UMTRI-2002-3

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Report No. UMTRI-2002-3
February 2002

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2002-3		
4. Title and Subtitle Driving Performance with and Preference for HID Headlamps		5. Report Date February 2002 6. Performing Organization Code 302753
7. Author(s) Sivak, M., Flannagan, M.J., Schoettle, B., and Mefford, M.L.		8. Performing Organization Report No. UMTRI-2002-3
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road 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 Adac Plastics, AGC America, Autoliv, Automotive Lighting, Avery Dennison, BMW, Corning, DaimlerChrysler, Denso, Donnelly, Federal-Mogul Lighting Products, Fiat, Ford, GE, Gentex, GM NAO Safety Center, Guardian Industries, Guide Corporation, Hella, Ichikoh Industries, Koito Manufacturing, Labsphere division of X-Rite, Lang-Mekra North America, LumiLeds, Magna International, North American Lighting, OSRAM Sylvania, Pennzoil-Quaker State, Philips Lighting, PPG Industries, Reflexite, Renault, Schefenacker International, Stanley Electric, TEXTRON Automotive, Toyota Technical Center U.S.A., Valeo, Vidrio Plano, Visteon, Yorka, 3M Personal Safety Products, and 3M Traffic Control Materials.
Information about the Affiliation Program is available at: http://www.umich.edu/~industry

16. Abstract

This in-traffic study evaluated driving performance with and preference for HID low beams. Subjects drove two identical luxury sedans. One vehicle was equipped with HID low beams and the other with tungsten-halogen low beams. The main difference between the two beams was that the HID lamps provided more spread light. Driving performance was evaluated by analyzing steering frequencies. The hypothesis was that the wider beam pattern of the HID lamps would be beneficial by reducing the steering effort in the 0.3 to 0.6 Hz range, which has been used in previous studies as an index of steering-task difficulty.

The main finding is that the wider HID beam pattern made lane maintenance less demanding, as measured by a reduction in the steering frequencies between 0.3 and 0.6 Hz. The implication is that HID headlamps may be beneficial to safety, because their wider beam pattern allows more of the limited information processing resources of drivers to be allocated to other tasks.

When the subjects were not primed before driving to pay attention to the headlamps, they did not show, as a group, preference for either type of lamp. However, when they were told to pay attention to the headlamps, they overwhelmingly preferred the HID lamps.

17. Key Words		18. Distribution Statement
high-intensity discharge headlamps, HID headlamps, low beams, passing beams, steering, frequency analysis, Fourier transform, photometry		Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	18	

Acknowledgments

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

Adac Plastics
AGC America
Autoliv
Automotive Lighting
Avery Dennison
BMW
Corning
DaimlerChrysler
Denso
Donnelly
Federal-Mogul Lighting Products
Fiat
Ford
GE
Gentex
GM NAO Safety Center
Guardian Industries
Guide Corporation
Hella
Ichikoh Industries
Koito Manufacturing
Labsphere division of X-Rite
Lang-Mekra North America
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Reflexite
Renault
Schefenacker International
Stanley Electric
TEXTRON Automotive
Toyota Technical Center U.S..A.
Valeo
Vidrio Plano
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

We would like to thank Mike Hagan for instrumenting the test vehicles.

Contents

Introduction

High-intensity discharge (HID) headlamps have several advantages over tungsten-halogen headlamps, including greater light efficiency (lumens per watt) and longer life. However, from the human factors point of view, the primary attraction of HID headlamps is the promise of more illumination.

The consequences of more headlamp illumination depend on where the extra light is directed. Extra light down the road (i.e., near the horizontal) should result in longer detection distances of pedestrians and other low-contrast critical objects. Brighter foreground should yield a more pleasing beam pattern. Wider spread of illumination should lead to better detection of objects in curves and at intersections, and to easier road-tracking performance.

