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A FIELD STUDY OF DISCOMFORT GLARE FROM HIGH-INTENSITY DISCHARGE HEADLAMPS

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16. Abstract

This study was designed to assess possible differences in the glare produced by tungsten-halogen and high-intensity discharge (HID) headlamps. Twelve subjects, three young females, three young males, three older females, and three older males, made de Boer ratings of discomfort glare for tungsten-halogen and HID lamps in a static field setup. The lighting conditions were similar to those seen while driving on a dark, two-lane road when glare from an oncoming car is encountered.

Analysis of the discomfort ratings indicates that when tungsten-halogen and HID lamps produce equal discomfort glare, the tungsten-halogen lamps will produce more photopic lux at the eye of the observer. The difference is approximately 0.30 log units. This difference is in the same direction as a prediction based on laboratory results for the effect of wavelength on discomfort glare, but it is considerably larger than the prediction. This discrepancy must be resolved before we can confidently predict how drivers will react to glare from HID headlamps in actual traffic.

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CONTENTS

INTRODUCTION

The spectral power distributions of high-intensity discharge (HID) headlamps consist mostly of lines, in contrast to the spectrum of a tungsten-halogen headlamp, which is continuous. Also, most HID spectra are weak in the long-wavelength region in comparison to a tungsten-halogen spectrum, which is strongly biased toward long wavelengths. The correlated color temperatures of HID lamps are thus generally higher than for tungsten-halogen headlamps. These differences have raised questions about possible perceptual effects of introducing HIDs as automotive headlamps, which until now have been exclusively tungsten-filament lamps. One specific issue that has been raised is whether HID headlamps have different discomfort glare properties. The present study is one of a series of experiments that we have conducted to address this issue.

We had previously conducted two laboratory studies designed to evaluate the discomfort glare properties of HID lamps (Flannagan, Sivak, Ensing, & Simmons, 1989; Flannagan, Sivak, & Gellatly, 1991). Those studies used monochromatic glare stimuli to derive a glare efficiency function analogous to the CIE luminous efficiency functions. The glare efficiency function closely followed the scotopic luminous efficiency function at a low level of background luminance (0.034 cd/m^2, near the middle of the mesopic range) and was about halfway between the scotopic and photopic luminous efficiency functions at a higher background level (3.4 cd/m^2, near the bottom of the photopic range). Our current best estimate of the state of dark adaptation of a driver using low beams on an otherwise dark road is equivalent to a uniform field at 1.0 cd/m^2 (Olson, Aoki, Battle, & Flannagan, 1990). These results therefore suggest that the relative amounts of discomfort glare produced by light sources with different spectra will not be predicted by weighting their spectral power distributions by the photopic luminous efficiency function, as is done in most conventional photometry, but by a function lying in between the photopic and scotopic luminous efficiency functions.

Results from the previous studies can be used to make approximate predictions for the relative discomfort glare produced by light sources of differing spectral distributions, including tungsten-halogen and HID headlamps. But the predictions are based on responses to monochromatic sources, and on the responses of subjects adapted to laboratory lighting conditions that were designed to be comparable to the lighting conditions seen by a driver at night, but that nevertheless could not completely reflect the real world. The purpose of the present study was to extend and validate the laboratory studies by measuring the relative discomfort glare produced by actual HID and tungsten-halogen headlamps under field conditions with lighting typical of actual night driving.

METHOD

Subjects

There were 12 subjects: 3 younger males, 3 younger females, 3 older males, and 3 older females. The younger group ranged from 19 to 23 with an average age of 21.0. The older group ranged from 62 to 76 with an average age of 70.8. The subjects were recruited from outside our institute and were paid for their participation. None of them were previously familiar with HID headlamps.

Apparatus

Subjects sat in an automobile equipped with standard tungsten-halogen lamps. The glare car was equipped with HID and tungsten-halogen lamps. A pair of lamps of each type was mounted in the standard arrangement, one lamp on each side of the front of the vehicle. Large neutral density filters of varying density were placed on the front surface of the lamp housings to produce five different illumination levels from each lamp type. The beam patterns of the two lamp types were different, and the amounts of illumination that they produced at the eyes of the observers could not be equated exactly, but we made them approximately equal by careful positioning of the glare vehicle. The unfiltered illuminances were then close enough that the ranges of illuminance produced by the neutral density filters overlapped substantially.

Field setup

Testing was conducted in a parking lot adjoining the UMTRI building. The area was very dark, with no artificial lighting in or near the lot. The subjects' vehicle and the glare vehicle were placed in fixed positions to simulate a meeting on a two-lane road with lanes 12 ft (3.66 m) wide. The distance from the headlamps of the glare car to the subjects' eyes was 150 ft (45.7 m). The intervening pavement was dry asphalt.

