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16. Abstract

Headlamps with high-intensity discharge (HID) sources produce more light than lamps with tungsten-halogen (TH) sources. The extra light offers the possibility of improving a driver's ability to see at night, which in turn may lead to better safety. Because low-beam headlighting necessarily involves a tradeoff between seeing and glare control, the extra light has also raised questions about the glare from HID headlamps. However, photometric analyses of the possible benefits of HID headlamps suggest that, in terms of the test points in U.S. Federal Motor Vehicle Safety Standard 108 (FMVSS 108), HID headlamps achieve both greater seeing light and lower glare levels.

The fact that HID lamps produce less glare in formal terms is at odds with the popular impression that they are more glaring than TH headlamps. One possible reason for this is that the test points in FMVSS 108 represent headlamp performance in static terms, without explicitly considering vehicle movement and road geometry. In contrast, the Comprehensive Headlamp Environment Systems Simulation (CHESS) model that was developed in the 1970s by Ford Motor Company is an attempt to evaluate headlighting performance under a wide range of real-world conditions. In this study, we applied the CHESS model to headlamps from surveys of U.S. headlighting for the 2004 model year that included TH and HID lamps.

The results indicate that: (1) HID headlamps as a group achieve substantially higher scores than TH lamps in terms of the CHESS overall figure of merit, which is intended to balance seeing and glare effects, (2) TH lamps produce a large range of discomfort glare effects and the HID lamps are within that range, although at the high end, and (3) differences among lamps, and the advantage of HID lamps over TH lamps, are more pronounced in the CHESS subscales that are intended to measure pedestrian visibility than in the CHESS overall figure of merit.

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Introduction

Headlamps with high-intensity discharge (HID) sources produce more light than lamps with tungsten-halogen (TH) sources. The extra light offers the possibility of improving a driver's ability to see at night, which in turn may lead to better safety. Because low-beam headlighting necessarily involves a tradeoff between seeing and glare control, the extra light has also raised questions about the glare from HID headlamps. However, photometric analyses of the possible benefits of HID headlamps indicate that, in terms of the test points in U.S. Federal Motor Vehicle Safety Standard 108 (FMVSS 108, 2007), HID headlamps achieve both greater seeing light and lower glare levels.

As part of an analysis of headlamps for the 2004 model year (Sivak, Schoettle, & Flannagan, 2004), we compared the light output of TH and HID lamps at some of the major photometric test points in FMVSS 108. Figure 1 shows data from that study. While HID lamps direct more light toward a key visibility test point (0.6° down, 1.3° right), they also direct *less* light toward a key glare test point (0.5° up, 1.5° left).

The fact that HID lamps produce less glare, in these formal terms, is at odds with the popular impression that they are more glaring than TH headlamps. One possible reason for this is that the test points in FMVSS 108 represent headlamp performance in static terms, without explicitly considering vehicle movement and road geometry. In contrast, the Comprehensive Headlamp Environment Systems Simulation (CHESS) model that was developed in the 1970s by Ford Motor Company is an attempt to evaluate headlighting performance under a wide range of real-world conditions (Bhise, Farber, Saunby, Troell, Walunas, & Bernstein, 1977). Since it was developed, several studies have used CHESS in headlamp evaluations (e.g., Bhise, Matle, & Hoffmeister, 1984; Perel, 1985).

In this study, we applied the CHESS model to headlamps from our recent surveys of U.S. headlighting for the 2004 model year, which included TH and HID lamps (Schoettle et al., 2004; Sivak, Schoettle, & Flannagan, 2004). Many issues are involved in comparisons between TH and HID lamps (e.g., Sivak, Flannagan, Schoettle, & Adachi, 2003), and CHESS analysis cannot settle all of them, but it appears that it might be useful as a supplement to simpler analyses based on static test points.