The potential benefit of a wider beam pattern in decreasing the workload required for road tracking was the primary focus of this study. The hypothesis was that additional light directed towards the road delineation at intermediate distances should make road tracking easier, thus allowing some information processing capacity to be shifted from tracking to other driving-related tasks. The secondary focus of this study was to evaluate driver preference for HID versus tungsten-halogen low beams.

Background

Steering performance as an indicator of driver workload

Frequency analyses of steering behavior indicate that virtually all steering frequencies are below 1 Hz, with a majority of energy being between 0.1 and 0.6 Hz (McLean and Hoffmann, 1971, 1973; Wierwille, Gagne, and Knight, 1967). Furthermore, two frequency bands tend to characterize different aspects of driver steering behavior (McLean and Hoffmann, 1971):

- A peak in the frequency band between 0.1 and 0.2 Hz corresponds to preview steering.
- A peak in the frequency band between 0.3 and 0.6 Hz corresponds to compensatory steering.

Blaauw (1984) calculated the proportion of energy in the higher frequency band (0.3 to 0.6 Hz). His results suggest that there is a shift to these higher frequencies when task demands for lateral control are increased because of narrower lanes, higher speeds, or restricted preview. The effect of restricted daytime preview on steering frequencies was also obtained by McLean and Hoffmann (1973). Conversely, Schumann (2000) found that increased nighttime preview (provided by post-mounted delineators) decreased the proportion of steering energy in the 0.3 to 0.6 Hz band.

Based on the findings above, we selected the proportion of energy in the 0.3 to 0.6 Hz band out of energy in the 0.1 to 0.6 Hz band as an index of task workload, with the lower proportion indicating easier workload (and thus more desirable).

Driver preferences for HID versus tungsten-halogen low beams

In 1993, we published a study on in-traffic evaluation of HID headlamps (Sivak, Flannagan, Traube, Battle, and Sato, 1993). In the first of two experiments, subjects drove or rode through a variety of roadway environments in an HID- or tungsten-halogen-equipped car, but with no prior knowledge that the study was intended to investigate headlighting. The beam patterns of the two systems were similar. No preference for either type of headlamps was found in the first experiment.

In the second experiment, the same subjects participated in a head-to-head comparison of HID and tungsten-halogen headlamps, with all subjects experiencing both types of headlamps. The instructions asked subjects to pay attention to the color rendition provided by the headlamp illumination. The results showed that the subjects who had the more extensive experience with the HID headlamps in the first experiment overwhelmingly preferred the HID over the tungsten-halogen headlamps. The subjects who did not have the more extensive experience with the HID headlamps in the first experiment (because they experienced the tungsten-halogen lamps) showed no preference.

The previous study (Sivak et al., 1993) used headlamps of a design that is now 10 years old. Current low beams tend to have sharper vertical gradients than those of a decade ago, and the HID lamps in the previous study were experimental lamps. Consequently, we decided to also include preference ratings in the present study, to investigate the effects of recent developments in both tungsten-halogen and HID beam patterns.

Method

Equipment

Two leased 2001 luxury sedans of the same model were used as subject vehicles. One of the vehicles was equipped with HID low beams and the other with tungsten-halogen low beams. Otherwise, the two vehicles had the same components, such as engine size, suspension, and tires.

The manufacturer of the headlamps provided us with photometry for the left and right lamps of both types for the model and year in question (for a total of four candela matrices). Figure 1 presents the difference in the combined illuminance on the road surface from the two HID lamps and the two tungsten-halogen lamps, mounted at the appropriate positions for the given vehicles. The positive values in Figure 1 favor the HID lamps, while the negative values favor the tungsten-halogen lamps.

As is evident from Figure 1, the HID lamps provided substantially more spread illumination (both at near and far distances). In addition, the HID lamps delivered more foreground illumination immediately in front of the vehicle (up to about 8 m). The tungsten-halogen lamps provided more foreground illumination from about 8 m to 20 m, and more illumination in a narrow cone straight ahead starting at about 35 m.

