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16. Abstract

This study evaluated subjects' impressions of performance of high-intensity discharge (HID) headlamps after in-traffic experience, with a special emphasis on color appearance of stop signs. In the first of two tasks, subjects drove (or rode) 19 km through a variety of roadway environments in a car equipped with either HID or tungsten-halogen low-beam headlamps. Instructions to the subjects did not mention color appearance. The second task involved a head-to-head comparison of HID and tungsten-halogen headlamps. In this task, subjects drove (or rode) twice along a 4-km route in a residential area, and they were instructed to pay special attention to the color appearance of stop signs and other objects.

The main finding from Task 1 is that subjects who experienced HID headlamps did not report more (or fewer) spontaneous negative comments on color appearance of stop signs or other objects than did subjects who experienced tungsten-halogen headlamps. Furthermore, the evaluations of overall performance of the two types of headlamps were very similar. In the head-to-head comparison in Task 2 there was no evidence of problems with color appearance when using HID headlamps. Furthermore, subjects preferred HID headlamps in terms of overall performance, and in making stop signs and other objects stand out from their background. However, this preference for HID headlamps was present only for subjects who had the relatively extended exposure to the HID headlamps in Task 1.

The results of this study provide no evidence of problems with color appearance of stop signs and other objects when using HID headlamps. Furthermore, the study indicates that observers perceive HID headlamps as helping stop signs and other objects stand out from their backgrounds. Finally, the present results imply that, given a somewhat extended exposure to HID headlamps, drivers would prefer them over current tungsten-halogen headlamps.

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# INTRODUCTION

The development of high-intensity discharge (HID) headlamps has raised questions regarding the color perception of retroreflective stop signs. The reason for this concern is that HID light sources, in comparison to tungsten-halogen light sources, emit proportionally less energy in the long-wavelength end of the visible spectrum—precisely in the most reflective wavelength region of retroreflective red stop signs.

As part of our research program, we performed three previous studies related to the issue of color perception when using HID headlamps. The first, analytical study (Sivak, Simmons, and Flannagan, 1991) evaluated the colorimetric properties of retroreflective traffic signs when illuminated by HID headlamps. Two aspects were investigated: (1) colorimetric shift of individual sign materials when illuminated by HID as opposed to tungsten-halogen light sources, and (2) colorimetric separations of the red sign material from the yellow, orange, and brown sign materials when illuminated by HID light sources. Spectral reflectances of 14 sign materials and spectral power distributions of seven HID headlamps (along with a tungsten-halogen headlamp) were used to derive the CIE tristimulus values for the sign materials. These values were then transformed into the CIELAB space—a perceptually uniform color space. The results of the analyses indicate that the magnitude of the colorimetric shift increased with increasing correlated color temperature of the light source. The resulting colorimetric separations of red from yellow, orange, and brown for the HID light sources also tended to increase with increasing correlated color temperature.

The second of our previous studies was a photometry study (Flannagan, Sivak, Gellatly, and Luoma, 1992), designed to compare the magnitudes of the shifts in chromaticity of stop signs illuminated by HID and tungsten-halogen headlamps to the range of chromaticities of stop signs under tungsten-halogen headlamps. A stratified sample of 25 stop signs was selected in Ann Arbor, Michigan. Stratification was by sign material (enclosed, encapsulated, microprism), age (more than five years in service, less than one year in service), and compass direction faced by the legend side of the sign (north, south). The chromaticities of these signs were measured in the field under both tungsten-halogen and HID (D1) illumination. The shifts between the chromaticities of the signs when they were illuminated with the tungsten-halogen and the HID light sources were in the direction of orange, and they were moderate relative to the range of chromaticities under the tungsten-halogen source. We concluded that, although the sizes of the shifts should not be interpreted as indicating a problem with color rendering by HID headlamps, they were not small enough to allow us to dismiss the possibility of a problem.

The third study was a laboratory investigation (Sivak, Flannagan, Gellatly, and Luoma, 1992), designed to address experimentally the consequences of colorimetric shifts of red sign materials in different colorimetric directions. Subjects were shown individual color samples under controlled lighting conditions. Their task was to indicate, on each trial, whether the sample color was acceptable for stop signs. Additionally, at the end of each experimental session, subjects were asked to select a single, most appropriate color for stop signs from among 16 simultaneously presented color samples. An implicit assumption underlying this study was that subjective preference is related to performance: stimuli that are closer to the most preferred stimulus lead to better performance in terms of measures such as percent correct identification, reaction time, etc. Although direct evidence confirming this assumption does not exist, there is some indirect evidence. Stimulus-response situations that are compatible with the population stereotype lead to shorter reaction times than situations that are incompatible with the population stereotype (Kantowitz and Sorkin, 1983). There were two main findings of this study. First, there was an overwhelming agreement among the subjects concerning the most appropriate red color for stop signs out of the 16 colors presented—a saturated red. Second, observers were differentially sensitive to colorimetric shifts in different directions from this most appropriate color. From among the investigated colorimetric-shift directions, subjects were most sensitive to hue shifts towards orange (generally in the same direction as the shift that was obtained in the above-mentioned photometry study of in-use stop signs), while they were relatively insensitive to saturation shifts towards pink.

These three studies suggest that (1) HID headlamps result in colorimetric shifts of the red stop-sign materials towards orange, and (2) observers in a laboratory setting are sensitive to such shifts, and they prefer the situation under tungsten-halogen over HID illumination. However, it is not clear how these findings would influence driver evaluation of headlamp performance. Consequently, the present study was designed to investigate the influence of actual driving context on (1) color perception using HID and tungsten-halogen low-beam headlamps, and (2) observer preferences for HID versus tungsten-halogen headlamps.

