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16. Abstract

This analytical study examined the effects of mounting height on discomfort glare from reduced-power high-beam daytime running lamps. Of interest were the effects for mounting heights between 0.864 m (34 in) and 1.372 m (54 in)—the range in which full-power low beams are currently allowed, but reduced-power high beams are not. Three analyses were performed. The first analysis involved estimating the illuminance reaching a preceding driver via rearview mirrors. The second analysis compared glare illuminance from reduced-power high beams to that from full-power low beams. The third analysis evaluated the expected changes in discomfort-glare ratings from reduced-power high beams as a function of increased mounting height. The analyses were based on photometric information from 5 high beams and 43 low beams, and they were performed for 5 following distances and 3 lateral offsets of the vehicles.

The results showed that allowing mounting heights from 0.864 to 1.372 m increased glare illuminance at following distances of 25, 50, and 100 m by less than 25%—an amount generally considered to be inconsequential. At following distances of 8.5 and 15 m the resultant illuminance increase was generally more than 25%. However, for some of the conditions at these following distances, the illuminance from reduced-power high beams was less than that from full-power low beams. Finally, for those conditions at 8.5 and 15 m in which high beams produced more illuminance than did low beams, the expected change in discomfort glare produced by high beams compared to that at the current maximum mounting height was found to be only modest.

The present findings indicate that allowing reduced-power high beams with mounting heights between 0.864 and 1.372 m would not appreciably increase discomfort glare for preceding drivers when compared to (a) glare from reduced-power high beams at a mounting height of 0.864 m, or (b) glare from currently allowed full-power low beams.

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Contents

Introduction

Current U.S. regulations allow a variety of lamps to be used as daytime running lamps (DRLs). Included among these lamps are high beams, but with the restrictions that the luminous intensity at H-V (the intercept of the horizontal and vertical axes) is no more than 7,000 cd, and that the mounting height is not greater than 0.864 m above the road surface (FMVSS, 1994, p. 219). These restrictions are based on concerns with rearview-mirror glare for preceding vehicles under conditions of dusk/dawn and heavy overcast during daytime (Kirkpatrick, Baker, and Heasly, 1987; Kirkpatrick and Marshall, 1989). On the other hand, when low beams are used at full voltage as DRLs, there is no DRL-specific mounting-height restriction. Consequently, the maximum mounting height for low-beam DRLs is 1.372 m (FMVSS, 1994, p. 307)—the same as for any conventionally used headlamps (high beam or low beam).

Of interest in this study was the above-mentioned mounting-height restriction for reduced-power high beams when used as DRLs. Because the maximum mounting height of headlamps is 1.372 m, this restriction requires dedicated DRL headlamps if (a) high-beams were to be used as DRLs, and (b) the mounting height of the standard headlamps on the particular vehicle was between 0.864 m and 1.372 m.

The limiting aspect of glare in automotive headlighting is generally discomfort as opposed to disability glare. Schmidt-Clausen and Bindels (1974) have developed a model for predicting the amount of discomfort experienced as a function of illuminance at the eye, glare angle, and adaptation luminance. However, this model cannot be used for setting the upper limit of glare illuminance because later studies have shown that discomfort glare is a function of additional factors, including the range of other stimuli present (Kirkpatrick et al., 1989), the angular size of the glare source (Sivak, Simmons, and Flannagan, 1990), and the difficulty of the driver's concurrent task (Sivak, Flannagan, Ensing, and Simmons, 1990). On the other hand, the model of Schmidt-Clausen and Bindels can be used to estimate the *relative* effects of changes in parameters of interest (i.e., changes in illuminance, glare angle, or adaptation luminance) on ratings of discomfort.

The present analytical study was designed to evaluate the effects of increasing the mounting height of high-beam DRLs from 0.864 m to 1.377 m. Three analyses were performed. The first analysis examined glare illuminance at the eyes of the preceding driver via rearview mirrors. The rationale was that if the difference in illuminance at a mounting height of interest and at the current maximum allowed height of 0.864 m is 25% or less, then the difference is not noticeable (Huey, Decker, and Lyons, 1994).

