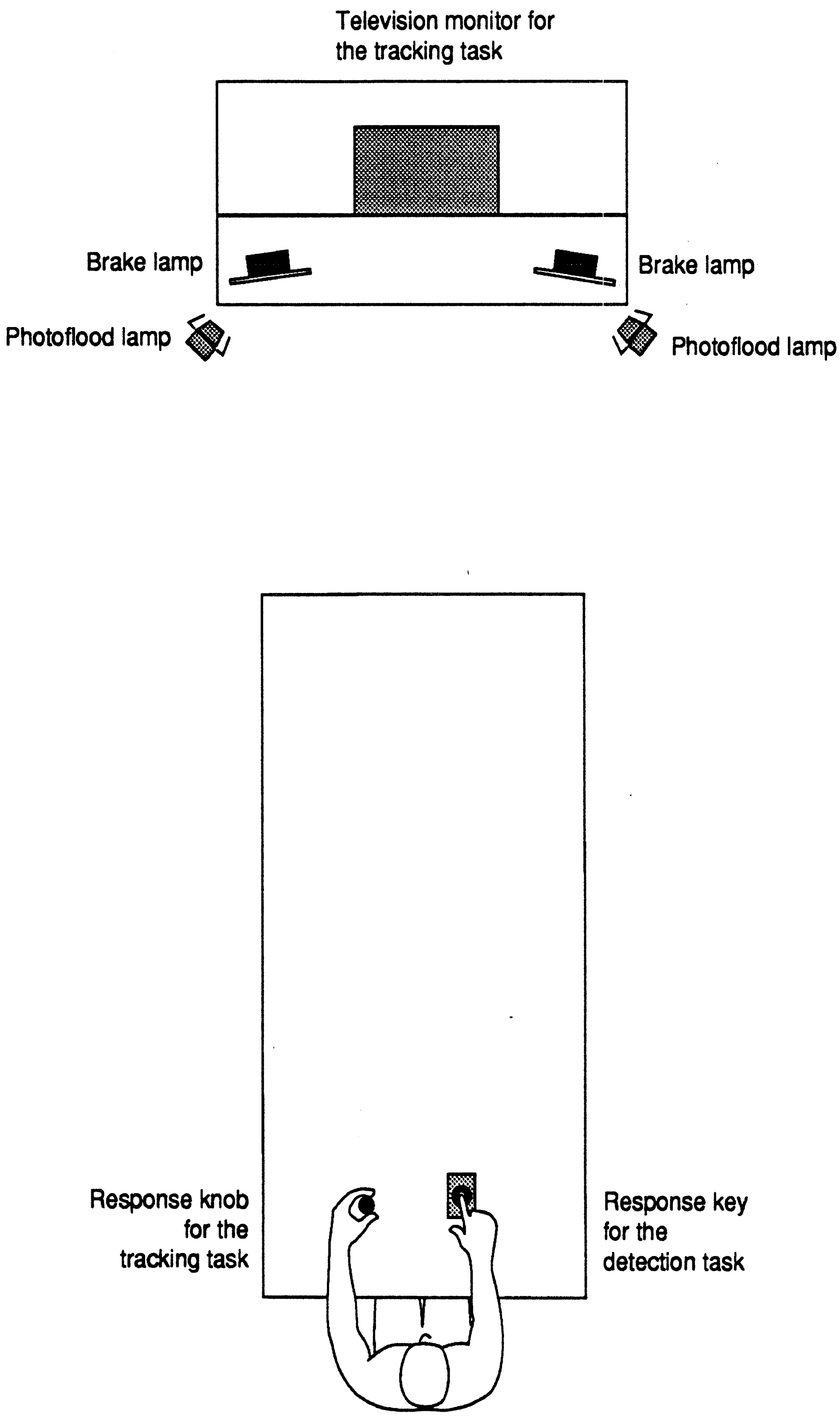

Figure 1. A schematic diagram of the experimental setup.