## METHOD

### Tasks

**Task 1.** The study consisted of two tasks. The first task involved in-traffic experience using either HID or tungsten-halogen headlamps. No specific instructions concerning the purpose were given prior to this task. The instructions indicated that subjects would be driving or riding in a car for about half an hour. They were instructed to look around as they were driving (or riding), noticing anything that they felt might be different or worth noting at the end of the session.

At the end of the drive, all subjects were asked to fill out a questionnaire containing 16 questions, with one question per page. The questions (see Table 1) started with general inquiries concerning the performance of the headlamps. Progressively, the questions got more specific concerning color perception in general, color perception of traffic signs, and color perception of stop signs and vehicle rear lights.

The route was 19.4 km long, and it consisted of the following segments: a four-lane rural divided roadway without limited access (3.2 km), two-lane residential streets (7.1 km), a two-lane rural roadway (2.6 km), a four-lane rural limited-access roadway (3.9 km), and a five-lane suburban nondivided roadway (2.6 km). Subjects encountered a total of 17 stop signs on this route.

Table 1.
Questions used in Task 1.

| Number | Question |
|---|---|
| 1 | What is your impression concerning the performance of these headlamps? |
| 2 | What is your impression concerning the performance of these headlamps on expressways? |
| 3 | What is your impression concerning the performance of these headlamps on residential streets? |
| 4 | What is your impression concerning the performance of these headlamps on straight sections of road? |
| 5 | What is your impression concerning the performance of these headlamps on curved sections of road? |
| 6 | How good were the headlamps in helping to detect objects in the distance? |
| 7 | How good were the headlamps in making objects to stand out from their background? |
| 8 | How good were the headlamps in helping you see the colors of objects? |
| 9 | Did you notice anything particular about traffic signs? (Yes or No.) If yes, indicate what. |
| 10 | Did you notice anything particular about stop signs? (Yes or No.) If yes, indicate what. |
| 11 | Rate the visibility of stop signs at far distance. |
| 12 | Rate how well stop signs stood out from the background. |
| 13 | Rate the legibility of stop signs. |
| 14 | Rate the quality of the red color of stop signs. |
| 15 | Did you notice anything particular about the brake and tail lights on vehicles ahead of you? (Yes or No.) If yes, indicate what. |
| 16 | Rate the quality of the red color of brake and tail lights. |

All questions, with the exception of questions 9, 10, and 15, used the following five-point response scale: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good.

**Task 2.** The second task involved a head-to-head comparison of HID and tungsten-halogen headlamps. In this task, subjects drove (or rode) twice along a short route in a residential area. Prior to this task, the subjects were instructed to "pay attention to how colors look with these headlamps. We would like you to pay special attention to the red color of stop signs."

The route in this task was 3.9 km long, and it consisted mostly of two-lane residential streets. Subjects encountered a total of seven stop signs on this route. It took subjects about seven minutes to traverse this route each time.

After completing the two runs of Task 2, subjects were given a brief questionnaire (see Table 2).

Table 2.
Questions used in Task 2.

| Number | Question |
|---|---|
| 1 | Rate the overall performance of each lamp type. |
| 2 | Rate the performance of each lamp type in making objects in general stand out from their background. |
| 3 | Rate the performance of each lamp type in helping you to see the colors of objects in general. |
| 4 | Rate the performance of each lamp type in making stop signs stand out from their background. |
| 5 | Rate the performance of each lamp type in helping you to see the color of stop signs. |

All questions used the following five-point scale: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good. The two headlighting systems were referred to as the "first" and "second" lamp type.

## Equipment

Two cars were used as subject vehicles: a 1990 Cadillac Sedan de Ville, and a 1992 Cadillac Eldorado. Each of the two cars was equipped with both HID and tungsten-halogen low-beam headlamps. The spectral power distributions for the four HID lamps were examined and found to be very similar. Figure 1 shows the spectral power distributions for one of the HID lamps, along with a typical distribution for a tungsten-halogen lamp.

Figure 2 shows the luminous intensity values at 14 test points (or regions) that evaluate the compliance with the U.S. federal regulations (FMVSS, 1991) for all eight headlamps (four tungsten-halogen and four HID) used in this study. The locations of the test points are listed in Table 3. A visual inspection of Figure 2 indicates that the two types of headlamps had similar luminous output at the U.S. test points. However, the isocandela diagrams (not shown) revealed that the HID headlamps provided more lateral-spread illumination.

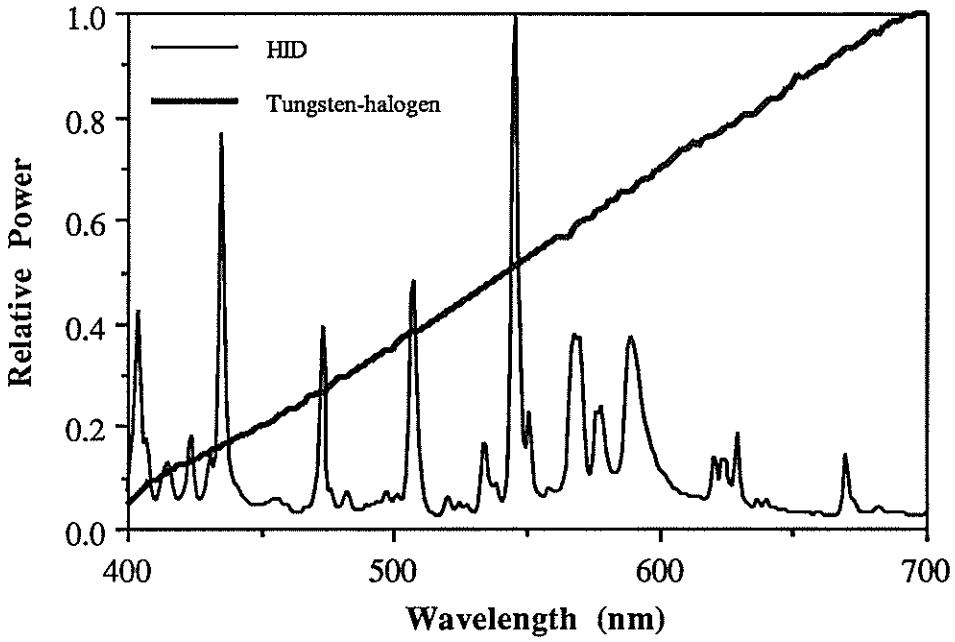



Figure 1. The relative spectral power distributions of a typical tungsten-halogen headlamp and of one of the four HID headlamps used in this study. (The power distributions of all four HID headlamps were very similar.)