Stimuli

There were five lux levels for each of the two lamps types. The total range of glare illumination at the eye point of the observer was from 0.02 to 4.6 photopic lux, with the steps between stimuli equal on a log scale (about 0.6 log units per step).

Procedure

Subjects were run in groups of three, all sitting in the front seat of the subjects' car. Thus only one member of each group observed the glare stimuli from the driver's position, with the other two occupying front passenger positions. Previous discomfort glare field studies performed at UMTRI have indicated that there is no difference in discomfort glare across these positions (Sivak & Olson, 1988).

Subjects were seated in the vehicle and allowed to adapt to the prevailing lighting conditions for 10 minutes. During this time instructions were read to them. The low beam headlamps of the subjects' vehicle (tungsten-halogen lamps) were on throughout the experiment. The headlamps of the glare vehicle were off during this period, and were turned on for brief intervals on each of a set of trials as described below.

Twenty trials were presented to each group of subjects. Each subset of ten trials included all combinations of the two lamp types and the five illuminance levels. Those treatments were randomized within the subsets of ten, with each group of three subjects getting a different random order. On each trial the appropriate set of neutral density filters was placed over the headlamps and the lamps were turned on. On every trial, just before the lamps were turned on subjects were instructed to cover their eyes briefly (this was to eliminate any possible influence of a noticeable flash that accompanied each onset of the HID lamps). After the lamps were on, the subjects were instructed to open their eyes and to look straight ahead, i.e., just to the right of the glare source as if they were looking straight ahead in their lane of travel. Five seconds after the subjects began looking, the glare lamps were turned off. The subjects then immediately recorded a discomfort glare rating by writing a number from 1 to 9 on their data sheets. The numbers were ratings on the de Boer scale of discomfort glare (de Boer, 1967). This scale goes from 1 to 9, and has verbal anchors for each of the odd numbers as follows: (1) unbearable, (3) disturbing, (5) just acceptable, (7) satisfactory, and (9) just noticeable.

RESULTS AND DISCUSSION

The first 10 trials for each subject were regarded as practice and are not included in these summaries. Figure 1 shows the de Boer ratings averaged over all 12 subjects. The mean rating is shown for each of the five illuminance levels for each of the two lamp types. Ratings are shown as functions of log photopic lux at the subjects' eyes. Note that ratings are lower (indicating more discomfort) for the higher illuminance levels, as expected. Ratings are slightly curvilinear functions of log illuminance, as illustrated by the second-order polynomial fits shown in Figure 1. The most important aspect of the figure for our present purposes is the fact that the data for the tungsten-halogen lamps are always markedly higher than for the HID lamps. This indicates that when the lamps produce equal photopic lux at the eye of the observer, people will report more discomfort for the HID lamps.

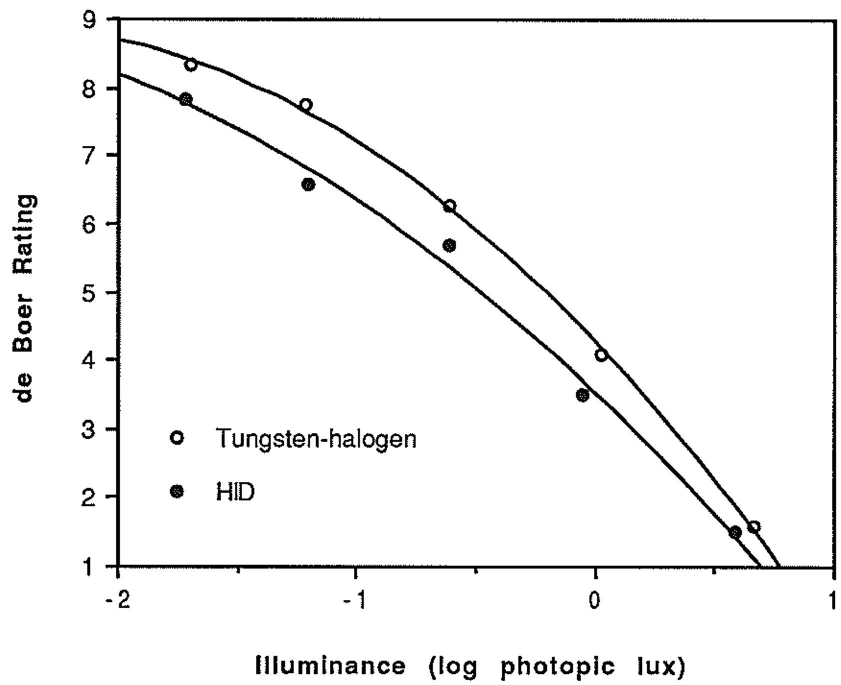

Figure 1. De Boer ratings for the two lamp types as functions of log photopic lux at the eyes of the observers. Data are means over all 12 subjects. Curves are the best-fitting second-order polynomial models for each lamp type.