The second analysis examined the illuminance from reduced-power high beams to the illuminance from full-power low beams. The logic here was that glare illuminances from full-power low beams (at the mounting heights in question) are currently considered to be acceptable. Consequently, the illuminance from reduced-power high-beams would have to exceed the illuminance from full-power low beams by more than 25% to be of potential consequence.

The third analysis estimated the relative changes in discomfort glare for reduced-power high beams as functions of mounting height. The changes in discomfort glare were estimated by using a model developed by Schmidt-Clausen and Bindels (1974).

The analyses were based on photometric information from 5 high beams photometered for this study, and 43 U.S. low beams.

Method

Overview

The basic calculations involved computing the illuminance reaching the driver's eye point from reduced-power high beams and/or full-power low beams via all three rearview mirrors. Of interest were illuminances for mounting heights between 0.864 m (34 in) (the current maximum for reduced-power high-beam DRLs) and 1.372 m (54 in) (the current maximum for any headlamp). The illuminance values were then used to estimate changes in discomfort glare using an equation developed by Schmidt-Clausen and Bindels (1974). The calculations were performed for a range of following distances and lateral offsets of the vehicles. Table 1 lists the three specific analyses that were performed.

Table 1
The analyses performed as functions of mounting height.

Analysis	Description	Criterion
1	Illuminance from reduced-power high beams	Increase of more than 25% in comparison to 0.864 m
2	Ratio of illuminance from reduced-power high beams to illuminance from full-power low beams	Ratio of more than 1.25
3	Changes in discomfort glare using the de Boer scale	Increase in discomfort of more than 0.5 de Boer units

Table 1 also lists the criterion values that we used to evaluate the results of the analyses. The particular criteria selected are important because they determine the interpretation of the analyses. The selected criteria for the first two analyses were the same. Specifically, if the difference in illuminance were 25% or less, then the difference was considered not to be of practical consequence. This criterion was based on findings by Huey, Decker, and Lyons (1994) on just-noticeable differences.

The third analysis, evaluating discomfort glare, used as the criterion 0.5 units on the de Boer scale. The de Boer scale is a 9-point rating scale, with qualifiers only for the odd points as follows: 1 (unbearable), 2, 3 (disturbing), 4, 5 (just acceptable), 6, 7 (satisfactory), 8, 9 (just noticeable). Schmidt-Clausen and Bindels (1974) developed a model that predicts de Boer discomfort-glare rating as a function of glare illuminance, glare angle, and adaptation luminance. However, as indicated above, other factors (such as the range of other stimuli present, the angular size of the glare source, and the difficulty of a concurrent task) affect discomfort-glare ratings. Consequently, the Schmidt-Clausen and Bindels model cannot be used to estimate a universally applicable upper limit of tolerable glare illuminance. On the other hand, the model of Schmidt-Clausen and Bindels can be used to estimate the relative effect on discomfort glare of changes in a given parameter; we used it to estimate the changes in glare ratings as a function of changes in illuminance. The selected criterion of 0.5 units can be interpreted as one quarter of the difference between "just acceptable" and "disturbing," or one quarter of the difference between "satisfactory" to "just acceptable." In comparison, de Boer ratings have been shown to change by more than 1 unit in response to the range of other stimuli present (see Kirkpatrick and Marshall, 1989), 0.8 units in response to the difficulty of a concurrent task (Sivak, Flannagan, Ensing, and Simmons, 1991), 0.7 units in response to prior experience (Sivak, Olson, and Zeltner, 1989), and 0.2 units in response to the angular size of the glare source (Sivak, Simmons, and Flannagan, 1991).

The first analysis was performed for all conditions of interest. The second analysis was performed only for conditions that exceeded the criterion on the first analysis. Analogously, the third analysis was performed only for conditions that exceeded the criterion on the second analysis. A flow chart diagramming the interrelations of the three analyses is shown in Figure 1.