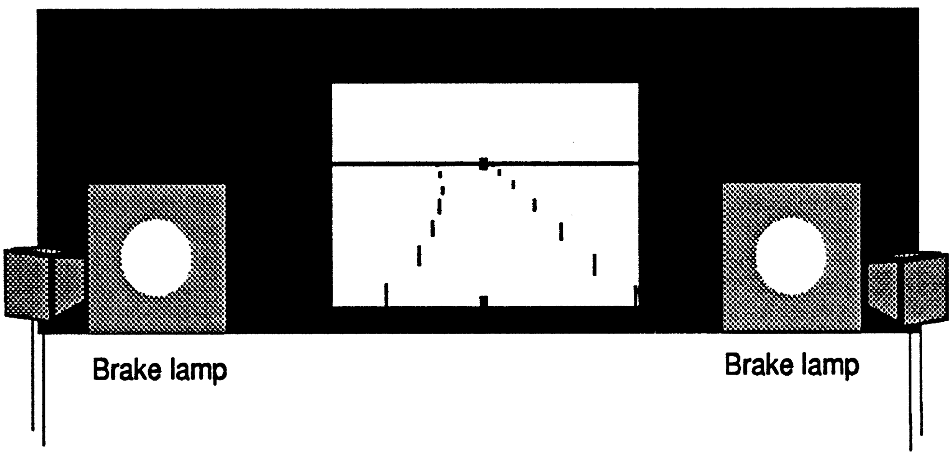

Figure 2. A schematic diagram of the subject's view.

Brake Lamps

Each body-color lamp was formed by first placing a body-color grating and then a matching panel in front of the lamp housing.* The gratings were comprised of alternating body-color and transparent horizontal stripes (each 1.5 mm wide). Each matching body-color panel was 30.4 cm (1 ft) square with a centered circular aperture of diameter 15.2 cm (6 in). All of the lamps (including the conventional) were roughly equated for on-state luminance. Because the gratings required for the body-color lamps reduced their on-state luminance, the conventional lamp (which did not have a grating) required a custom-built housing to reduce its on-state luminance to match the body-color lamps. Consequently, three housings were used–two for the body-color lamps and one for the conventional lamp. All the housings used the same type of bulb, No. 3497 (27 W).

The illuminances at the subject's eyes were measured using a Minolta illuminance meter T-1. Averaged over all testing days, the illuminance from the nine lamps in the on state ranged from 8.80 lux to 9.44 lux, with the mean of 9.09 lux. Treating the lamps as point sources, the calculated luminous intensity directed towards the eyes of the subject averaged from 119.8 cd to

* The red body-color panel was used with the conventional lamp for all but a few trials. There were 20 trials (out of a total of 3240) when the red lamp was run with the conventional lamp in the same block, so two red body-color panels were required, but only one was available. In these cases, the conventional lamp was surrounded by the black body-panel. Given the limited number of these trials, it was decided that no adjustment of the data was needed to compensate for this inconsistency. Also, no effect of the body-color panel was expected or incorporated into the design.

128.5 cd, with the mean of 123.7 cd. The luminance across the face of each lamp varied substantially, being highest in the middle and lowest at the edges. The actual distributions of luminance were not fully measured, but the average luminances across the faces of the lamps, based on the illumination measured at the subject's eye point, were calculated. Those values ranged from 6602 cd/m^2 to 7078 cd/m^2, with the mean of 6817 cd/m^2. The average luminances for all lamps in the on state are listed in Table 1. This table also lists the corresponding off-state luminances.

Chromaticity values for each of the lamps in the on and off states were measured with a Photo Research Pritchard 1980A spot meter equipped with TF-80 tristimulus filters, and are given in Table 2. This table also lists the chromaticity coordinates of the body-color panels. In most cases, these are similar to the off-state coordinates of the corresponding lamp. However, because the lamp chromaticity was created with a grating of narrow body-color stripes, and bands of conventional red showed through between these stripes, the chromaticities of the lamp in the off state are shifted slightly towards red. The shift is larger for body colors that are farther away from red, such as green and blue (see Figure 3). In their on states, all of the lamps appeared red. All the lamps in their on states were within the current U.S. standard of red required for brake lamps (FMVSS, 1991).

Design

Four chromatically neutral lamps, black, dark gray, light gray, and white, with Munsell lightness values of 2, 4, 7, and 9, respectively, were chosen for this study. The four chromatic lamps used (with Munsell coordinates in parenthesis) were red (5R 4/14), yellow (5Y 4/6), green (5G 4/10), and blue (5PB 4/10). These lamps all had Munsell values of 4, so they were equated in lightness with the second darkest neutral lamp (dark gray). A conventional lamp was also tested, making for the total of nine lamps in the study.