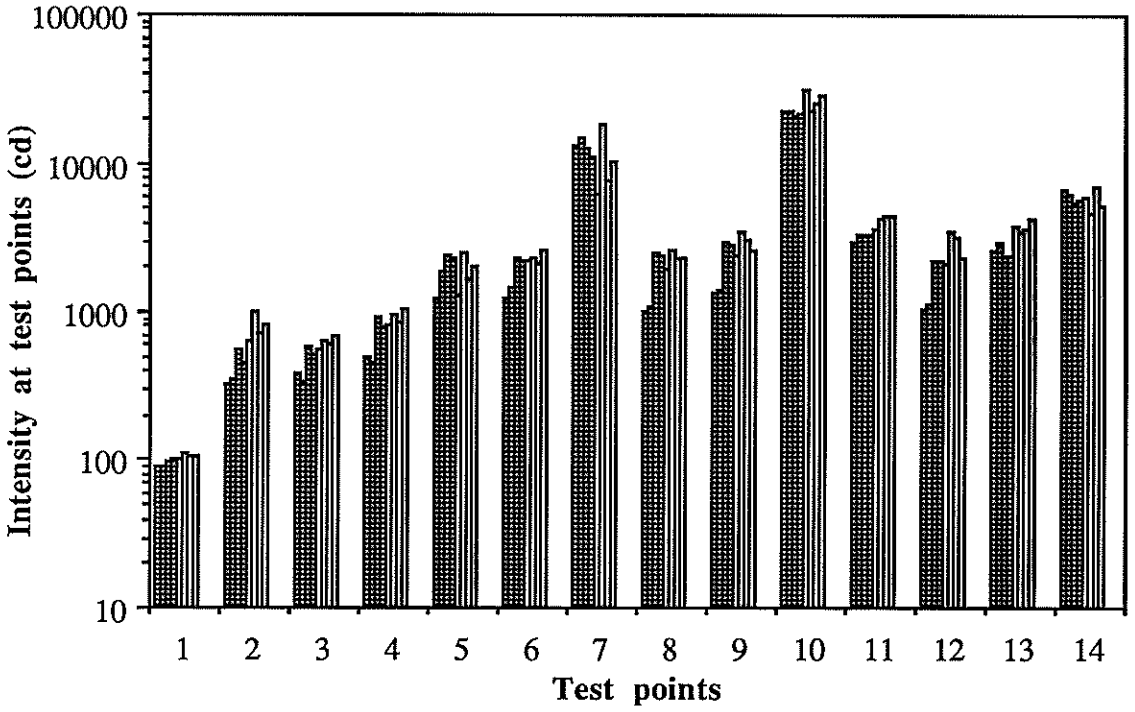



Figure 2. Luminous intensity values at 14 test points (or regions) that evaluate the compliance with the U.S. Federal Motor Vehicle Safety Standard 108 for all eight headlamps used in this study. The locations of these test points are listed in Table 3. The shaded bars represent the tungsten-halogen headlamps and the open bars the HID headlamps.

Table 3.
Locations of the test points in Figure 2.

| Number in Figure 2 | Location | Photometric maximum | Photometric minimum |
|---|---|---|---|
| 1 | 10U, 5L to 10R | X | |
| 2 | 1.5U, 1R to 10R | X | |
| 3 | 1U, 1.5L | X | |
| 4 | 0.5U, 1.5L | X | |
| 5 | 0.5U, 1R to 3R | X | |
| 6 | 0.5D, 1.5L | X | |
| 7 | 0.5D, 1.5R | X | X |
| 8 | 1D, 6L | | X |
| 9 | 1.5D, 9L | | X |
| 10 | 1.5D, 2R | | X |
| 11 | 1.5D, 9R | | X |
| 12 | 2D, 15L | | X |
| 13 | 2D, 15R | | X |
| 14 | 4D, 4R | X | |

## Subjects

Thirty six paid subjects participated in this study. There were six males and six females in each of three age groups: younger (17-30 years of age, mean 23.6), middle-aged (36-46 years of age, mean 40.1), and older (60-82 years of age, mean 67.7).

## Procedure

Three subjects of the same sex and age group were tested at a time. Males were always tested in the Sedan de Ville, and they all sat in the front seat. Females were tested in the Eldorado; because it had two front bucket seats (rather than a bench seat like the Sedan de Ville), one of the three females sat in the center of the back seat and leaned forward so that her view would be similar to that from the front seat. (One of the originally-scheduled younger females did not show up. Consequently, the remaining two younger females who were scheduled for that time period were run as a driver and a front-seat passenger, respectively, and a third younger female was run singly on another night in the center rear seat.)

Groups of six subjects were scheduled simultaneously. However, to keep the two test cars separated, there was a five-minute delay before the second group of three subjects left for the route. Subjects chose among themselves who would drive and who would sit in the other two positions during the test. Two groups of six subjects (all from the same age group) were tested each night. All testing was done in October 1992 between about an hour after sunset and midnight.

In Task 1 each subject traveled the entire route using only one type of headlamps. For half the subjects in each age-by-sex group the type was HID, and for the other half it was tungsten-halogen. In Task 2 all subjects used both types of headlamps. For all groups of subjects, the system that was used in Task 1 was the first one to be used in Task 2.