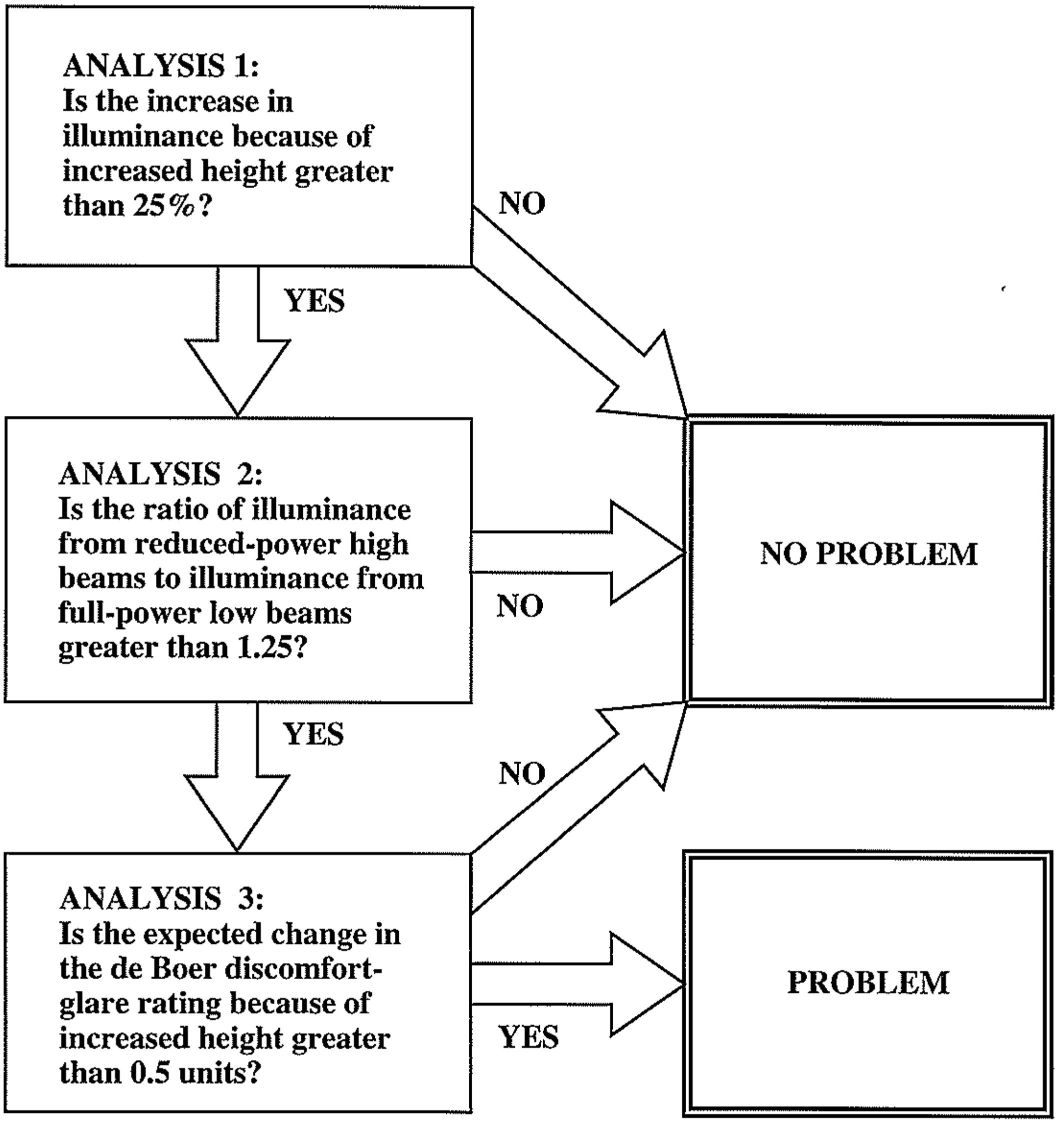

Figure 1. A flow-chart of the three analyses performed.

Rearview mirrors

Reflectance. We calculated the combined illuminance from all three rearview mirrors. It was assumed that the left outside and center inside mirrors were plane, and that the right outside mirror was convex. The reflectance levels chosen for the two plane mirrors were 50% (left outside) and 80% (center inside). The reflected illuminance from a convex mirror is a more complex matter. It corresponds to the square of the relative magnification, which, in turn, depends on the radius of the mirror, eye-to-mirror distance, and distance of the source of illumination from the mirror (Platzer, 1995). The reflected illuminance from a convex mirror is always less than the reflectance from a corresponding plane mirror. Platzer (1995) presents calculations showing that a reflectance of a typical convex mirror for objects at intermediate distances is about one fifth of a corresponding plane mirror. Thus, if we assume the reflectance of an outside plane mirror to be 50% (as used in our simulation for the left outside mirror), then a reasonable value for a typical right outside convex mirror is 10%. That is the value used in the present calculations.