Within a set of trials, only two lamps were shown at a time, one to the left and one to the right of the center of the tracking-task monitor. The decision to present only two of the nine lamps at a time was made so that this study would be comparable with the previous one (Sivak et al., 1991). Given that nine lamps were to be compared, there were 72 possible ordered pairings of the lamps, and a set of nine was chosen from these. The particular pairings used were not expected to affect reaction time. This set of nine pairs was canonical, in the sense that any assignment of lamps could be made to the pairings. The actual lamps were assigned to this ordering using rows of 9 x 9 Latin square, resulting in nine different orderings. The positions of the lamps were counterbalanced so that each lamp appeared on the left in one block and on the right in another block for each subject. Thus, lamp position and lamp color were within-subject variables. There was also one between-subjects variable, age.

Table 1
Average luminances of the brake lamps as viewed from the subject's eye point, and the coefficients of variation.

Lamp	Off-State Luminance (cd/m^2)	On-State Luminance (cd/m^2)	On-State Coefficient of Variation
Red	877	6729	0.022
Green	680	6744	0.019
Blue	685	6782	0.023
Yellow	776	7078	0.019
Black	336	6714	0.020
Dark Gray	715	6602	0.023
Light Gray	1819	6868	0.023
White	3433	6928	0.022
Conventional	511	6909	0.004

Table 2
Chromaticity coordinates of the brake lamps and body-color panels. Note that all lamps appear red in the on state, and that the off-state colors are similar to the body-color panels.

Lamp	Off State		On State		Body-Color Panel	
	x	y	x	y	x	y
Red	0.624	0.327	0.676	0.323	0.652	0.319
Green	0.392	0.459	0.674	0.323	0.253	0.563
Blue	0.333	0.307	0.669	0.320	0.255	0.290
Yellow	0.512	0.433	0.675	0.324	0.501	0.446
Black	0.494	0.366	0.678	0.321	0.419	0.388
Dark Gray	0.458	0.379	0.670	0.326	0.416	0.395
Light Gray	0.443	0.391	0.664	0.325	0.422	0.399
White	0.439	0.392	0.654	0.327	0.423	0.399
Conventional	0.674	0.319	0.672	0.327	0.652	0.319