In order to test the statistical significance of the difference between lamps shown in Figure 1, we fit second-order polynomial models, like the ones shown in Figure 1, to each subject's data individually. At the level of individual subjects, the curvilinear trends seen in Figure 1 are not as clear, but the fits are nevertheless quite good. Figure 2 shows a histogram of the r^2 values for all of the model fits (2 models for each of 12 subjects, yielding 24 models in all). Using the resulting equations, we calculated the predicted log photopic lux value that should yield a de Boer rating of 4.0 for each subject with each type of lamp. The value on the de Boer scale chosen for this analysis is somewhat arbitrary. The number 4.0 was chosen because it was near the middle of the range of ratings that subjects made, and because every subject had ratings spanning that value. For each subject we then computed the difference between log photopic lux for the tungsten-halogen lamps and log photopic lux for the HID lamps. The resulting values indicate the difference in photopic lux that should exist between tungsten-halogen and HID lamps that are equated for discomfort glare. A negative value indicates that HID lamps need to be more intense (in terms of photopic lux) than tungsten-halogen lamps in order to produce equal discomfort. Positive values indicate that the tungsten-halogen lamps need to be more intense than the HID lamps of equal discomfort.

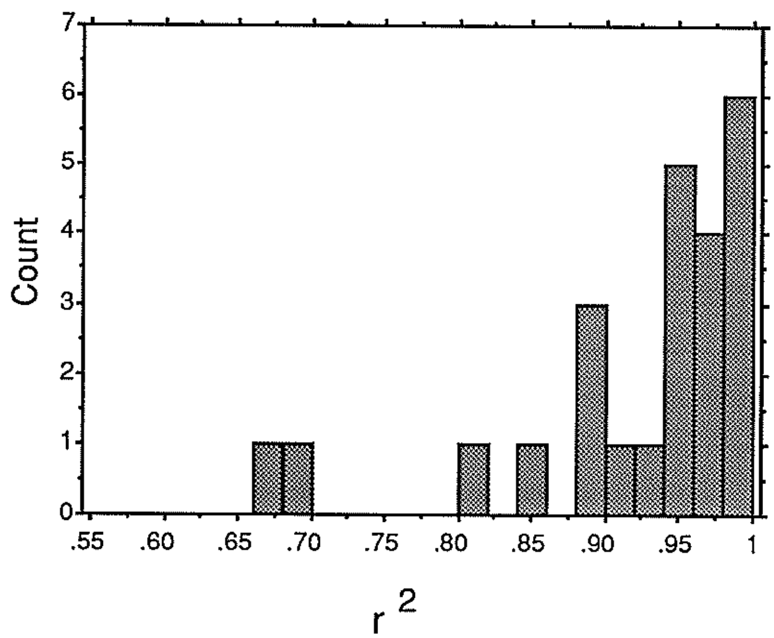

Figure 2. Distribution of r^2 values for quadratic fits to de Boer ratings versus log photopic lux. Models were fit for each of 2 lamp types for each of 12 subjects (24 models in all).

There were no effects due to sex or age in the resulting differences. The differences for all 12 subjects are plotted in Figure 3. The mean logarithmic difference is 0.30 (corresponding to a factor of 2.00), which is significantly different from 0.0, $t(11) = 2.95$, $p = .013$. Thus, on average, the tungsten-halogen lamps need to be more intense to produce glare equal to the

HIDs. Note however, that there is a considerable range across subjects. Two subjects have values below zero, indicating slight reversals of the overall trend. Also, there is one subject (a young female) who shows an effect in the direction of the overall trend, but is well beyond the group. We have no reason to exclude her data, but because she is an outlier it is interesting to consider what happens to the overall picture without her data. The mean difference is decreased to 0.22 (corresponding to a factor of 1.66), but, because the measurement error is reduced, the test against a value of 0.0 becomes even more significant, $t(10) = 3.14, p = .011$. The conclusion remains qualitatively the same: when lamps are equated in discomfort glare, the tungsten-halogen lamps will be producing more photopic lux.