The vehicle instrumentation included a Trimble DSM21H 12-channel GPS receiver with a dual channel MSK beacon receiver for differential correction. Latitude and longitude were updated at 10 Hz; these variables were used to locate the route segments to be analyzed. A string pot wound around a spool on the steering column transduced the steering wheel angle. This signal was amplified to provide a full-scale range of ±100 degrees, anti-alias filtered (4 pole Butterworth with a cutoff at 10 Hz) and sampled at 40 Hz.

Fourier analysis was used to analyze the steering angle data. A discrete Fourier transform (DFT) was used to transform the sampled angular data into sinusoidal frequency data, based on angular changes between each sampled data point. The frequency range analyzed within the DFT was 0.1 to 0.6 Hz, with resolution of 0.003 Hz.

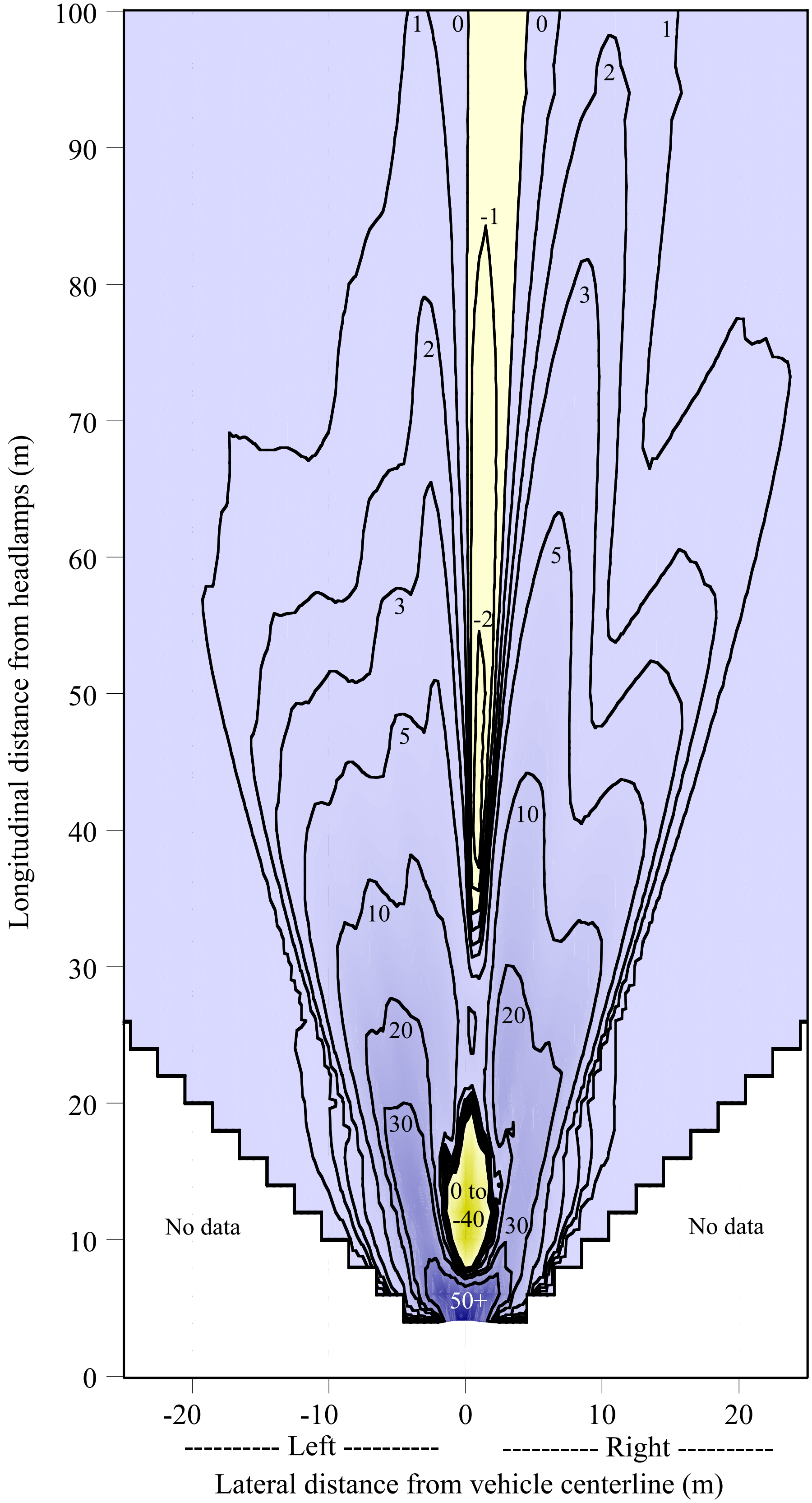