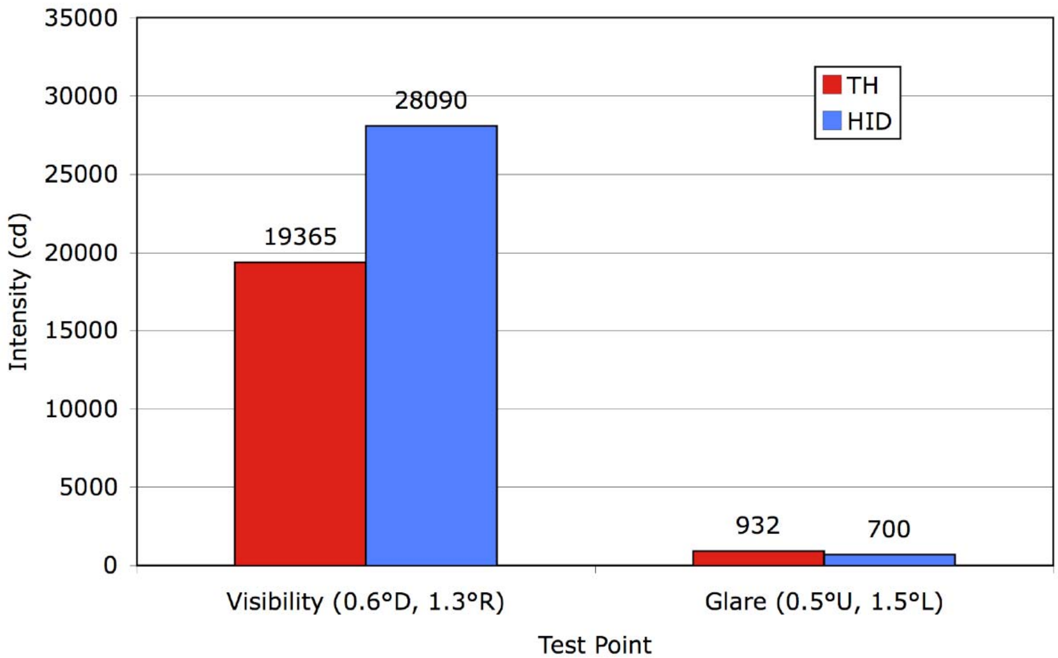

Figure 1. Light output of samples of TH and HID lamps for the 2004 model year at two key test points in FMVSS 108 (adapted from Sivak et al., 2004).

Method

Headlamps

We used headlamp photometric data from low-beam headlamps that we had photometered for two recent studies of headlighting on vehicles of the 2004 model year (Schoettle et al., 2004; Sivak et al., 2004). The TH lamps that we used were the lamps on the 20 best selling vehicles in the U.S. market, as described by Schoettle et al. (2004). The HID lamps were the lamps from the 5 best selling vehicles in the U.S. market for which HID low beams were offered as either standard or optional equipment, as described by Sivak et al. (2004). Table 1 summarizes the sources of the headlamp data.

Table 1
Headlamps used in the current study.

Study	Number and type
Schoettle, et al. (2004)	20 TH
Sivak, et al. (2004)	5 HID

Use of CHESS

Candela matrices for each headlamp were formatted as used by CHESS: a grid of test points at half-degree intervals, from 15 degrees left to 15 degrees right, and from 4 degrees up to 4 degrees down. CHESS was run for each individual lamp. In each case, the photometry for the lamp being evaluated was also used for the glare lamps that it was opposed by in the glare encounters simulated by CHESS. High beams were not evaluated. The CHESS overall figure of merit, as well as the primary subscales generated by CHESS, were recorded for each lamp. Those measures are listed and briefly described in Table 2.

Table 2
Measures generated by CHESS.

Measure	Description
Overall figure of merit	Based on all of the other measures, represents an attempt to balance visibility and glare effects of headlamps; higher numbers are better on this measure and on all of the others, except discomfort glare
Pedestrian visibility, unopposed	Measures visibility of pedestrians when oncoming glare is not present
Pedestrian visibility, opposed	Measures visibility of pedestrians in the presence of oncoming glare, includes the effects of disability glare
Delineation visibility, unopposed	Measures visibility of road edge lines when oncoming glare is not present
Delineation visibility, opposed	Measures visibility of road edge lines in the presence of oncoming glare, includes the effects of disability glare
Discomfort glare	Measures the effect of oncoming glare on visual comfort rather than on objective ability to see; is often, but not always, correlated with disability glare; higher numbers represent worse glare

Results and Discussion

The CHESS ratings for all 25 lamps (20 TH and 5 HID) are listed in Table 3, along with the means for the TH and HID groups. The means are presented graphically in Figure 2. The average figure of merit is 73.4 for the TH lamps and 79.0 for the HID lamps.