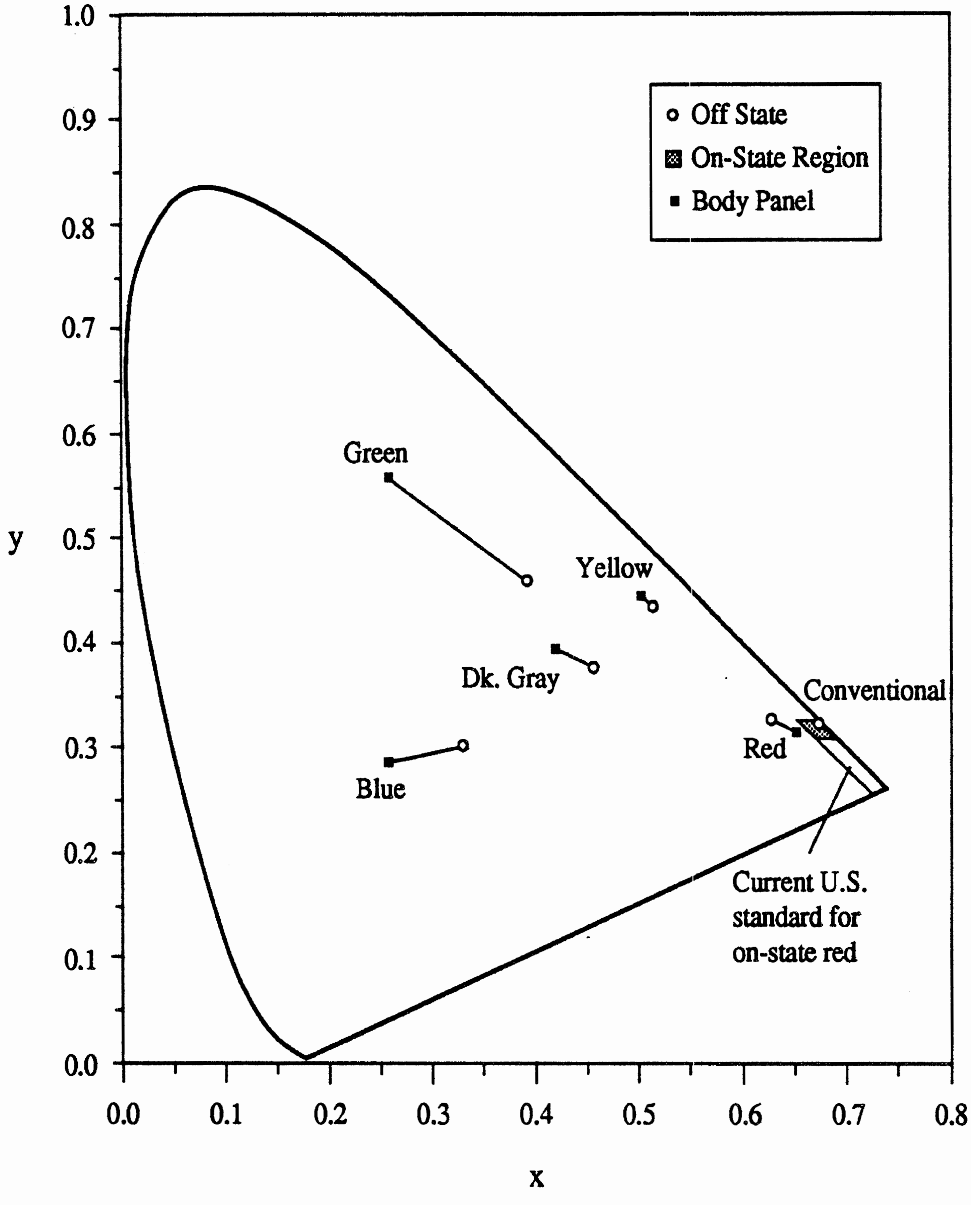

Figure 3. Chromaticity coordinates from Table 2. All on-state values fall within the small shaded region which is contained in the larger region denoting the U.S. standard for red. The lines connect the chromaticities of the lamps in the off state with the chromaticities of the corresponding body panels. The conventional lamp did not have a specially constructed body panel (see footnote, p. 4).

Subjects

Eighteen paid subjects participated in the study. Nine subjects were between the ages of 19 and 29, and nine were between the ages of 60 and 82. There were five females and four males in each age group. All nine lamp orderings were used within each age group. Subjects were compensated monetarily for their participation.

Photometry Checks

Illuminance values at the subject's eye point for each of the lamps in each of the positions were recorded each day the experiment was run. From these values, a coefficient of variation was computed for each lamp and this value is also listed in Table 1. The coefficient of variation is computed as the standard deviation of the measures divided by the mean value. Note that the coefficient of variation for the conventional lamp is much smaller than for the other lamps. A likely explanation for this is that the use of two housings for all lamps, other than the conventional, increased the variance of their luminances.

Procedure

Each subject was tested individually during a one-hour session consisting of ten blocks, including one practice block of 10 trials, and nine test blocks of 20 trials each. The tracking task was explained first, and subjects were allowed to practice until they felt comfortable with it. The reaction time task was then introduced. On each trial, either the left or the right brake lamp was energized. If the subject responded within one second, the lamp was turned off immediately, otherwise the lamp was turned off after one second. Responses longer than three seconds were not recorded; these were considered missed trials and were rerun at the end of the block. There were five lengths of inter-trial intervals: 6, 8, 10, 12, and 14 seconds. These intervals were randomized, so that the onset of the next lamp appeared unpredictable to the subject. Whether the left or right lamp would be energized on a given trial was also randomized (independently). Short breaks were given at the end of each block while the experimenter exchanged lamps.

RESULTS AND DISCUSSION

Practice trials, and nine trials for which reaction time was greater than one second, were first removed from the data set. An analysis of variance was then performed on the reaction times. The analysis incorporated two within-subject variables, position and lamp, and one between-subjects variable, age. As in our previous study (Sivak et al., 1991), the effect of age was statistically significant ($F_{1, 14} = 6.61, p < 0.05$), with younger subjects responding faster than older subjects (345 msec versus 414 msec). The effect of lamp position was also significant ($F_{1, 14} = 5.60, p < 0.05$), with faster reaction times to the right than the left lamp position (375 msec versus 384 msec). Of primary interest, the effect of the lamp was significant ($F_{8, 112} = 4.27, p < 0.001$). No interaction was significant.