Figure 1. The difference in the combined illuminance (in lux) on the road surface from the two HID lamps and the two tungsten-halogen lamps, mounted at the actual vehicle positions. Positive values favor the HID lamps, while negative values favor the tungsten-halogen lamps.

Hypothesis

The basic hypothesis of the study was that the wider beam pattern of the HID headlamps should make the steering task less demanding (as measured by a decreased proportion of steering frequencies between 0.3 and 0.6 Hz), and thus beneficial because more of the driver's limited information processing resources could be allocated to other tasks.

Tasks

The study was performed at night on dry pavement**.** It consisted of two tasks, presented in different orders for each half of the subjects, as schematically illustrated in Figure 2.

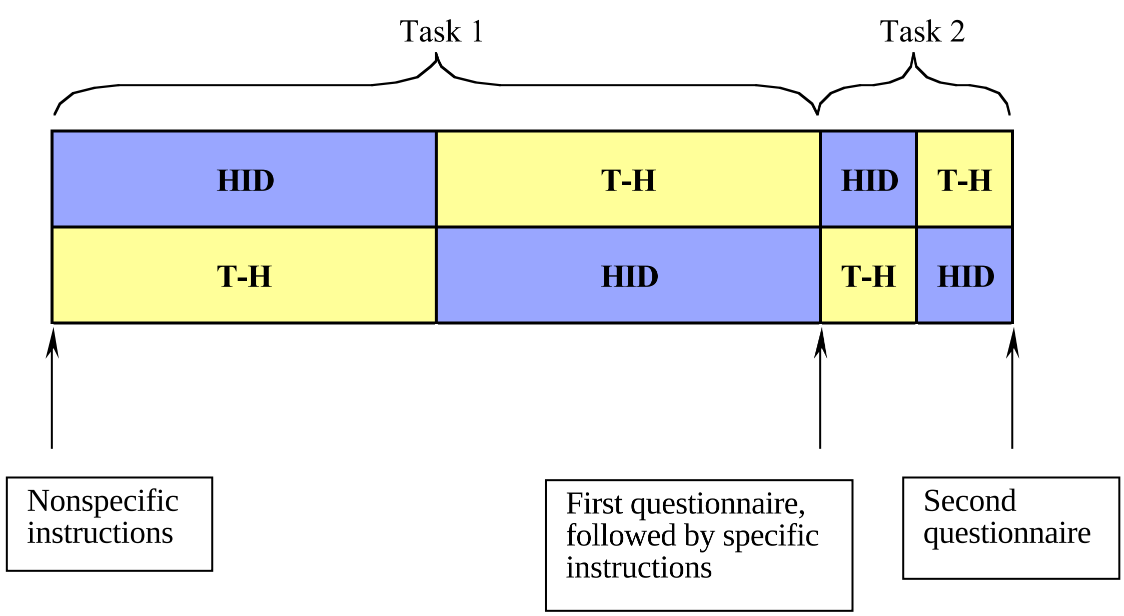

Figure 2. A schematic representation of the presentation orders of the two tasks. One half of the subjects received the order shown in the top bar, and the other half the order shown in the bottom bar.