After completing the questionnaire of Task 1, subjects were given a short break. Subjects were then informed that in Task 2 they would be asked to traverse a different, shorter route twice using two different headlighting systems, and that they should pay special attention to the color of stop signs and other objects during these two runs. After the completion of these two runs, a second questionnaire was administered. A schematic diagram of the design of both tasks is shown in Figure 3.

An experimenter was seated in the rear seat of each test vehicle. He instructed the driver concerning the route to be taken by indicating where to turn.

Each test session lasted about 90 minutes.

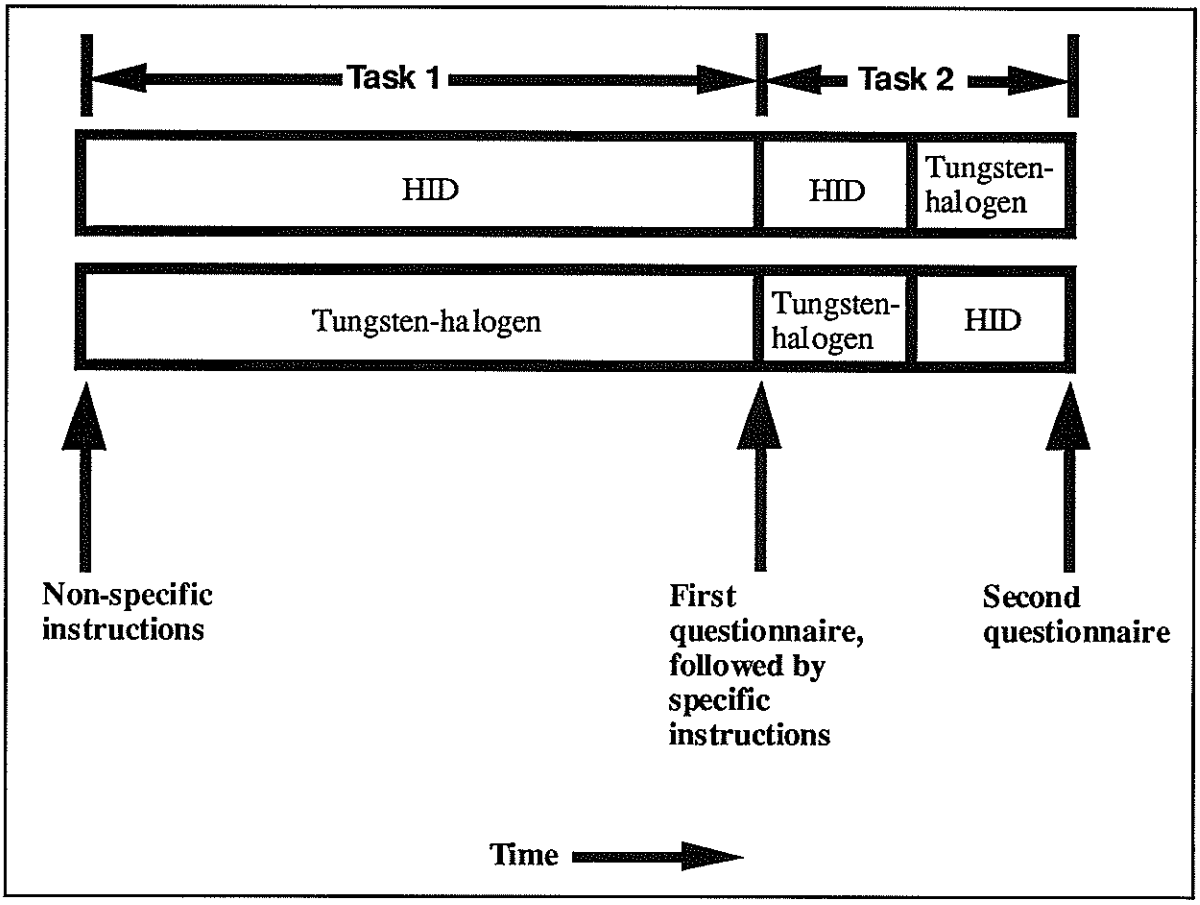



Figure 3. A schematic diagram of the design of both tasks in this study. Half of the subjects had the sequence of headlamps shown in the upper bar, and the other half had the sequence shown in the lower bar.

## RESULTS

### Task 1

In this task, subjects traveled through an extended route using either HID or tungsten-halogen low-beam headlamps, with no specific instructions to pay attention to color appearance of stop signs or other objects. Analyses of variance evaluated the differences in responses to the 16 questions in Table 1 between subjects with HID and tungsten-halogen experience. The analyses used the following as main factors: headlamp, age group, and sex. (Preliminary analyses found that seating position had no effect on responses to any of the 16 questions. Consequently, the data were collapsed across the three seating positions.)

**Effects of headlamp.** The main finding is that for none of the 16 questions in Table 1 were the differences between the two types of headlamps statistically significant. Three of the questions asked subjects whether they noticed anything particular about traffic signs (Question 9), stop signs (Question 10), or brake and tail lights (Question 15). The comments to these open-ended questions are summarized in Table 4. The comments are grouped into four categories: positive (e.g., *brighter, showed up well, easy to read*), negative (e.g., *word STOP not as obvious, color bleached out*), irrelevant (e.g., *they [traffic signs] had a V-shaped pattern*), and none. There is no evidence in Table 4 to suggest that the HID headlamps lead to more negative comments.