Glare angle. There is evidence that discomfort glare is affected by glare angle (e.g., Schmidt-Clausen and Bindels, 1974). In our simulation, the differences in the glare angles for the left outside and center inside mirrors were relatively small (36° and 42°, respectively). The glare angle for the right outside mirrors was substantially larger (63°), but its contribution to the total illuminance was small because its reflectance was set at only 10%. Consequently, the present calculations disregarded the differences in glare angles for the three mirrors.

Location. The locations of the mirrors (as well as the field-of-view angles listed below) were selected to approximate those on a 1994 Ford Taurus. The locations are described in Table 2.

Table 2
Location of the rearview mirrors with respect to the driver's eye point.

Mirror	Mounting height (m)	Longitudinal distance from the driver's eye point (m)	Lateral separation from the driver's eye point (m)
Left outside	0.970	0.670	0.465
Center inside	1.230	0.470	0.410
Right outside	0.970	0.670	1.285

Fields of view. The field of view for the center inside mirror was set at ±20°, with the limiting factor being the width of the rear window. The fields of view for the left outside and right outside mirrors were set at -15° and +2.5°, and -2.5° and +28°, respectively.

Headlamp location

The following headlamp mounting heights were examined: 0.864, 0.966, 1.067, 1.168, 1.270, and 1.372 m (measured from the ground to the center of the lamp). (These values correspond to 4-inch steps from 34 inches to 54 inches.)

The headlamp separation was set at 1.22 m. This separation was used for both high beams and low beams.

Headlamp photometry

High beams. Five high beams were photometered for this study. The lamps included one of each of the following types: H4666, H5001, H5051, H6024, and H6054. The photometric information for each lamp consisted of a candela matrix in 0.5° steps from 20° left to 20° right, and from 5° down to 10° up. All lamps were measured at 12.8 V. The photometry was performed in 1995, and thus the high beams represent a sample of lamps from the mid 1990s. The data were normalized so as to have the highest luminous output at H-V. This was achieved by adjusting the horizontal and vertical coordinates, if needed. The luminous intensities were then scaled down so that the peak intensity (at H-V) was 7,000 cd—the maximum allowed for high beams used as DRLs.

Low beams. The low beams in this study included 43 lamps that are documented in detail in Sivak, Flannagan, and Sato (1994). The photometric information for each lamp consisted of a candela matrix in 0.5° steps from 20° left to 20° right, and from 5° down to 5° up. All lamps were measured at 12.8 V. The photometry was performed between 1990 and 1993, and thus the low beams provide a sample of lamps from the late 1980s and early 1990s.

Values used. The calculations for high beams and low beams used the corresponding median values at each test point.

Additional geometry considerations

Lane widths of 3.7 m were simulated. The glare car was always in the center of its lane. Three lateral offsets of the preceding car in relation to the glare car were simulated: -3.7, 0, and 3.7 m. These offsets represent the preceding car being in the centers of the left adjacent lane, the same lane, and the right adjacent lane, respectively.

Other, intermediate offsets are also possible, but they represent conditions that are likely to be more transient than the offsets corresponding to the centers of lanes.

Driver position

Driver eye height was set at 1.14 m from the ground, while the lateral displacement from the center of the vehicle was set at 0.41 m.

Windows

The attenuation through the rear window was taken into account in calculating the illuminance falling on the center inside mirror. Similarly, the attenuation through the side windows was included in deriving the illuminance reaching the driver from the side mirrors. The transmittance of the rear and side window glass was set at 75%.

Following distance

Five following distances were examined: 8.5, 15, 25, 50, and 100 m (measured from headlamp to the eye point of the preceding driver).

Results and Discussion

Analysis 1: Illuminance from reduced-power high beams at the driver's eye point

Tables 3 through 5 show the total illuminance reaching the preceding driver from all three mirrors as functions of mounting height, lateral displacement, and following distance. There are five noteworthy trends in relation to mounting height.

First, the total illuminance was generally an inverted-U-shaped function of mounting height, with the maximum not at the highest mounting height but near the mounting heights of the mirrors (0.97 m and 1.23 m).