Task 1. The first task involved in-traffic driving using both HID and tungsten-halogen low beams. The route was 20-km long, and it included a variety of roads (rural, urban, and limited-access). The instructions did not prime the subjects that the focus of the task would be on headlighting. The specific instructions were as follows:

> The purpose of this study is to measure several aspects of how people drive cars at night. In the study, you will be driving each of two cars over a predetermined route on nearby roads. Both cars have instruments for measuring detailed information about the movements of the cars on the road. Although your driving will be recorded, we would like to reassure you that the quality of your driving will not be evaluated in any way. The results that we are interested in have nothing to do with how good a driver someone is. Because we do not want to influence how you approach this experiment, we would prefer not to discuss details of what we are measuring until you have completed driving (at which time we will give you a complete explanation of what we are measuring and what we expect to find out). During the experiment we would like you simply to drive as you normally would.

After driving the route twice (once with each headlamp type), the subject was asked to compare the two cars on eight aspects: braking, acceleration, steering and handling, ride, seating, headlamps, visibility of instruments, and overall preference. The comparisons were made using an answer sheet that included a 120-mm-long horizontal line for each of the eight aspects (see Figure 3). The left end of the line was labeled "first car much better," the right end "second car much better," and the mid-point "no difference." The subject was instructed to indicate the degree of preference by making a mark anywhere on the line. Each response was quantified by measuring the distance along the line from the left edge.

|--|--|

First car much better No difference Second car much better

Figure 3. Response line used to compare the headlamps on the two runs in Task 1.

Sixteen paid subjects participated in this task. There were eight younger subjects (ranging from 21 to 26 years old, with a mean of 21.9) and eight older subjects (ranging from 63 to 76 years old, with a mean of 67.1). Each age group included four males and four females. All subjects were licensed drivers.

Task 2. The second task also involved in-traffic driving using both HID and tungsten-halogen low beams. The route in Task 2 was 5-km long, and it traversed a residential neighborhood. In contrast to the nonspecific instructions in Task 1, the subjects were primed to pay attention to the headlamps. The specific instructions were as follows:

> In the next part of the study, you will again drive each of the two cars, in the same order. This time, however, rather than simply driving, we would like you to concentrate on the headlamps of the cars and make some ratings of those lamps. In order to make it easier to compare the headlights, the two cars have been selected to be mechanically the same. The only differences between the two cars are the headlamps and the color of the body and the interior. In order not to influence your ratings of the lamps, I would rather not describe the ways in which the lamps are different until after you have made those ratings. Please just call them as you see them, and we will tell you all about the lamps and answer any questions that you might have after you have driven the cars again and made your ratings. As before, please just drive as you normally would, but this time pay special attention to the headlamps as you drive.

After driving the route twice (once with each headlamp type) the subject was asked to evaluate the following 12 performance aspects of each lamp type:

overall
making objects in general stand out
helping to see colors in general
making stop signs stand out
helping to see the red color of stop signs
performance on straight sections of road
performance on curves
performance in the foreground
performance in the distance, straight ahead
performance to the sides
evenness of light distribution
general appearance of colors

The evaluation of each aspect was performed using a five-point response scale (very good, good, fair, poor, very poor). The actual format in which the scales were presented to subjects is shown in Figure 4, using the item for "overall performance" as an example.

Rate the overall performance of each lamp type:

First lamp type:	**Second lamp type:**
Very Good	Very Good
Good	Good
Fair	Fair
Poor	Poor
Very poor	Very poor

Figure 4. A sample response scale for the evaluation of overall performance in Task 2.

Eight of the sixteen subjects from Task 1 participated in Task 2. There were four younger subjects (ranging from 21 to 22 years old, with a mean of 21.3) and four older subjects (ranging from 64 to 68 years old, with a mean of 66.5). Each age group included two males and two females.

Results

Steering performance

Steering performance was evaluated during Task 1 only. From the total route of 20 km, we selected three relatively dark and straight segments for analysis. The three segments totaled 7 km.