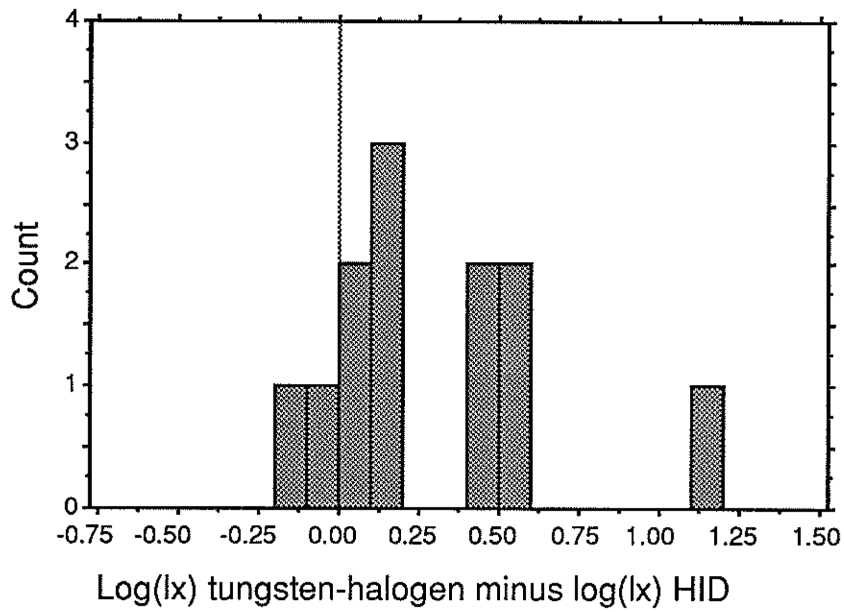

Figure 3. Individual subjects' values for the difference in predicted log photopic lux values for tungsten-halogen and HID lamps when the lamps are equated for discomfort glare (de Boer value 4.0).

Our laboratory investigations of the effect of wavelength on discomfort glare indicated that photopic values would not accurately determine discomfort glare, and that is qualitatively confirmed by the present results. However, in the present data the difference between the glare properties of tungsten-halogen and HID lamps is considerably greater than we would predict based on our laboratory data. The laboratory data indicate that discomfort glare should be approximately related to scotopic photometric values. If we make the simplifying assumption that discomfort glare is *exactly* related to scotopic values, we can then make a prediction for the data that were obtained empirically in this study. The logic goes as follows: We know the spectra for the HID and tungsten-halogen lamps (shown in Figures 4 and 5, along with the CIE scotopic and photopic luminous efficiency functions). We scale those spectra so that they produce equal values when convolved with the CIE scotopic luminous efficiency function. The scaled spectra should then represent two light sources capable of producing equal discomfort glare. We can then calculate the difference in photopic values for those two spectra by convolving them with the CIE photopic luminous efficiency function. The resulting prediction is that the log of the photopic value for tungsten-halogen minus the log of the photopic value for HID should be 0.037 (corresponding to a factor of 1.09). That is in the same direction as the empirical result (positive), but considerably smaller, even in comparison to the data after the outlier has been eliminated.

Currently we do not have a satisfactory explanation for this discrepancy between the laboratory and field results. We believe that both approaches are methodologically sound. If that is true, then they must somehow be reconciled before we can confidently predict how drivers will react to glare from HID headlamps in actual traffic. One intriguing difference between the laboratory and field glare-rating tasks is that the former was done in a relatively abstract context, whereas the latter was explicitly and strongly oriented to automobile headlighting. Subjects presumably brought their previous experience with the color of headlamps to the experimental situation, and they saw conventional headlamps interspersed randomly with HIDs from trial to trial. Perhaps the novelty of the HID lamps, and the contrast between them and the headlamps that the subjects were familiar with, amplified a difference in discomfort glare that might otherwise have been more in line with the laboratory results.

This hypothesis can be tested in further field studies by varying the context in which subjects make their glare ratings. For example, the hypothesis predicts that the difference between glare ratings for HID and tungsten-halogen headlamps should be reduced as HIDs become more familiar. Perhaps simply giving subjects greater experience with HIDs would reduce the difference that was observed in this study.