The pedestrian visibility measures are considerably lower than the values for the figure of merit, while the road delineation measures are considerably higher. This reflects the fact that pedestrians are hard to see relative to road delineation. As expected, visibility is worse for both pedestrians and road delineation when glare is present than when it is not. The gap between TH and HID lamps is greater for the pedestrian measures than for the overall figure of merit. This is partly because the discomfort effects of glare are not taken into account in the visibility measures (although the disabling effects of glare are included for the "opposed" measures).

Unlike the evaluations of TH and HID photometry that were based on FMVSS 108 test points (Sivak et al., 2004), the CHESS discomfort glare measure shows an advantage for the TH lamps. On the discomfort glare measure, for which higher numbers represent worse glare, the TH lamps averaged 3.9 and the HID lamps averaged 7.1.

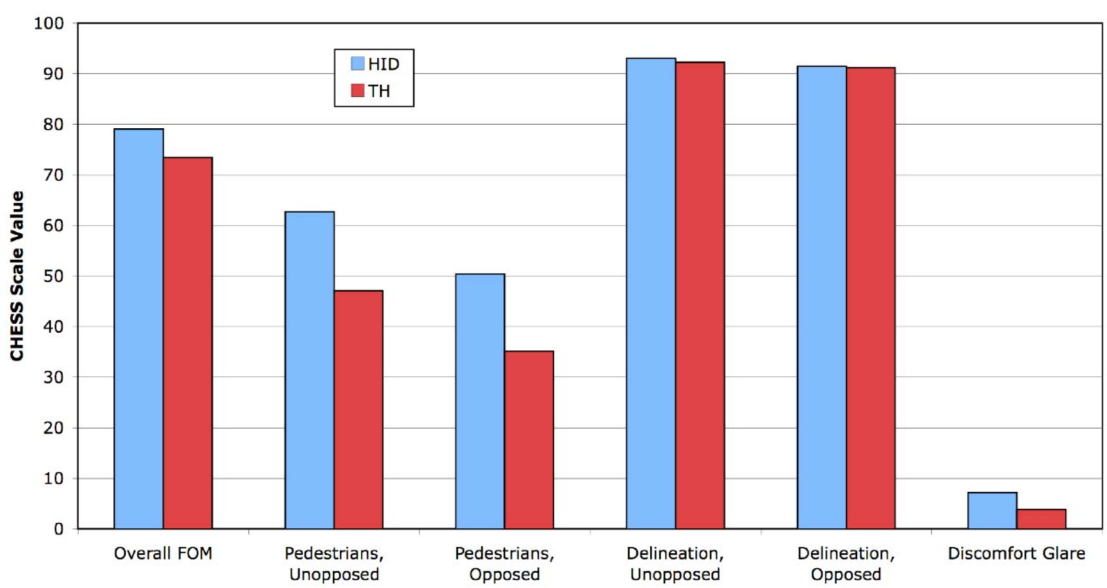

Figure 2. Average values for the groups of HID and TH lamps on the CHESS overall figure of merit (FOM) and on the five CHESS subscales.

Table 3

CHESS figure of merit and subscales for all 25 headlamps used in this study.