Table 4.
Summary of comments to the three open-ended questions in Task 1. The entries are percentages, for each headlamp type, of subjects who fell into each comment-type category. (Because of rounding, the percentages do not necessarily add up to 100.)

| Question | Positive comments | | Negative comments | | Irrelevant comments | | No comments | |
|---|---|---|---|---|---|---|---|---|
| | T-H | HID | T-H | HID | T-H | HID | T-H | HID |
| Did you notice anything particular about traffic signs? | 28 | 44 | 11 | 6 | 6 | 6 | 56 | 44 |
| Did you notice anything particular about stop signs? | 28 | 56 | 6 | 6 | 11 | 0 | 56 | 39 |
| Did you notice anything particular about the brake and tail lights on vehicles ahead of you? | 6 | 0 | 0 | 0 | 0 | 0 | 94 | 100 |

**Effects of age group and sex.** Age group had a statistically significant main effect only on Question 3 (performance on residential streets), $F$ (2,24) = 4.54, $p$ = .021, with middle aged subjects assigning more favorable ratings (4.6 on a five-point scale) than older subjects (4.1) and younger subjects (3.5). Sex had a statistically significant main effect only on Question 9 (anything particular about traffic signs), $F$ (1,24) = 9.00, $p$ = .006, with males responding "yes" more often than females (67% vs. 33%).

## Task 2

In this task, subjects traveled through a short route using both types of headlamps, with specific instructions to pay attention to the color appearance of stop signs and other objects. The results for each of the five questions in this task are presented in turn. The main factors in these analyses of variance were actual headlamps (i.e., headlamps to be evaluated), prior headlamps (i.e., headlamps used in Task 1), age group, and sex. (Preliminary analyses found that seating position had no effect on responses to any of the five questions. Consequently, the data were collapsed across the three seating positions.) The effects of age group and sex, as well as the effects of interactions involving these factors, were not statistically significant for any of the five questions. Consequently, what follows is the presentation of the effects of actual and prior headlamps.

**Overall performance of each lamp type (Question 1).** The effect of actual headlamps was statistically significant, $F(1,24) = 14.67$, $p = .0008$, with the HID headlamps rated as better than the tungsten-halogen headlamps (4.2 vs. 3.6 on a five-point scale). The effect of prior headlamps was not significant, $F\ (1,24) = 2.04$, $p = .166$. However, the interaction between the actual and prior headlamps was significant, $F(1,24) = 23.76$, $p = .0001$, with the HIDs rated as better than the tungsten-halogens only by subjects who had the HIDs as the prior headlamps in Task 1 (see Figure 4).

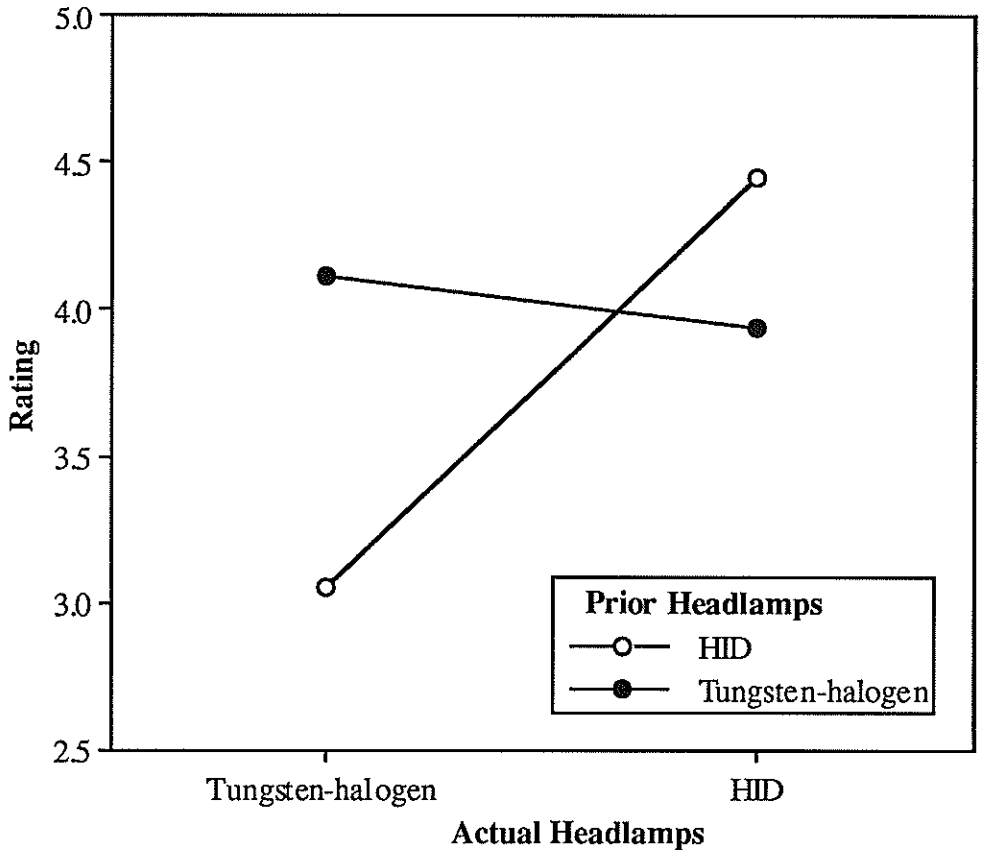



Figure 4. The effect of actual and prior headlamps on overall performance. The ratings used the following five-point scale: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good.

**Performance of each lamp type in making objects in general stand out from their backgrounds (Question 2).** The effect of actual headlamps was statistically significant, $F(1,24) = 16.29$, $p = .0005$, with the HID headlamps rated as better than the tungsten-halogen headlamps (4.3 vs. 3.5). The effect of prior headlamps was not significant, $F(1,24) < 1$. The interaction between the actual and prior headlamps was significant, $F(1,24) = 7.48$ $p = .012$, with the HIDs rated as better than the tungsten-halogens primarily by subjects who had the HIDs as the prior headlamps in Task 1 (see Figure 5).