Figure 5 presents the average percentage of steering effort in the 0.3 to 0.6 Hz range (out of 0.1 to 0.6 Hz, the total range considered) for all 16 subjects. For each segment, the HID headlamps yielded a lower percentage of steering effort in the 0.3 to 0.6 Hz range than did the tungsten-halogen headlamps. Figure 6 presents the data averaged across the three segments. Analysis of variance showed that the effect of lamp type was statistically significant, $F(1,12) = 9.6$, $p < 0.01$.

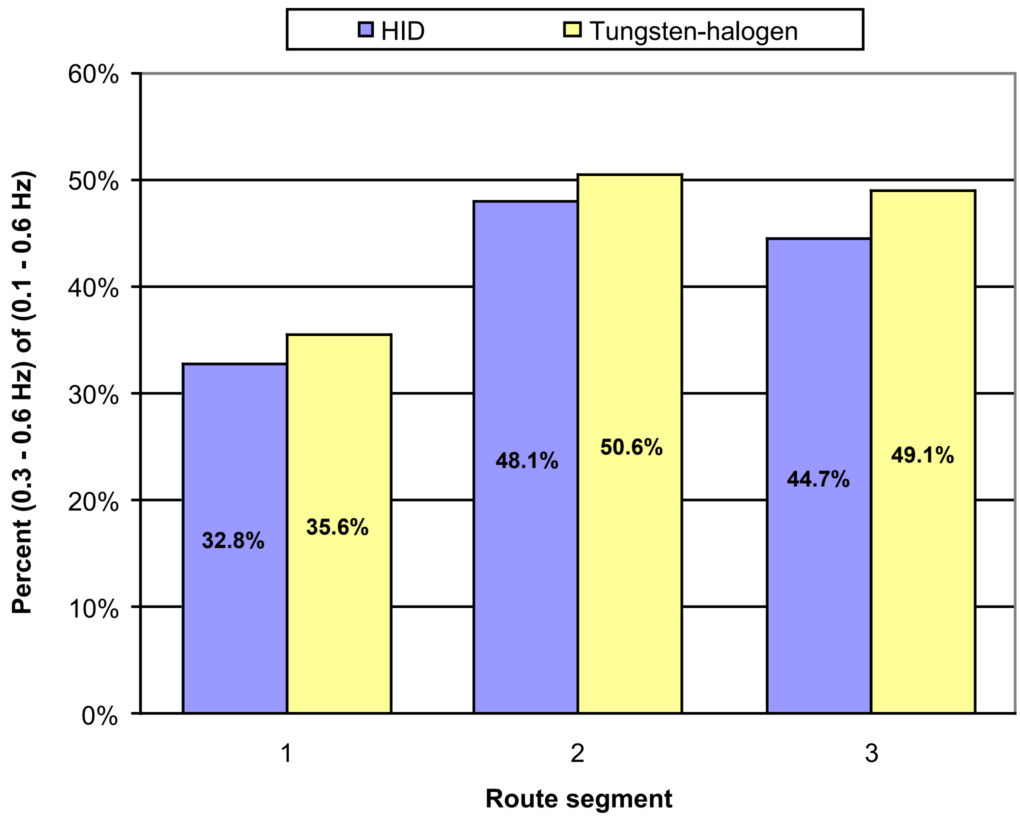

Figure 5. Percentage of steering effort in the 0.3 to 0.6 Hz range out of the total range of 0.1 to 0.6 Hz for each of the three route segments.

