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Foreground Illumination from Headlamps: Effects on Visual Performance and Preference

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Abstract

Current design standards for low beam headlamps allow substantial flexibility regarding their luminous intensity distributions. Some headlamps produce high levels of foreground illumination, resulting in increased brightness of the roadway pavement near the vehicle, and this is often considered desirable or beneficial. Some drivers might prefer not only high but uniform foreground illumination. At almost any driving speed, however, objects within the foreground are likely too close to avoid by slowing down or steering. Additionally, published models of disability glare suggest that foreground illumination should negatively impact the visibility of objects located further ahead along the roadway while driving. To evaluate the role of foreground light level and uniformity level on preference and visisibility, several lighting scenarios were created having different levels of foreground illuminance and uniformity. Subjects in the study responded to the onset of small targets positioned in and along the road, ahead of the foreground, and they also judged the quality of the headlamp beam patterns. They preferred high, but not necessarily uniformly distributed, light levels in the foreground. However, their ability to detect targets was slightly worse with higher foreground light levels, although the decrement in performance was not statistically significnant. The results suggest that high foreground light levels have a negative or at best, very little, influence on detection of possible hazards while driving, yet they may convey a sense of improved lighting quality.

Keywords: ....headlamp, lamp, intensity, foreground, visibility, preference, uniformity

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ABSTRACT

Current design standards for low beam headlamps allow substantial flexibility regarding their luminous intensity distributions. Some headlamps produce high levels of foreground illumination, resulting in increased brightness of the roadway pavement near the vehicle, and this is often considered desirable or beneficial. Some drivers might prefer not only high but uniform foreground illumination. At almost any driving speed, however, objects within the foreground are likely too close to avoid by slowing down or steering. Additionally, published models of disability glare suggest that foreground illumination should negatively impact the visibility of objects located further ahead along the roadway while driving. To evaluate the role of foreground light level and uniformity level on preference and visisibility, several lighting scenarios were created having different levels of foreground illuminance and uniformity. Subjects in the study responded to the onset of small targets positioned in and along the road, ahead of the foreground, and they also judged the quality of the headlamp beam patterns. They preferred high, but not necessarily uniformly distributed, light levels in the foreground. However, their ability to detect targets was slightly worse with higher foreground light levels, although the decrement in performance was not statistically significnant. The results suggest that high foreground light levels have a negative or at best, very little, influence on detection of possible hazards while driving, yet they may convey a sense of improved lighting quality.

INTRODUCTION

Vehicle headlamps serve forward visibility when driving at night. Among the metrics used to characterize headlamp performance, detection distances to targets are perhaps the most common (e.g., Falge, 1934; Roper and Howard, 1938). Generally, photometric requirements for headlamps have been informed by research studies using such metrics. However, there is also increasing awareness and appreciation of the value of customer preferences with respect to the design of headlamp beam patterns.

For instance, the overall intensity of headlamps appears to be strongly related to driver subjective preference, or to subjective impressions of headlamp quality. Neumann and Stoll (1996) reported that the more light headlamps produced, the more likely they were to be rated as good or acceptable. O'Day et al. (1997), analyzed the photometric characteristics of headlamps that elicited different kinds of subjective ratings, and found that the width of the beam pattern was related to the likelihood that the headlamp pattern would be rated as strong or sufficient.

Uniformity, as well as overall light level also appears to be an important factor related to perceived quality of headlamp beam patterns. O'Day et al. (1997) compared the gradients of different illumination patterns and found that they could predict ratings of balanced or smooth appearance, in contrast to uneven or choppy appearance. Wang et al. (1995) stated that non-uniform beam patterns could be associated with increased driver discomfort.

Völker et al. (2003) found that the amount of illumination in the region of the pavement surface just ahead of the vehicle were most closely related to subjective impressions of the headlamp beam pattern. This finding is consistent with earlier research by Schumann et al. (1997), who found that the foreground illumination in one's own lane seemed to have the greatest influence on perceptions of uniformity of headlamp beam patterns.