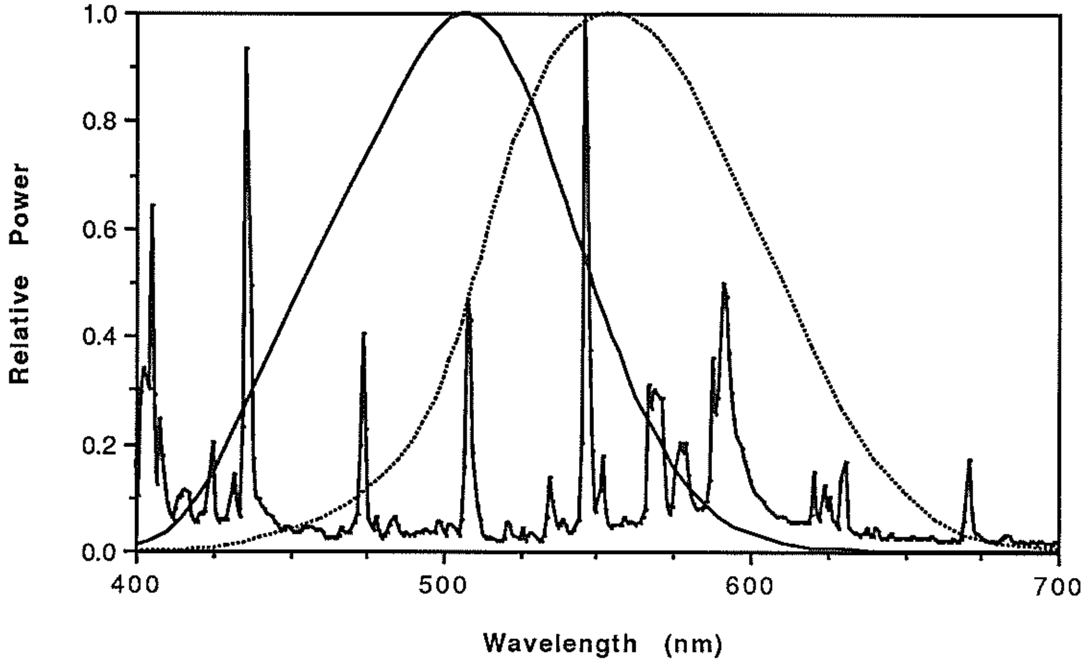

Figure 4. Relative spectral power distribution of the HID bulb used in this study (Philips D1). The CIE photopic (dotted curve) and scotopic (solid curve) luminous efficiency functions are also shown.

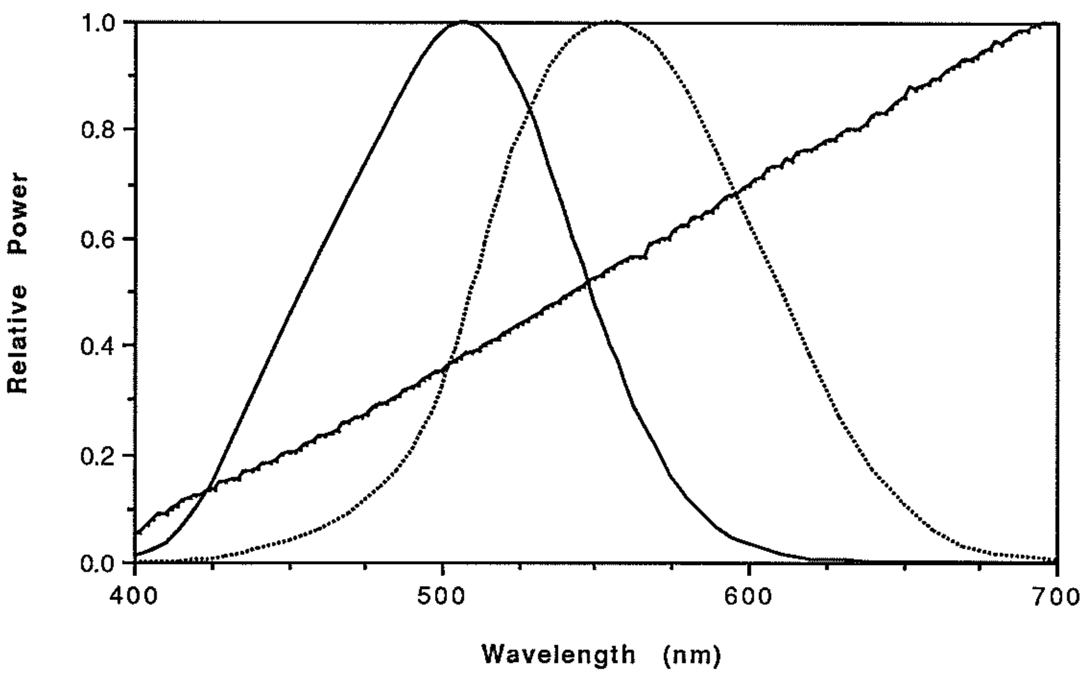

Figure 5. Relative spectral power distribution of a typical tungsten-halogen headlamp. The CIE photopic (dotted curve) and scotopic (solid curve) luminous efficiency functions are also shown.

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