Source type	Overall FOM	Pedestrians unopposed	Pedestrians opposed	Delineation unopposed	Delineation opposed	Discomfort glare
TH	70.6	42.1	26.8	91.9	90.7	5.9
TH	76.9	51.8	41.1	93.7	93.0	3.3
TH	71.3	43.9	30.0	92.0	90.7	6.1
TH	76.5	54.0	42.2	92.7	91.4	4.6
TH	74.6	50.7	40.5	91.9	91.5	4.0
TH	75.3	48.4	38.0	93.2	92.4	2.5
TH	75.5	58.8	42.7	92.5	91.0	13.1
TH	74.5	45.6	38.3	92.4	91.7	1.0
TH	72.6	43.9	34.1	92.2	90.8	0.9
TH	71.8	44.6	34.1	91.5	90.8	1.9
TH	72.3	44.6	31.4	92.1	90.7	3.3
TH	71.9	45.4	31.5	92.0	90.5	5.5
TH	73.5	46.5	34.2	92.3	90.7	3.4
TH	73.1	45.3	37.5	91.6	91.0	0.9
TH	72.5	50.2	32.1	92.0	90.7	9.4
TH	72.1	43.5	30.8	92.0	91.4	1.4
TH	73.9	50.4	36.9	92.0	90.6	5.8
TH	69.2	35.4	24.8	91.4	90.9	0.4
TH	73.4	45.3	33.0	92.4	91.3	0.8
TH	76.4	50.8	42.2	92.8	91.5	3.0
TH means	73.4	47.1	35.1	92.2	91.2	3.9
HID	78.4	63.4	52.4	92.4	91.4	7.3
HID	79.6	63.7	50.8	93.3	91.1	8.8
HID	81.1	65.0	53.4	93.8	92.0	6.2
HID	76.4	61.3	48.0	91.9	90.9	8.5
HID	79.5	59.8	47.4	93.7	92.1	4.8
HID means	79.0	62.6	50.4	93.0	91.5	7.1

Further details about the relationship between the TH and HID groups of lamps can be seen in Figure 3, which presents a histogram of individual lamps for overall figure of merit. There is little overlap between the two groups: only the highest rated TH lamps are slightly above the lowest rated HID lamp. Figure 4 and Figure 5 present similar histograms for the unopposed and opposed pedestrian visibility measures, respectively. For these measures, the separation between the groups is even stronger. There is one virtual tie between the highest rated TH and the lowest rated HID on unopposed pedestrian visibility, and there is a substantial gap between the groups on opposed pedestrian visibility.

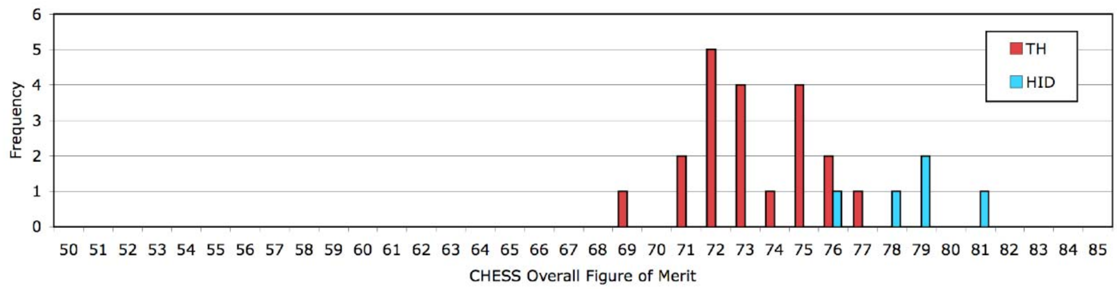

Figure 3. Histogram of scores on the CHESS overall figure of merit for individual TH and HID lamps.

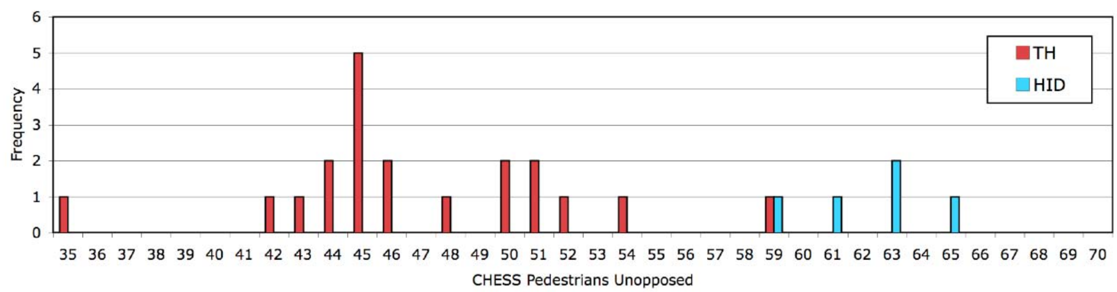

Figure 4. Histogram of scores on the CHESS pedestrians-unopposed subscale for individual TH and HID lamps.