The various research studies cited above lead to the conclusion that high and uniform levels of illumination, particularly in the foreground areas closer to the vehicle, are generally perceived as positive attributes when judging headlamp beam patterns. The reasons and justification for desiring high light levels well ahead of the vehicle are probably self-evident; such light levels assist in visual acquisition and response to potential roadway hazards. The reasons and justification for the positive perceptions of high and uniform illumination in the foreground are less clear. There do not appear to be any safety-related benefits to foreground illumination from headlamps (Flannagan and Flanigan, 2003). Since drivers need to view the forward scene at distances greater than a few meters ahead in order to see and respond appropriately to potential hazards, foreground illumination probably does not provide useful hazard-detection illumination. The visual foreground does, however, assist in lane-keeping maneuvers (Land and Horwood, 1995). Yet even when the visibility of the foreground is highly degraded, lane-keeping performance does not suffer (Land and Horwood, 1995), suggesting that only low levels of foreground illumination are necessary for lane-keeping. Based on the scattering theory of disability glare (Fry, 1954), high levels of foreground illumination might actually reduce forward visibility by serving as a glare source in the field of view that detracts from the visibility of objects further ahead. Flannagan et al. (1995) found that the presence of foreground illumination tended to result in reduced pedestrian detection distances on dry pavement, but not reliably. Flannagan et al. did not assess subjective impressions during their study.

The present report describes the results of a field study to assess, simultaneously, the subjective impressions from forward lighting systems with varying amounts and uniformity of foreground illumination, and the visual performance of subjects as they respond to targets located in the field of view.

METHODS

A static field study was performed along a paved asphalt surface using a vehicle parked behind a set of properly aimed halogen projector low-beam headlamps (Figure 1). Twelve subjects, aged from 24 to 46 years (with a median of 30) participated in the study. The headlamps were mounted on a rack alongside two sets of halogen auxiliary fog lamps, which were used to provide supplemental levels of foreground illumination in front of the vehicle between distances of 3 and 8 m (10 and 26 ft), within the region found by Völker et al. (2003) to be strongly related to subjective impressions of headlamp illumination. Both sets of auxiliary lamps produced similar amounts of foreground illumination, but they differed in the uniformity of that illumination. The auxiliary lamps were tilted downward in order to illuminate only the foreground as much as possible. All lamps were operated at 12.8 V dc.

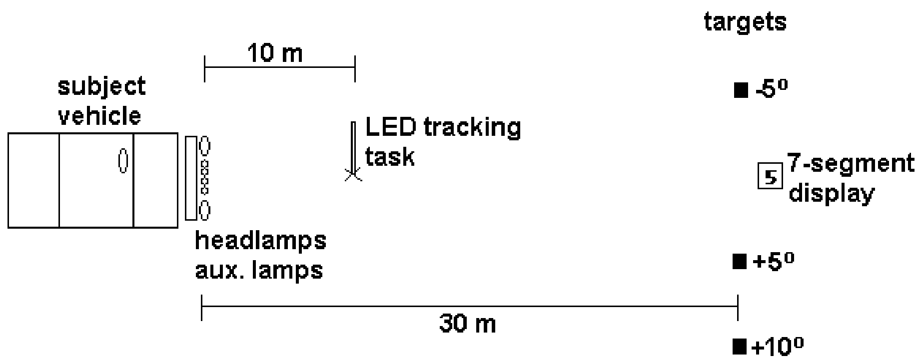

Figure 1. *Sketch of experimental setup.*

The targets were placed 30 m ahead of the vehicle at angular locations corresponding to 5° to the left (-5°), 5° to the right (+5°) and 10° to the right (+10°) of the center of the hypothetical driving lane. At an angular position of 0° (straight ahead), either a tracking task was positioned 10 m ahead, or a seven-segment numerical display was positioned 30 m ahead, depending on the session. Each served as the visual fixation point during different experimental session(s).

Because the auxiliary lamps contributed a small amount of illuminance onto the targets located 30 m ahead, the vertical aim of the headlamps was modified slightly for each condition in order to maintain as constant an illuminance as possible on each of the three targets. Figure 2 shows the mean illuminance distribution on the three targets for all experimental conditions.