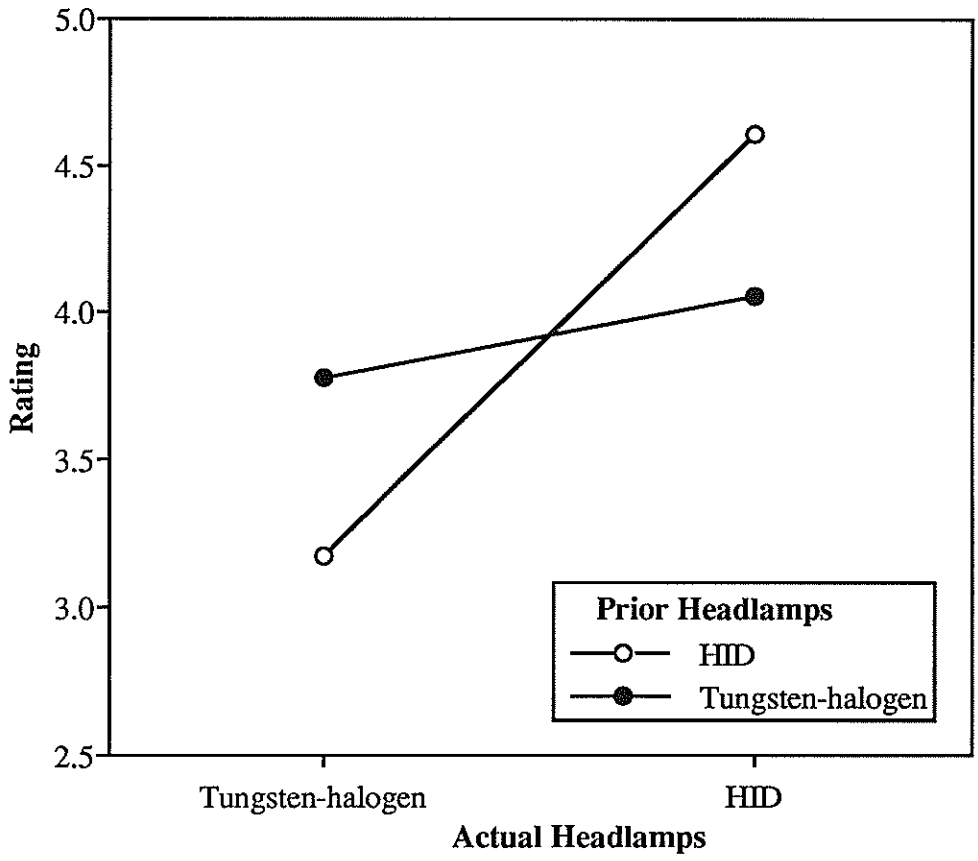



Figure 5. The effect of actual and prior headlamps on making objects in general stand out from their backgrounds. The ratings used the following five-point scale: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good.

**Performance of each lamp type in helping to see the colors of objects in general (Question 3).** The effect of actual headlamps was not statistically significant, $F(1,24) = 2.68$, $p = .114$, nor was the effect of prior headlamps $F(1,24) < 1$. The interaction between the actual and prior headlamps was significant, $F(1,24) = 7.00$, $p = .014$, with the HIDs rated as better than the tungsten-halogens only by subjects who had the HIDs as the prior headlamps in Task 1 (see Figure 6).

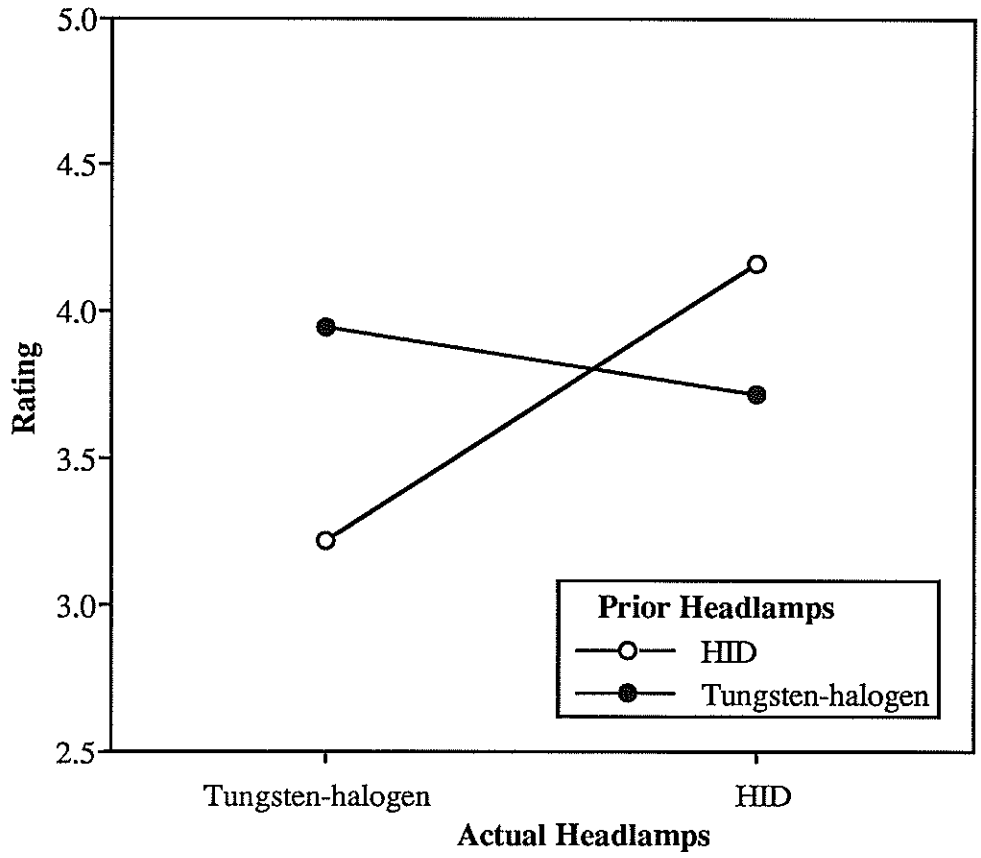



Figure 6. The effect of actual and prior headlamps on helping to see the colors of objects in general. The ratings used the following five-point scale: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good.