The mean reaction time for each lamp is listed in Table 3. In relation to the grand mean of reaction times (379 msec), the magnitude of this effect was modest. The fastest and slowest mean reaction times differed by 33 msec. The results do, however, appear to be systematic and worth examining further.

Table 3
Mean reaction times for the nine lamps.

Lamp	Mean Reaction Time (msec)
Red	386
Green	364
Blue	373
Yellow	376
Black	375
Dark Gray	373
Light Gray	386
White	397
Conventional	386

Effect of Luminance Contrast

As planned, the lamps were separated into two groups, one that varied in lightness but was approximately equal in chromaticity, and another that varied in chromaticity but was approximately equal in lightness. The mean reaction times for these groups are shown in Figures 4 and 5, respectively. The mean reaction time for the conventional lamp is shown for comparison in both figures. Figure 4 shows a trend of increasing reaction times with increasing off-state lightness of the lamps. The linear component of this trend is statistically significant ($F_{1,112} = 13.95$, $p < 0.001$), although the data appear to deviate from linearity somewhat for the black lamp. The linear component accounts for 86% of the variance of reaction times. Because the on-state luminances were approximately equated, this contrast was determined by off-state luminance. The effect of off-state lightness shown in Figure 4 can therefore be interpreted as an effect of luminance contrast. Figure 4 shows that performance was impaired relative to the conventional lamp only for the white lamp. Thus, although the effect of reduced luminance contrast is significant, it is detrimental only when there is a high off-state luminance.

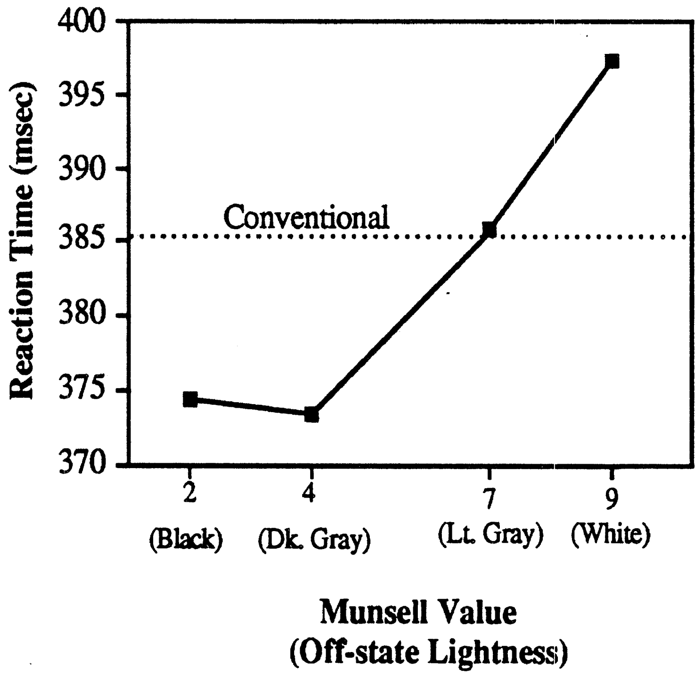

Figure 4. Reaction times to chromatically neutral lamps.

Effect of Chromaticity Contrast

Figure 5 shows that the red lamp yielded reaction times that are approximately equivalent to those of the conventional lamp. All other chromatic lamps, and the chromatically neutral lamp of equal lightness (dark gray), yielded improved performance relative to the conventional lamp. The pattern of reaction times for chromatic lamps can be qualitatively explained in terms of the degree of difference between the body color and the on-state color (red). Reaction times are longest for the red and conventional lamps that have the smallest color difference between the on and off states (i.e., the lowest chromaticity contrast). The green lamp has the fastest reaction time, which is reasonable because green and red are complementary colors, meaning that green is perceptually very different from the on-state red. The lamps with intermediate reaction times (yellow, dark gray, and blue) are grouped in Figure 5. They are all more different from the on-state red than is the off-state red, but not as different as green. Since color differences have not been quantitatively assessed, the ordering of reaction times within this group cannot be predicted.