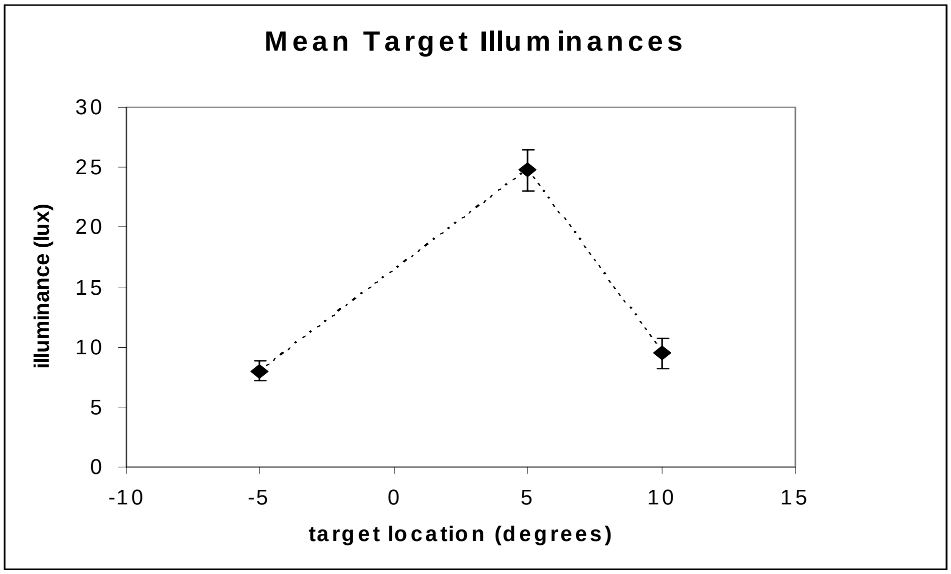

Figure 2. *Mean illuminances on the targets.*

Target Detection

For the target detection measurements, three foreground illuminance conditions were used in order to study the influence of the amount of foreground illumination:

- Headlamps alone (denoted HL)
- Headlamps plus the more uniform auxiliary lamp set (denoted HL+A)
- Headlamps plus the more uniform auxiliary lamp set plus the less uniform auxiliary lamp set (denoted HL+A+B)

Figures 3, 4 and 5 show the measured horizontal illuminance from each condition at distances from 3 to 8 m (10 to 26 ft) ahead of the vehicle, for a 2 m (6 ft) width ahead.