**Performance of each lamp type in making stop signs stand out from their backgrounds (Question 4).** The effect of actual headlamps was statistically significant, $F(1,24) = 10.87$, $p = .003$, with the HID headlamps rated as better than the tungsten-halogen headlamps (4.4 vs. 3.7). The effect of prior headlamps was not significant, $F$ (1,24) < 1. The interaction between the actual and prior headlamps was significant, $F(1,24) = 6.11$, $p = .021$, with the HIDs rated as better than the tungsten-halogens primarily by subjects who had the HIDs as the prior headlamps in Task 1 (see Figure 7).

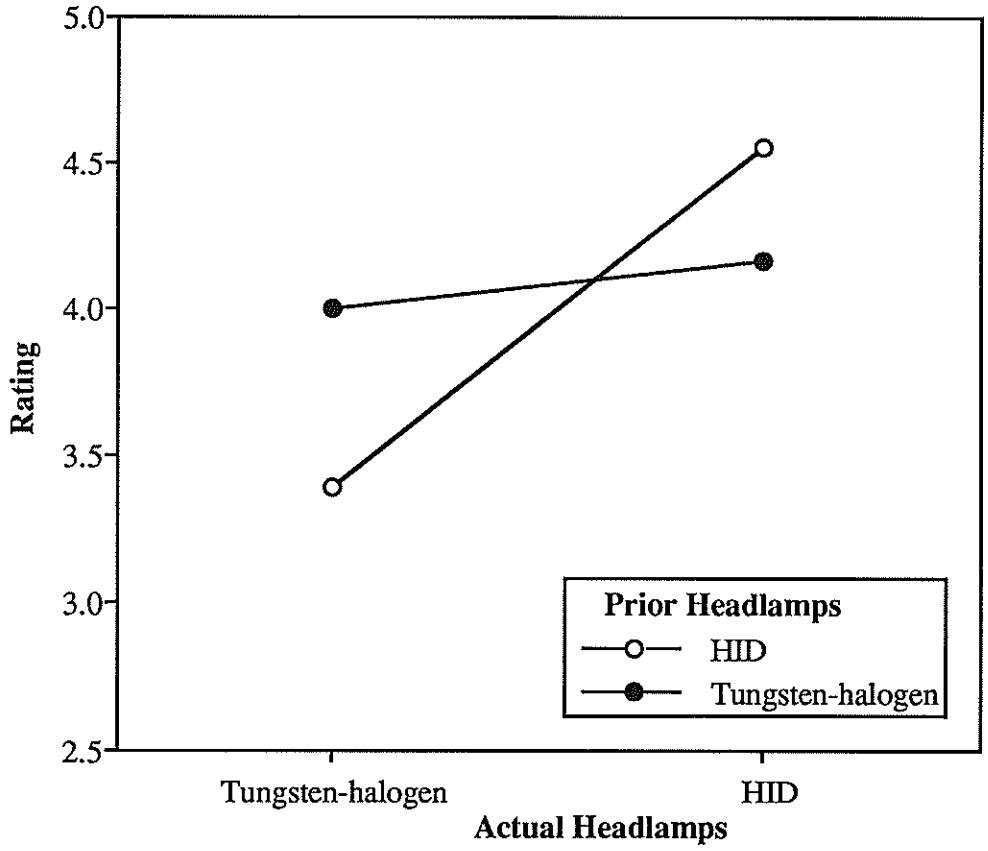



Figure 7. The effect of actual and prior headlamps on making stop signs stand out from their backgrounds. The ratings used the following five-point scale: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good.

**Performance of each lamp type in helping to see the colors of stop signs (Question 5).** The effect of actual headlamps was not statistically significant, $F(1,24) = 1.03$, $p = .320$, nor was the effect of prior headlamps, $F(1,24) < 1$. The interaction between the actual and prior headlamps was significant, $F(1,24) = 7.81$, $p = .010$, with the HIDs rated as better than the tungsten-halogens only by subjects who had the HIDs as the prior headlamps in Task 1 (see Figure 8).