The pattern of color effects evident in Figure 5 is corroborated by statistical analysis. The difference between the red and green lamps is highly significant ($F_{1,\,112} = 9.90$, $p < 0.001$). The difference between the red lamp and the group of intermediate lamps in Figure 5 is also significant ($F_{1,\,112} = 5.73$, $p < 0.05$). The difference between the intermediate lamps and the green lamp was marginally nonsignificant ($F_{1,\,112} = 2.95$, $p = 0.09$), but in the predicted direction. If this line of reasoning is correct, it follows that any body-color other than red can only *improve* performance relative to conventional lamps, since all nonred off-state colors must be farther away from the on-state red than the off-state red.

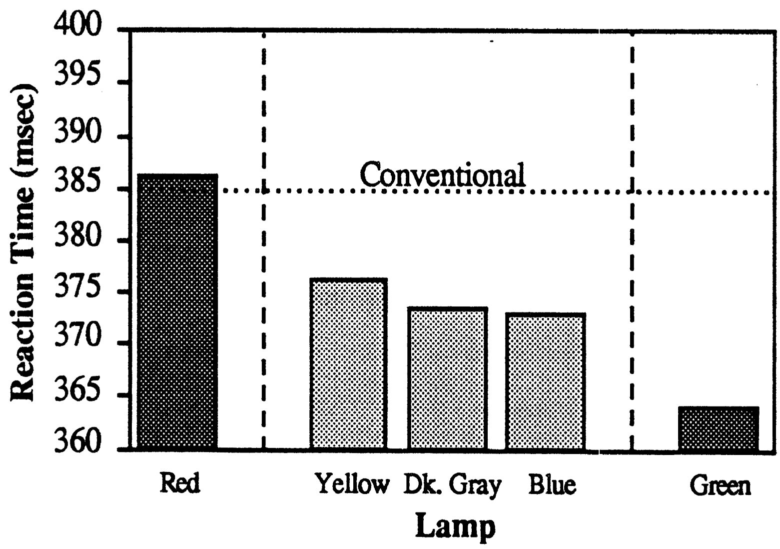

Figure 5. Reaction times to chromatic lamps. The lamps are partitioned because the three lamps in the center were grouped for the analysis. All the lamps, including the dark gray were approximately equal in off-state lightness.

Comparison with Sivak, Flannagan, & Gellatly (1991)

Two of the lamps used in this study were similar to the lamps used by Sivak, Flannagan and Gellatly—the black body-color lamp and the conventional lamp. The results for these two lamps are essentially the same across the two studies, but there were some differences. Sivak et al. found a 19 msec difference in reaction time between the lamps, whereas only an 11 msec difference was found in this study. Also, overall reaction times were longer in the previous study. Sivak et al.'s grand mean was 448 msec compared with the grand mean of 379 msec in this study. The most likely explanations for these differences are that the lamps used in the present study were substantially bigger (area of 181.5 cm^2 versus 84.4 cm^2) and somewhat brighter (123.7 cd versus 100.4 cd) than those used by Sivak et al.

CONCLUSIONS

This study found significant effects of both luminance and chromaticity contrast on reaction time to brake lamps. However, neither of these effects was large. Furthermore, the lighting conditions used here—high illuminances on the faces of the brake lamps—were designed to minimize the luminance contrasts between the off states and on states for all lamps, thus maximizing task difficulty and overall reaction time. Assuming that there are diminishing returns in reaction-time reduction as contrast is increased, any differences in reaction time due to differences in contrast will be greater when contrasts are generally low. Intense sunlight, as represented by the laboratory conditions used here, should therefore maximize any differences among body-color and conventional brake lamps. At the other extreme, very dark nighttime conditions should make all the lamps indistinguishable in the off state and therefore equal in reaction time.

The effect of luminance contrast is such that lamps that are light in their off state yield slower reaction times. Performance with the lightest lamp in this study was slightly worse than performance with the conventional lamp. None of the chromatic lamps degraded performance relative to the conventional lamp. The pattern of responses to the chromatic lamps suggests that for all lamps that are different from red in their off state, the effect of chromaticity contrast will be to speed up reaction time slightly compared to the conventional lamp.

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