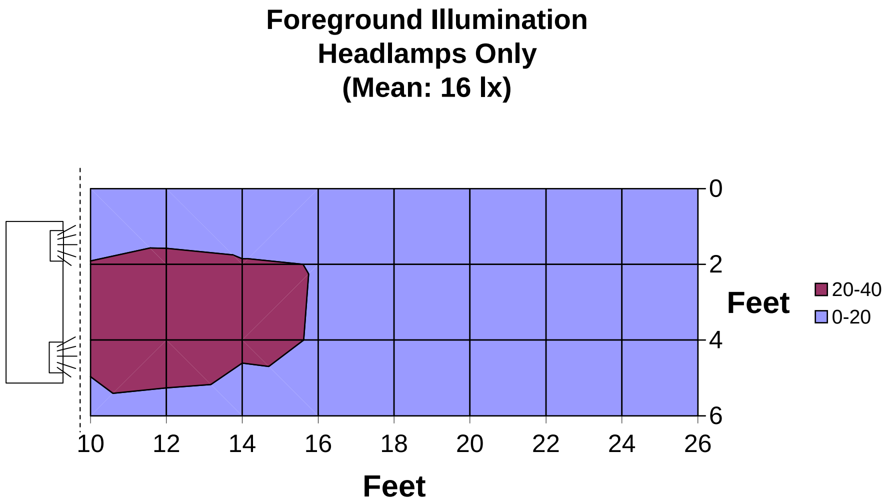

Figure 3. *Foreground illuminance (lx) from the HL condition.*

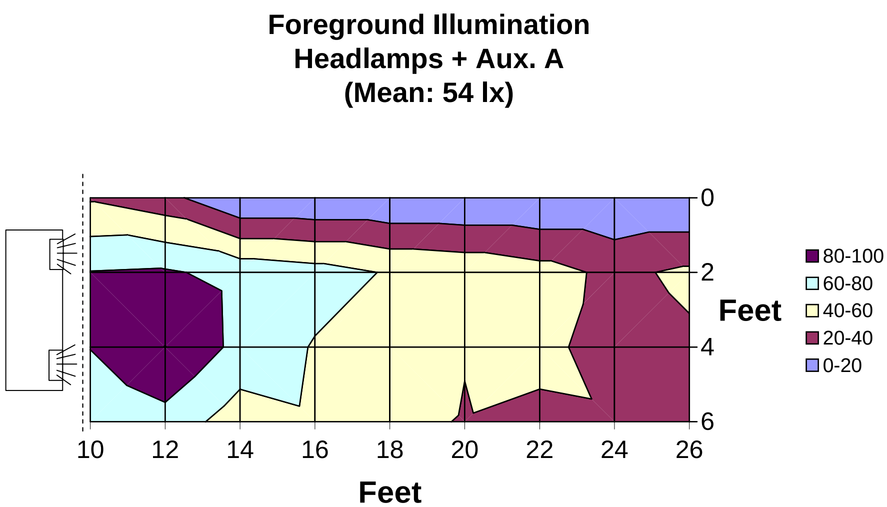

Figure 4. *Foreground illuminance (lx) from the HL+A condition.*

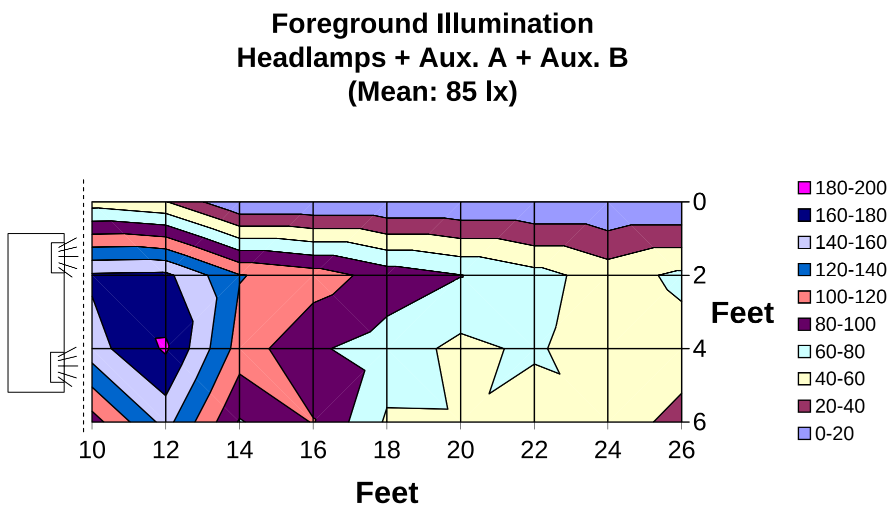

Figure 5. *Foreground illuminance (lx) from the HL+A+B condition.*

For each of these conditions, the tracking task located 10 m ahead was used as the secondary task and as a visual fixation point. Subjects were instructed to turn a knob on a handheld control box to adjust an array of red light-emitting diodes (LEDs) up or down, in order to center the array on a central amber LED. During pilot trials to test the apparatus, some subjects felt that this secondary task was difficult, so in order to assess the impact of the secondary task on visual detection, a fourth set of trials using only the HL condition were repeated during the main field study, in which a numerical display located 30 m ahead as a visual fixation point. Every second, the display showed a single digit in random order, and subjects were simply asked to look toward the display during these trials.

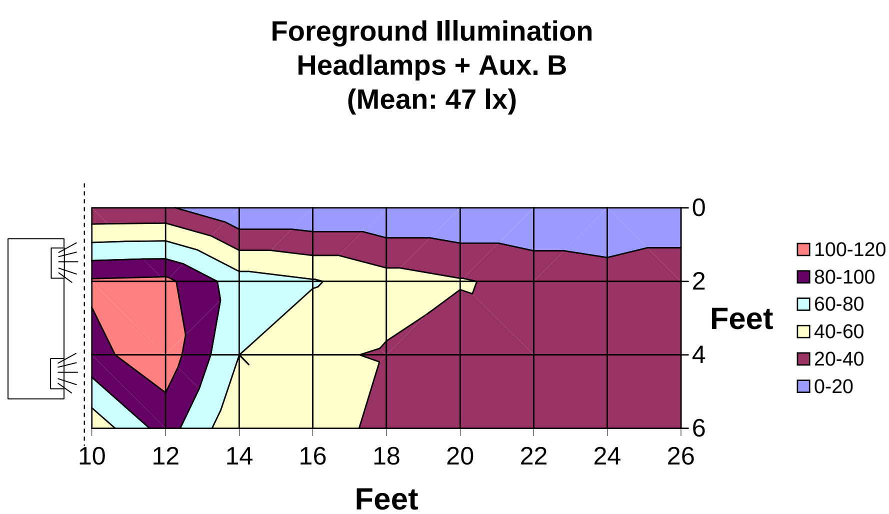

Figure 6. *Foreground illuminance (lx) from the HL+B condition.*

The targets consisted of square arrays of circular flip dots (white on one side, black on the other) normally displaying the black flip-dots. Through computer control, the targets were set up to flip at random intervals (between 2 and 4 s) and locations from black to white; subjects were instructed to release a switch on the hand-held control box as soon as they detected a target presentation in their peripheral view. In this way, response times to they targets could be measured with millisecond accuracy. For each lighting/secondary task condition, subjects responded to three repeated presentations of each target.