Second, increasing the mounting height from 0.864 m to 1.372 m did not always increase the total illuminance.

Third, the maximum percentage increase in illuminance from that at 0.864 m tended to decrease with increasing following distance.

Fourth, for following distances of 25, 50, and 100 m, any illuminance increases were all less than 25% for all lateral offsets, and thus of insignificant practical consequence.

Fifth, for following distances of 8.5 m and 15 m, and lateral offsets of -3.7 m and 0 m, increases in mounting height from 0.864 m tended to result in an increase of more than 25% in the total illuminance. Consequently, for these two following distances and two lateral offsets we examined whether reduced-power high beams produce substantially more illuminance than full-power low beams. That analysis is presented in the next section.

Table 3
Total illuminance (lx) at the driver's eye point for lateral offset of -3.7 m (the preceding car is one lane to the left in relation to the glare car).

Following distance (m)	Mounting height (m)						Largest increase from 0.864 m (%)
	0.864	0.966	1.067	1.168	1.270	1.372	
8.5	0.49	0.62	0.61	0.46	0.38	0.30	27
15	1.11	1.31	1.62	1.77	1.76	1.61	59
25	1.18	1.24	1.30	1.36	1.38	1.38	17
50	1.12	1.14	1.16	1.18	1.18	1.17	5
100	0.92	0.93	0.94	0.94	0.94	0.92	2

Table 4
Total illuminance (lx) at the driver's eye point for lateral offset of 0 m (the preceding car is in the same lane as the glare car).

Following distance (m)	Mounting height (m)						Largest increase from 0.864 m (%)
	0.864	0.966	1.067	1.168	1.270	1.372	
8.5	28.06	39.07	39.98	38.01	32.58	23.19	42
15	21.14	25.68	28.07	28.73	27.47	24.14	36
25	12.40	13.71	14.15	14.21	13.68	12.47	15
50	5.05	5.14	5.10	5.06	4.97	4.80	2
100	1.37	1.38	1.37	1.37	1.36	1.34	1

Table 5
Total illuminance (lx) at the driver's eye point for lateral offset of 3.7 m (the preceding car is one lane to the right in relation to the glare car).

Following distance (m)	Mounting height (m)						Largest increase from 0.864 m (%)
	0.864	0.966	1.067	1.168	1.270	1.372	
8.5	0.94	1.00	1.06	1.15	1.03	0.69	22
15	2.26	2.43	2.62	2.69	2.71	2.76	20
25	1.95	2.08	2.12	2.11	2.09	2.05	9
50	1.42	1.44	1.45	1.47	1.47	1.47	4
100	0.80	0.81	0.81	0.81	0.82	0.82	2

Analysis 2: Ratio of the illuminances from reduced-power high beams to the illuminance from full-power low beams

Tables 6 and 7 present the ratios of the illuminance from reduced-power high beams to that from full-power low beams for mounting heights between 0.864 and 1.270 m. These calculations were performed only for following distances of 8.5 and 15 m, and for lateral offsets of -3.7 and 0 m, because the preceding analysis showed that only in these conditions were the changes in high-beam illuminance, as a function of mounting height, of potential consequence (see Tables 3 through 5).

The main findings of this analysis are as follows:

First, for both lateral offsets, the ratio of illuminance from high beams to that of low beams was, generally, a decreasing function of mounting height. As a consequence, this ratio was always smaller at the highest mounting height than at the lowest mounting height. In all instances, this ratio was less than 1 (i.e., high beams produced less glare illuminance than low beams) for the two greatest mounting heights.

Second, for lateral offset of -3.7 m (the preceding car in an adjacent lane to the left), in all but two tested situations the illuminance ratios were either less than 1 or were between 1 and 1.25 (and thus, from a practical point of view, in these situations high beams did not produce appreciably more glare illuminance than did low beams). The two exceptions for mounting heights above 0.864 m were ratios of 1.3 and 1.28.

Third, for lateral offset of 0 m (the preceding car in the same lane), the illuminance ratios were greater than 1.25 for all but one combination of following distance and mounting heights between 0.966 and 1.168 m.