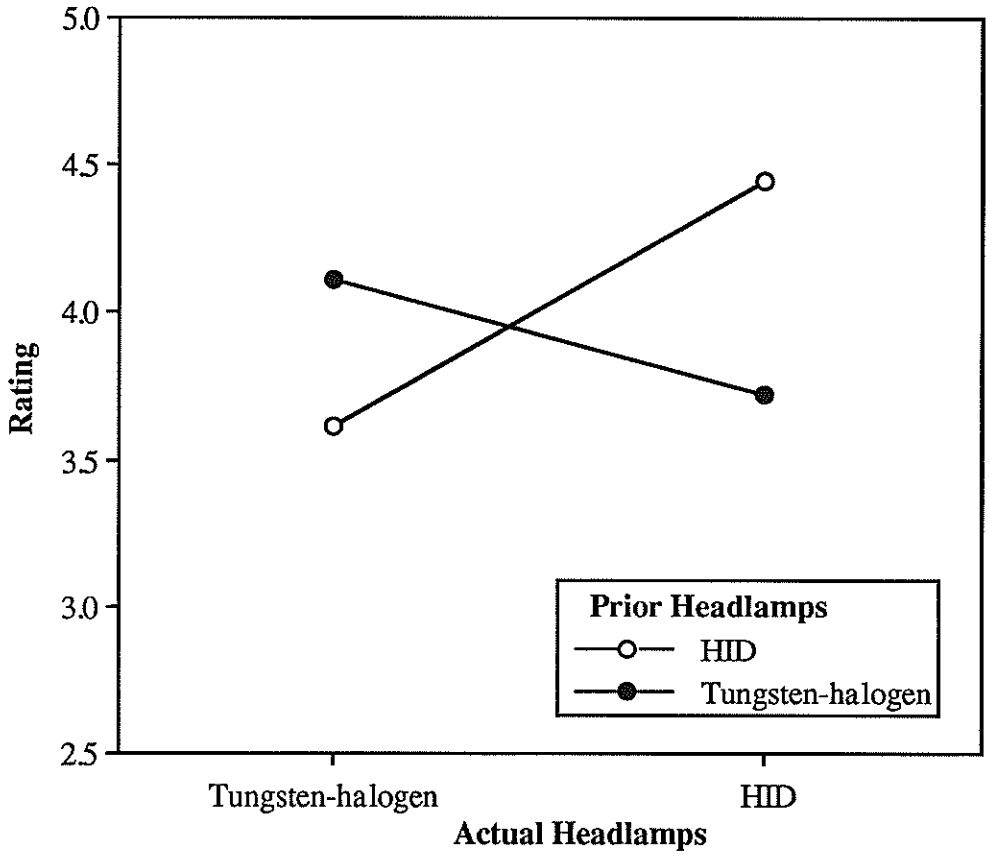



Figure 8. The effect of actual and prior headlamps on helping to see the colors of stop signs. The ratings used the following five-point scale: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good.

Table 5 summarizes the effects of actual headlamps and prior headlamps, as well as their interactions on the ratings.

Table 5.
Summary of the effects of actual and prior headlamps in Task 2.

| Question | Actual headlamps | Prior headlamps | Actual headlamps x prior headlamps |
|---|---|---|---|
| Rate the overall performance of each lamp type. | Significant | Not significant | Significant |
| Rate the performance of each lamp type in making objects in general stand out from their background. | Significant | Not significant | Significant |
| Rate the performance of each lamp type in helping to see the colors of objects in general. | Not significant | Not significant | Significant |
| Rate the performance of each lamp type in making stop signs stand out from their background. | Significant | Not significant | Significant |
| Rate the performance of each lamp type in helping to see the colors of stop signs. | Not significant | Not significant | Significant |

## DISCUSSION

This study evaluated subjects' impressions of performance of HID headlamps after in-traffic experience, with a special emphasis on color appearance of stop signs. The study involved two tasks. In Task 1 subjects drove (or rode) 19 km through a variety of roadway environments using either HID or tungsten-halogen low-beam headlamps. The instructions to subjects for this task did not mention color appearance. The second task involved a head-to-head comparison of HID and tungsten-halogen headlamps. In Task 2 subjects drove (or rode) twice along a 4-km route in a residential area, and they were instructed to pay attention to how colors of stop signs and other objects looked.

The main finding from Task 1 is that the subjects who experienced HID headlamps did not report more (or fewer) spontaneous negative comments on color appearance of stop signs or other objects than did the subjects who experienced tungsten-halogen headlamps. Furthermore, the evaluations of overall performance of the two types of headlamps were not different.

In the head-to-head comparison of Task 2 there was no evidence of problems with color appearance when using HID headlamps. Furthermore, subjects preferred HID headlamps in terms of overall performance, in making objects in general stand out from their background, and in making stop signs stand out from their background. However, for all three of these questions there were statistically significant interactions between the actual headlamps evaluated and the prior headlamps that the subjects were exposed to in Task 1. Specifically, the preference for HID headlamps was present primarily for subjects who had HID headlamps in Task 1. This finding suggests that a somewhat extended exposure (about 30 minutes/19 km) to HID headlamps is necessary for the HID preference to develop, since the 7-minute/4-km exposure in Task 2 did not appear to be sufficient for those subjects who had tungsten-halogen headlamps in Task 1.

The information in Figure 2 indicates that at the U.S. test points the luminous-intensity outputs of the HID headlamps were not substantially different from those of the tungsten-halogen headlamps. However, the HID headlamps provided more lateral-spread illumination. Consequently, the obtained differences in ratings between the two types of headlamps could be a consequence of the differences in luminous intensity. An alternative explanation is the difference in the spectral power distributions (see Figure 1). It is possible that the spectral power distribution of the HID headlamps leads to increased brightness contrast and/or color contrast for certain object/background combinations. This speculative explanation could account for the reported advantage of the HIDs in making objects stand out from their backgrounds, and this, in turn, could have resulted in the overall preference for the HIDs. However, the present study does not allow us to identify

whether the obtained subjective preferences for HID over tungsten-halogen headlamps are the consequence of differences in luminous intensity or spectral power distribution.

Previous studies found that HID headlamps result in substantial colorimetric shifts (Sivak et al., 1991; Flannagan et al., 1992) and that laboratory observers are sensitive to such shifts (Collins, 1988; Arens, Saremi, and Simmons, 1991; Sivak et al., 1992). The lack of negative findings in the present study concerning HID headlamps suggests that the resultant colorimetric shifts might not be of sufficient magnitude to cause a problem in actual driving. However, the present study did not use a performance measure, such as a frequency of missed stop signs; it was based on the assumption that if a colorimetric shift is large enough to affect performance, it will also affect subjective ratings. While this seems reasonable, it remains an assumption.

In summary, the results of this study provide no evidence of problems with color appearance of stop signs and other objects when using HID headlamps. Furthermore, the study indicates that observers perceive HID headlamps as helping stop signs and other objects to stand out from their backgrounds. Finally, the present results imply that, given a somewhat extended exposure to HID headlamps, drivers would prefer them over current tungsten-halogen headlamps.

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