Subjective Ratings

After the trials for each of the three headlamp conditions listed above that used the tracking task, subjects were asked to rate the quality of the headlamp illumination using the following nine-point scale:

9	excellent
8	
7	satisfactory
6	
5	just acceptable
4	
3	poor
2	
1	unacceptable

To assess whether the uniformity of foreground light had an influence on subjective quality ratings, a fourth lighting condition was used, consisting of the headlamps plus the less uniform auxiliary lamp set (HL+B; Figure 6). Although not used during the assessment of ratings for this fourth condition (since target detection was not measured under this condition), the tracking was set up and located 10 m ahead of the vehicle for this judgment to make the scene as close as possible to that for the other judgments.

RESULTS

Target Detection

The average response times under each combination of lighting and secondary task are plotted in Figure 7. A repeated-measures analysis of variance (ANOVA) performed on the response time data revealed statistically significant ($p<0.05$) effects of lighting/ secondary task combination and of target location.

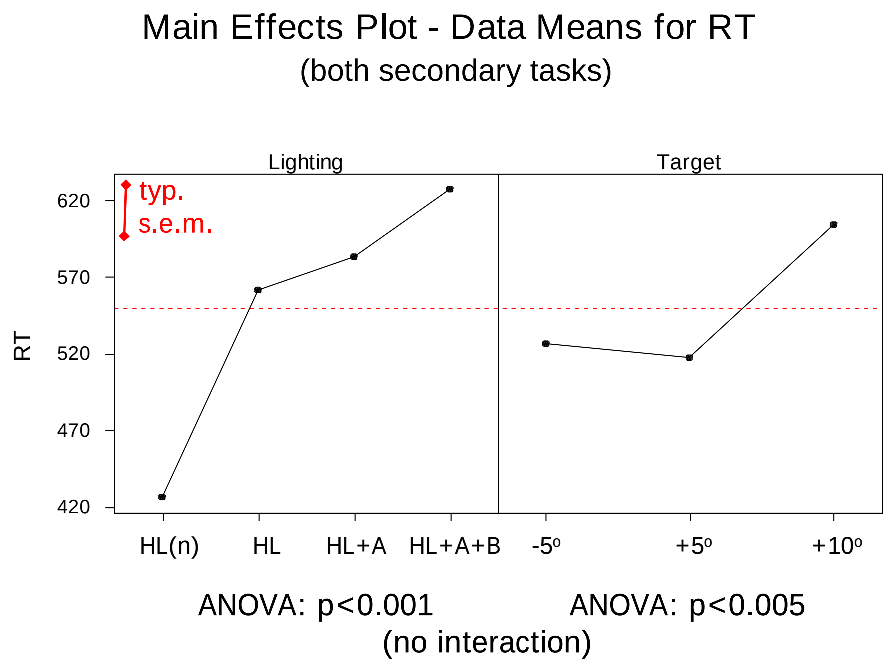

Figure 7. *Mean response times (size of typical standard error of the mean also shown) for each lighting/secondary task condition and for each target location.*

Inspection of Figure 7 reveals that the largest difference in response times among the conditions was attributable to the secondary task. Consistent with the responses of the pilot subjects, response times were indeed longer (by ~150 ms) when the subjects had to perform the tracking task than when they simply had to look toward the changing numerical display [denoted in Figure 7 as HL(n)], for the same lighting condition. When the data for the three lighting conditions using the tracking task were compared (having mean foreground illuminances of 16, 54 and 85 lx), there was a slight trend of increased response times with increased foreground illuminances, but there were not statistically significant ($p>0.05$) differences in the response times among these conditions.

As expected, the same ANOVA revealed statistically significant ($p<0.05$) effects of target location on response times, as expected based on the illuminances on each target (Figure 2) and on the distances between each target and the line of sight.