For those conditions in which the ratio of the illuminance from high beams to the illuminance from low beams exceeded 1.25, we performed a third and final analysis. That analysis estimated the likely changes in discomfort glare from reduced-power high beams as functions of mounting height. That analysis is documented in the next section.

Table 6
Ratio of the illuminance from reduced-power high beams to the illuminance from full-power low beams for lateral offset of -3.7 m. (The entries in bold are ratios exceeding 1.25 for mounting heights greater than 0.864 m.)

Following distance (m)	Mounting height (m)					
	0.864	0.966	1.067	1.168	1.270	1.372
8.5	1.04	1.21	1.02	0.60	0.34	0.16
15	1.29	**1.30**	**1.28**	1.07	0.78	0.51

Table 7
Ratio of the illuminance from reduced-power high beams to the illuminance from full-power low beams for lateral offset of 0 m. (The entries in bold are ratios exceeding 1.25 for mounting heights greater than 0.864 m.)

Following distance (m)	Mounting height (m)					
	0.864	0.966	1.067	1.168	1.270	1.372
8.5	3.68	**3.67**	**2.26**	1.12	0.46	0.18
15	4.09	**3.71**	**2.52**	**1.53**	0.85	0.46

Analysis 3: Estimated changes in discomfort glare from reduced-power high beams as functions of mounting height

The data in Tables 6 and 7 indicate that the ratio of the illuminance from reduced-power high beams to the illuminance from full-power low beams exceeded 1.25 for seven combinations of lateral offset, following distance, and mounting height greater than 0.864 m. For these seven conditions we calculated the expected change in the de Boer discomfort-glare rating compared to the same condition, but at a mounting height of 0.864 m. The results of these calculations are shown in Table 8. (According to the model of Schmidt-Clausen and Bindels, the magnitude of the change in the de Boer rating as a function of a change in illuminance is the same regardless of the particular values selected for the glare angle and adaptation luminance.)

The main finding in Table 8 is that for all conditions examined, the increases in the mounting height resulted in changes in the de Boer discomfort-glare rating of less than our criterion of 0.5 units (compared to the ratings at a mounting height of 0.864 m—the current upper limit).

Table 8
Estimated change in the de Boer discomfort-glare rating for conditions in which the ratio of the illuminance from reduced-power high beams to the illuminance from full-power low beams exceeded 1.25. The calculations were made using the equation from Schmidt-Clausen and Bindels (1974).

Lateral offset (m)	Following distance (m)	Mounting height (m)	Difference in the de Boer discomfort-glare rating compared to mounting height of 0.864 m
-3.7	15	0.966	0.14
-3.7	15	1.067	0.33
0	8.5	0.966	0.29
0	8.5	1.067	0.31
0	15	0.966	0.17
0	15	1.067	0.25
0	15	1.168	0.27

Summary and Conclusions

This analytical study examined the effects of mounting height on discomfort glare from reduced-power high-beam daytime running lamps. The effects of interest were for mounting heights between 0.86 and 1.37 m—the range in which full-power low beams are currently allowed, but reduced-power high beams are not. Three analyses were performed. The first analysis involved estimating the illuminance reaching a preceding driver via rearview mirrors. The second analysis compared glare illuminance from reduced-power high beams to that from full-power low beams. The third analysis evaluated the expected changes in discomfort-glare ratings from reduced-power high beams as a function of increased mounting height. The analyses were based on photometric information from 5 high beams and 43 low beams, and they were performed for 5 following distances and 3 lateral offsets of the vehicles.

The results showed that allowing mounting heights from 0.864 to 1.372 m would increase glare illuminance at following distances of 25, 50, and 100 m by less than 25%—an amount generally considered to be inconsequential. At following distances of 8.5 and 15 m the resultant illuminance increase was generally more than 25%. However, for some of the conditions at these following distances, the illuminance from reduced-power high beams was less than that from full-power low beams. Finally, for those conditions at 8.5 and 15 m in which high beams produced more illuminance than low beams, the expected change in discomfort glare produced by high beams compared to that at the current maximum mounting height was found to be only modest.

The present findings indicate that allowing reduced-power high beams with mounting heights between 0.864 and 1.372 m would not appreciably increase discomfort glare for preceding drivers when compared to (a) glare from reduced-power high beams at a mounting height of 0.864 m, or (b) glare from currently allowed full-power low beams.

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