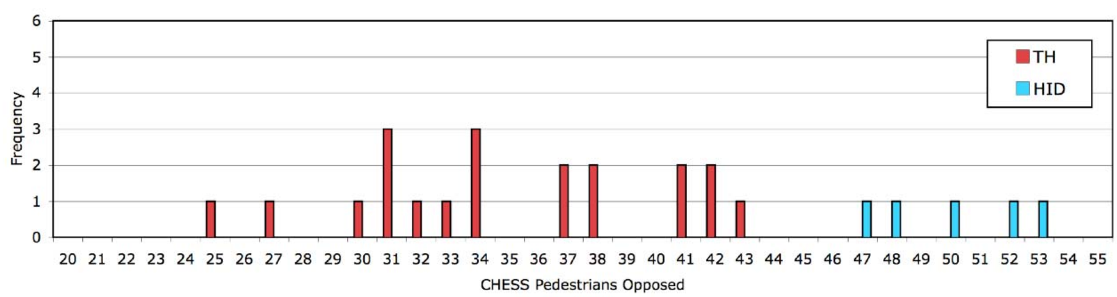

Figure 5. Histogram of scores on the CHESS pedestrians-opposed subscale for individual TH and HID lamps.

Figure 6 shows the relationship between discomfort glare and the overall figure of merit. Figure 7 shows a similar relationship between discomfort glare and the measure on which the TH and HID lamps are most clearly separated: opposed pedestrian visibility. In both sets of data, there is a positive correlation between discomfort glare and the visibility measure; that is, better visibility is associated with more discomfort. The correlation in Figure 6 is .37, and the correlation in Figure 7 is .43. On discomfort glare, the HID lamps fall in the upper range of the TH lamps, but they do not produce the most discomfort, and there is considerable overlap between the two groups on discomfort glare.

There does not seem to be evidence in Figure 6 or Figure 7 that the TH and HID lamps follow different relationships between visibility and discomfort glare. Although there is too much scatter in the data to allow for precise modeling, it may be that both the TH and HID lamps are part of a common sequence in which visibility and discomfort increase in some fixed proportion to each other. This is not surprising, because some of the factors that have been suggested to account for the popular impression that HID lamps are more glaring than TH lamps are not incorporated in CHESS. Examples include the blue-white color of HIDs (Flannagan, 1999) and the fact that HID lamps are often projector lamps, which present small illuminated areas and therefore high luminance (Schoettle, Sivak, Flannagan, & Adachi, 2002).

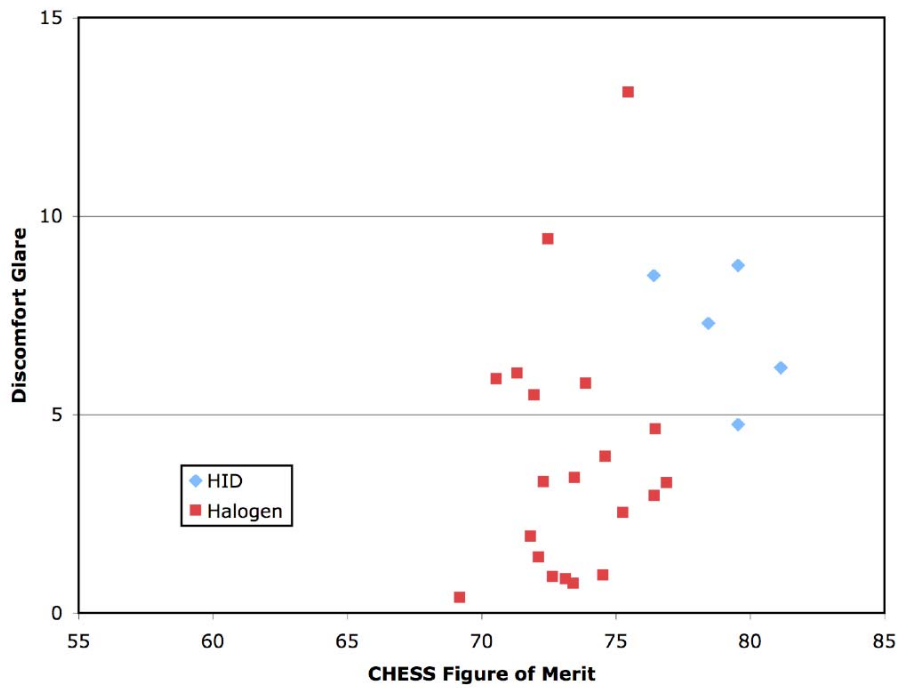

Figure 6. CHESS indices for discomfort glare (higher is worse) and overall figure of merit (higher is better).