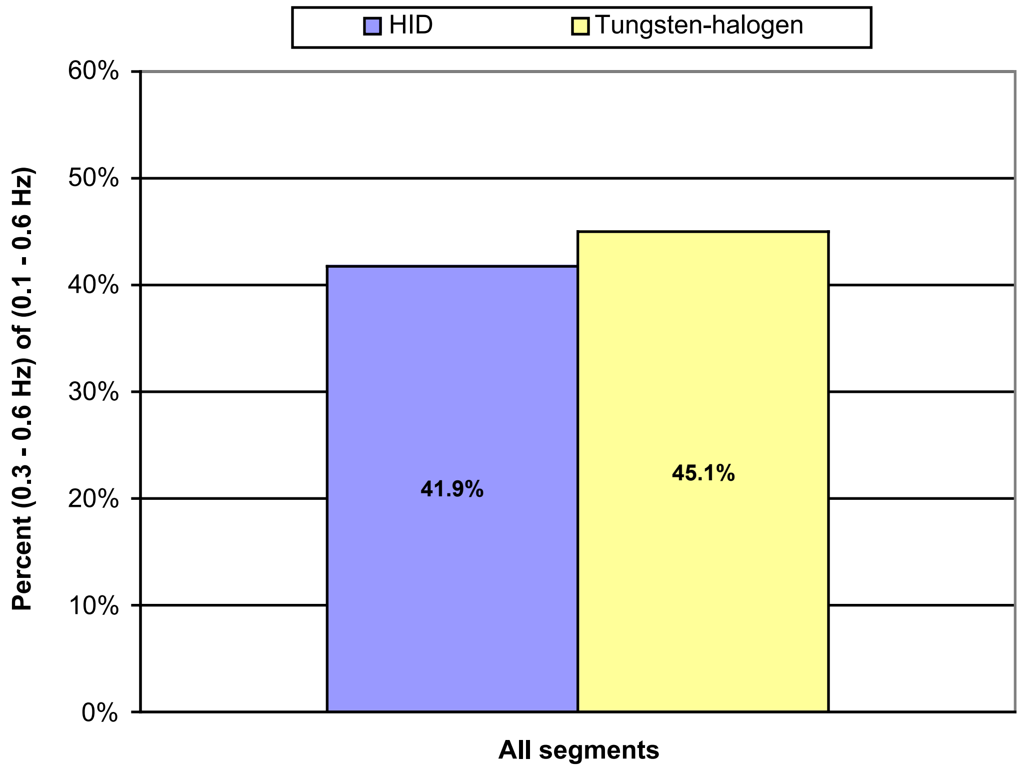

Figure 6. Percentage of steering effort in the 0.3 to 0.6 Hz range out of the total range of 0.1 to 0.6 Hz averaged across the three route segments.

Subjective preference

Task 1 (without priming). After driving the Task 1 route twice (once with each headlamp type), the subjects were asked to rate their preference between the two cars on eight different performance aspects. Table 1 lists subject preferences concerning the headlamps.

Table 1
Headlamp preference on Task 1 (without priming).

Headlamps preferred	Percent preferred
Tungsten-halogen	31
No preference	38
HID	31

Task 2 (with priming). After driving the Task 2 route twice (once with each headlamp type), the subjects were asked to rate 12 performance aspects of each lamp type using a five-point rating scale. Table 2 lists the mean responses by type of the headlamps. The entries in bold indicate differences that are statistically significant at $p = 0.05$ (using paired, one-tailed *t*-tests).

Table 2
Headlamp evaluation on Task 2 (with priming).
(1 = very good, 2 = good, 3 = fair, 4 = poor, 5 = very poor)
The entries in bold indicate statistically significant differences.

Aspect	HID	Tungsten-halogen
Overall	**1.1**	**2.5**
Making objects in general stand out	**1.2**	**2.6**
Helping to see colors in general	1.8	2.2
Making stop signs stand out	**1.2**	**2.1**
Helping to see the red color of stop signs	1.6	2.0
Performance on straight sections of road	1.4	2.0
Performance on curves	1.4	2.0
Performance in the foreground	1.6	2.2
Performance in the distance, straight ahead	**1.2**	**2.4**
Performance to the sides	**1.5**	**2.6**
Evenness of light distribution	**1.4**	**2.9**
General appearance of colors	**1.6**	**2.5**

Discussion

The main finding of this study is that the wider beam pattern provided by the HID headlamps made lane maintenance less demanding, as measured by a reduction in the steering frequencies between 0.3 and 0.6 Hz. This finding is consistent with a reduction in the steering effort in this range of frequencies obtained in situations that involve increased preview (e.g., Blaauw, 1984; McLean and Hoffmann, 1973; Schumann, 2000).