Subjective Ratings

Figure 8 shows the average quality ratings for each of the four conditions for which ratings were provided. A repeated-measures ANOVA revealed that there was a statistically significant ($p<0.05$) effect of lighting condition on the rating values. Subsequent post-hoc tests showed that there were no reliable differences between the two foreground conditions with similar illuminances but different uniformities; only the condition with the highest foreground illuminance (85 lx) was reliably different from the other conditions (with foreground illuminances of 16, 47 and 54 lx).

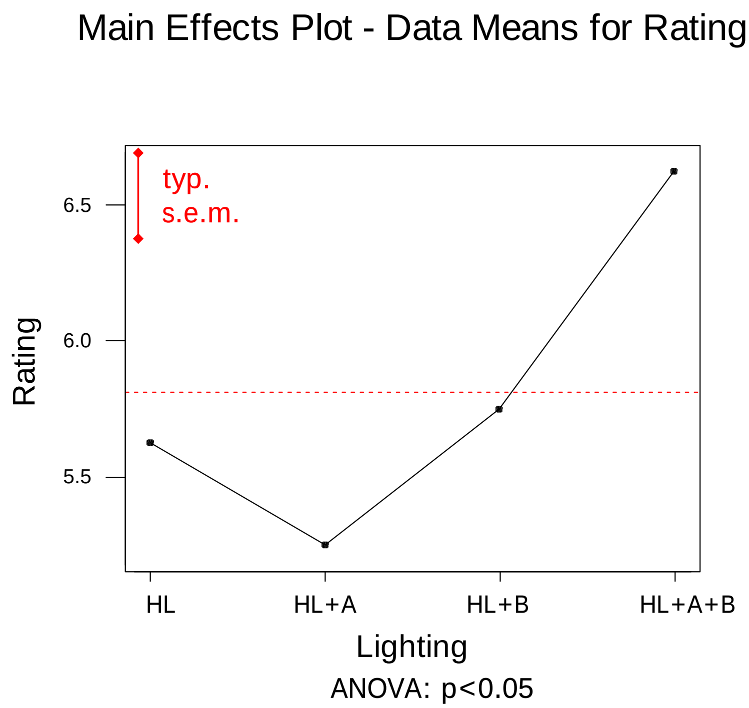

Figure 8. *Mean quality ratings (size of typical standard error of the mean also shown) for each lighting condition.*

DISCUSSION

The overall methodology using in the present study, measuring target detection with a secondary tracking task methodology, as well as the number of subjects used, was similar to that used in previous studies (e.g., Van Derlofske et al., 2001, 2002) to reliably measure differences between headlamps using different light sources. Although there was a trend between increased foreground illuminance and increased response times, the differences among these conditions were not statistically significant. Therefore, the present data cannot be used to state confidently that increases in foreground illuminance will decrease visibility of targets further down the road.

If the negative impact of foreground light on target response times is consistent with the magnitudes shown in Figure 7, one can estimate the number of subjects that would be required (also assuming variability among subjects consistent with that observed in the present study) to obtain statistical significance (McGuigan, 1990). This calculation reveals that in order to demonstrate reliably different response times between the HL and HL+A+B conditions, more than 100 subjects would be needed; to demonstrate reliable differences between the HL and HL+A conditions, more than 850 subjects would be needed! It is questionable whether it would be worth establishing statistical significance, given the modest response time differences that are involved (~50 ms between the HL and HL+A+B conditions).

The present results support the notion that individuals prefer high light levels in the foreground, even though these conditions have no measured benefits in terms of target detection further ahead in the scene. Interestingly, the two intermediate foreground illuminances used in the present study were not rated as higher in quality than the low illuminance, nor was the more uniform condition rated as better than the less uniform condition, when they produced similar average illuminances in the foreground.

From an experimental design point of view, using a centrally located secondary tracking task can make visibility more difficult (i.e., resulting in longer response times) than simply asking subjects to look toward a fixation point. Whether this factor interacts with other factors (Bullough and Van Derlofske, 2006), or simply gives a fixed response-time increment, is not yet known.

In summary, high light levels in the foreground are desirable by drivers, but there is no evidence that they serve any beneficial purpose in terms of visibility or any safety-related metrics. If anything, they might possibly detract from forward visibility further ahead, but the effects appear to be relatively small. This result is consistent with the findings of Flannagan et al. (1995).

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