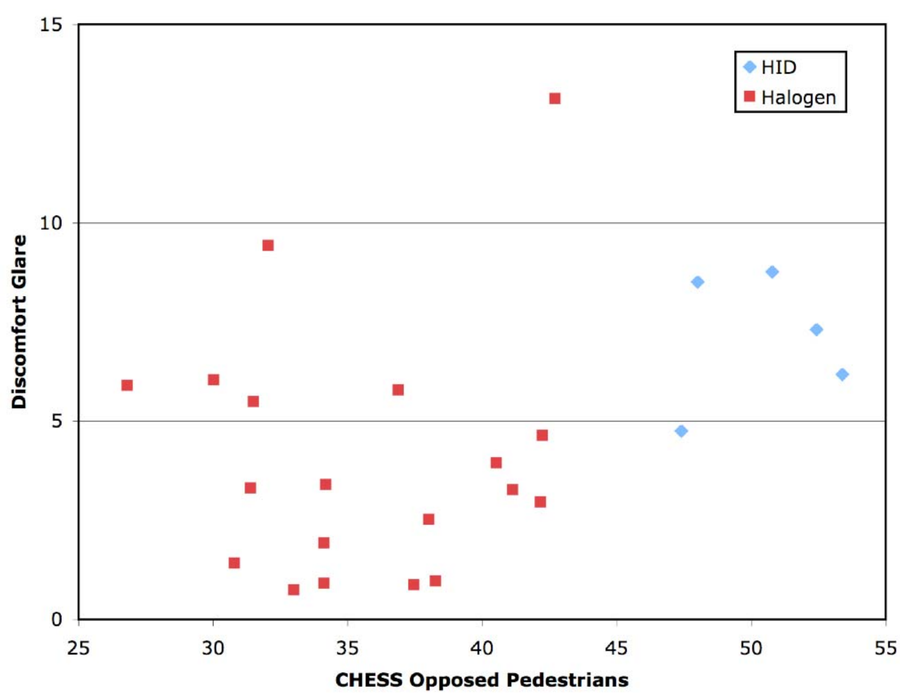

Figure 7. CHESS indices for discomfort glare (higher is worse) and pedestrian visibility in the presence of opposing glare (higher is better).

Summary and Conclusions

The results indicate that: (1) HID headlamps as a group achieve substantially higher scores than TH lamps in terms of the CHESS overall figure of merit, which is intended to balance seeing and glare effects, (2) TH lamps produce a large range of discomfort glare effects and the HID lamps are within that range, although at the high end, and (3) differences among lamps, and the advantage of HID lamps over TH lamps, are more pronounced in the CHESS subscales that are intended to measure pedestrian visibility than in the CHESS overall figure of merit.

Given the primary importance of pedestrian visibility for possible improvements in low-beam headlighting performance (Sullivan & Flannagan, 2002), it may be worth revisiting the way pedestrian visibility is weighted in the CHESS overall figure of merit. CHESS already weights pedestrian visibility heavily (Bhise et al., 1977), but perhaps not heavily enough. The present results illustrate that conclusions based on the overall figure of merit may be substantially different from conclusions based on the pedestrian visibility subscales.

CHESS evaluates headlamps by applying models of driver vision and visual discomfort from glare in thousands of simulated situations that are based on surveys of real-world roadway circumstances. Those circumstances include hills and curves, pedestrians in various locations, and the possible presence of glare from oncoming headlamps. In the present study, the CHESS results suggest that, on average, HID headlamps will produce somewhat higher levels of discomfort glare than TH headlamps. That is opposite the conclusion that might be reached from considering only light levels at static test points. Although CHESS itself is a complex system, and the real effects of headlamps are undoubtedly even more complex, it may be that the ability of CHESS to evaluate a reasonably representative set of roadway geometries accounts for the difference.

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