The subjects evaluated their preference for HID vs. tungsten-halogen headlamps under two sets of instructions: first without priming and then with priming that they should pay attention to headlamp performance. When they were not primed to pay attention to headlamps, there was no overall trend in headlamp preference. This is consistent with the generally accepted view that drivers do not spontaneously pay attention to headlamp performance. On the other hand, when they were told that the focus would be on headlighting, they overwhelmingly preferred HID headlamps. This preference for HID headlamps extended not only to those performance aspects that were based on the HID lamps providing more illumination for the functions in question (e.g., performance to the sides), but also to those aspects for which the HID lamps did not provide more illumination (e.g., performance in the distance, straight ahead). Additionally, the overall rating given to the HID lamps was more favorable than the rating given to any individual performance aspect. (The overall rating for the HID lamps was 1.1 on a 5-point scale; the ratings for the 11 individual performance aspects ranged from 1.2 to 1.8 [see Table 2].)

From the safety point of view, HID lamps would ideally deliver more light down the road at far distances (i.e., just below the horizontal and near the vertical). However, because of the current regulatory constraints imposed by glare maxima just above the horizontal, HID lamps will unlikely have more illumination just below the horizontal and near the vertical. (The HID lamps in this study actually produced less illumination in a narrow cone straight ahead than did the tungsten-halogen lamps.) The present results suggest that even if HID lamps do not have more light at far distances, they still may be beneficial to safety by providing more spread light.

Summary

This in-traffic study evaluated driving performance with and preference for HID low beams. Subjects drove two identical luxury sedans. One vehicle was equipped with HID low beams and the other with tungsten-halogen low beams. The main difference between the two beams was that the HID lamps provided more spread light. Driving performance was evaluated by analyzing steering frequencies. The hypothesis was that the wider beam pattern of the HID lamps would be beneficial by reducing the steering effort in the 0.3 to 0.6 Hz range, which has been used in previous studies as an index of steering-task difficulty.

The main finding is that the wider HID beam pattern made lane maintenance less demanding, as measured by a reduction in the steering frequencies between 0.3 and 0.6 Hz. The implication is that HID headlamps may be beneficial to safety, because their wider beam pattern allows more of the limited information processing resources of drivers to be allocated to other tasks.

When the subjects were not primed before driving to pay attention to the headlamps, they did not show, as a group, preference for either type of lamp. However, when they were told to pay attention to the headlamps, they overwhelmingly preferred the HID lamps.

References

Blaauw, G.J. (1984). *Car driving as a supervisory control task.* Soesterberg, The Netherlands: Institute for Perception TNO.

McLean, J.R. and Hoffmann, E.R. (1971). Analysis of drivers' control movements. *Human Factors*, *13*, 407-418.

McLean, J.R. and Hoffmann, E.R. (1973). The effects of restricted preview on driver steering control and performance. *Human Factors*, *15*, 421-430.

Schumann, J. (2000). *Post-mounted delineators and perceptual cues for long-range guidance during night driving* (Technical Report No. UMTRI-2000-42). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., Traube, E.C., Battle, D., and Sato, T. (1993). *In-traffic evaluations of high-intensity discharge headlamps: Overall performance and color appearance of objects* (Technical Report No. UMTRI-93-3). Ann Arbor: The University of Michigan Transportation Research Institute.

Wierwille, W.W., Gagne, G.A., and Knight, J.R. (1967). An experimental study of human operator models and closed-loop analysis methods for high-speed automobile driving. *I.E.E.E. Transactions on Human Factors in Electronics*, Vol. HFE-8, *No. 3*, 187-201.