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QUALITATIVE EVALUATION OF HEADLAMP BEAM-PATTERN UNIFORMITY

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16. Abstract

This study consisted of two experiments. In the first experiment, a survey of driver opinions concerning beam-pattern uniformity was conducted. The questions dealt with the uniformity of one's own low-beam pattern (from memory and after nighttime driving), the important areas of the beam pattern for uniformity, and the degree of prior attention paid to uniformity. A total of 48 respondents returned the questionnaire. The main results of this experiment are as follows: (1) Ratings of uniformity from memory were similar to those made after driving. (2) Foreground in one's own lane was rated as the most important area for uniformity.

The second experiment involved a field evaluation of the uniformity of a U.S. and a European beam pattern, first from memory after experiencing the beam pattern without prior instructions about uniformity, and then during actual viewing. A total of 16 subjects (both younger and older) participated. The main results of this experiment are as follows: (1) Although there was a tendency to assign higher uniformity ratings during viewing than from memory, the difference was not statistically significant. (2) Uniformity ratings tended to be based on illumination in one's own lane. (3) The European beam pattern was rated as being more uniform than the U.S. beam pattern. (4) The uniformity of the ECE beam pattern was not significantly related to the areas that were considered important for uniformity. On the other hand, the uniformity of the U.S. beam pattern was positively related to the relative importance of the illumination in one's own lane of travel.

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CONTENTS

INTRODUCTION

In evaluating automobile headlamps, visibility and glare considerations are usually of primary importance (e.g., Sivak and Flannagan, 1993). However, the subjective appearance of the headlamp beam pattern has recently become of substantial interest as well (e.g., Nakata, Ushida, and Takeda, 1992; Jack, O'Day, and Bhise, 1994, 1995; Neumann and Stoll, 1996; Wang, Kreysar, and Jiao, 1996; O'Day, Stone, Jack, and Bhise, 1997).

Using semantic differential and factor analysis, Jack and his colleagues have examined the contribution of a large number of beam-pattern qualities (such as pleasant, clean, and uniform) to the overall beam-pattern evaluation (Jack et al., 1994; 1995; O'Day et al., 1997). This research has shown that a factor that involves qualities such as uniformity and smoothness has a positive relation to the overall evaluation of beam patterns.

The relation of physical aspects of the beam pattern to perceived uniformity has also been addressed recently. Wang et al. (1996) found that the following three physical aspects of beam patterns related to perceived uniformity of beam patterns: the deviations from an "ideal" Gaussian distribution of intensity, the maximum intensity contrast, and the relative intensity gradients (all computed for horizontal cross-sections of the beam pattern). O'Day et al. (1997) found that vertical and horizontal gradients of luminance produced by a beam pattern on the road were related to perceived uniformity.

The present study was designed to add to the emerging information about beam pattern uniformity. The study focused on the issue of the important parts of the beam pattern for uniformity judgments. There were two parts in this study: an exploratory survey, and a controlled field experiment. In both parts, one of the manipulations involved whether the responses were based on memory or actual viewing. The memory conditions were designed to assess how people perceive uniformity spontaneously, and, indeed, how much they paid attention to uniformity when there was no instruction to consider uniformity at the time they were viewing the beam patterns.

EXPERIMENT 1: A SURVEY

Aim

This survey was designed to obtain information about drivers' opinions concerning beam-pattern uniformity. The questions were formulated to give the respondent as much freedom as possible in interpreting uniformity.

Design

A questionnaire was developed that consisted of two parts. The first part was to be answered before actual driving, and thus relied on the respondents' memories. The second part had to be answered immediately after driving at night. This design was chosen in order to obtain insight on how drivers "think about" uniformity before their attention is explicitly drawn to this issue.

A major goal of the survey was to identify the part(s) of the beam pattern that were most important in evaluating uniformity. Therefore, a simple sketch of the road ahead from the driver's view was developed. In this sketch (see Figure 1), the beam pattern was subdivided into three broad areas: foreground area, distant area, and side area composed of two sections (oncoming lane and right road shoulder).

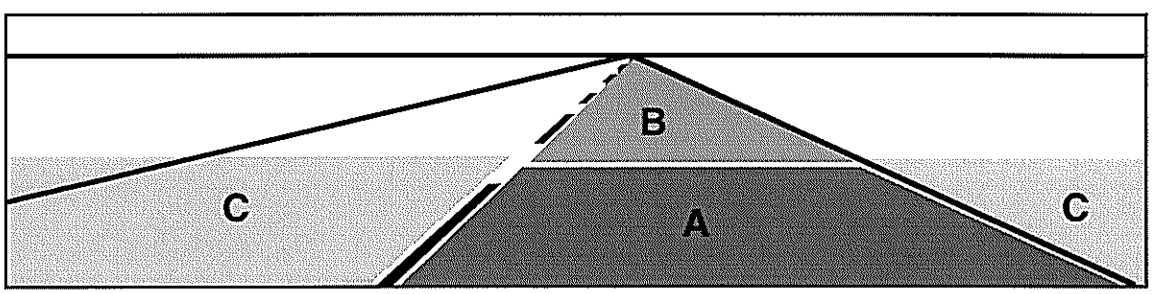

Figure 1. Areas of interest in judging beam-pattern uniformity.

Questionnaire

The questionnaire included the following items:

(1) Rate the overall uniformity of the beam pattern from your low-beam headlights as it appears on the ground ahead of you.

(2) Rate how important the light distribution in each of the areas in Figure 1 was in determining your rating of overall uniformity.

(3) Prior to participating in this survey, how much attention have you paid to headlight beam-pattern uniformity?

There were two versions of Questions 1 and 2. The first versions were answered before actual driving, while the second versions after nighttime driving. All questions had to be answered on 5-point rating scales with verbal anchors at both extremes of the scales.

Procedure

The questionnaire was distributed at UMTRI during one afternoon, along with a request to return it the following morning. The instructions emphasized that one part of the questionnaire should be filled out before actual driving, and the other part after night driving had been completed. The roads that the participants used during their nighttime drive were not controlled or monitored. There was no precipitation during the night in question.

Subjects

We distributed 80 questionnaires. Forty-eight people returned a completed questionnaire, including 28 males and 20 females. (One person did not answer some of the questions. Consequently, some of the analyses were based on the data from 47 respondents only.) The ages of the respondents ranged from 22 to 64 years with a mean of 42. Five of the respondents had some prior experience with headlight research. None of the respondents were involved in the design of the study.

Results

Overall uniformity of beam patterns

As indicated above, the respondents had to rate the uniformity of the beam pattern on their own vehicle twice: first before actual driving (which meant that they had to do the rating from memory), and second immediately after actual night driving. The differences between the ratings from memory (mean of 3.33) and after driving (3.17) were not statistically significant. The correlation coefficient across subjects for the ratings made from memory and after driving was $r(45) = .48$, $p < .01$, suggesting a moderate level of consistency between these two ratings.

Females tended to rate their low beams as being more uniform (3.47) than did males (3.07), but the difference was not statistically significant. Similarly, older subjects (older than 40) tended to assign greater uniformity (3.33) than did younger subjects (40 or younger) (3.08), but, again, the difference was not statistically significant.

Importance of different areas of the beam pattern for uniformity

The ratings of the importance of different areas of the beam pattern for uniformity were entered into an analysis of variance, using the following independent variables: nature of rating (from memory, after driving), sex, age (40 or younger, older than 40), and the area of the beam pattern being judged (foreground, distant, and sides). The main findings of interest were as follows. The area of the beam pattern was statistically significant, $F(2, 86) = 5.45$, $p = .006$, with the foreground being rated as most important for judging uniformity, and the side areas rated as least important (see Figure 2). There was a tendency for sides to be more important in judging uniformity when the rating was performed after driving than when it was performed from memory, with no apparent difference for foreground or distant areas (see Figure 3). However, this interaction of area and memory just failed to reach the conventional (.05) level of statistical significance, $F(2, 86) = 2.99$, $p = .06$. Finally, there was a tendency for females to rate the importance of all three areas equally, while males tended to favor the foreground area, followed by the distant area (see Figure 4). This interaction of area and sex, however, also did not reach statistical significance, $F(2, 86) = 1.77$, $p = .18$.

The correlation between the two sets of ratings (from memory and after driving) of the importance of the foreground area for uniformity was statistically significant, $r(45) = .68$, $p < .01$, as was the case for the distant area, $r(45) = .62$, $p < .01$, and for the side areas, $r(45) = .60$, $p < .01$. These findings imply a relatively high level of consistency of the two ratings.

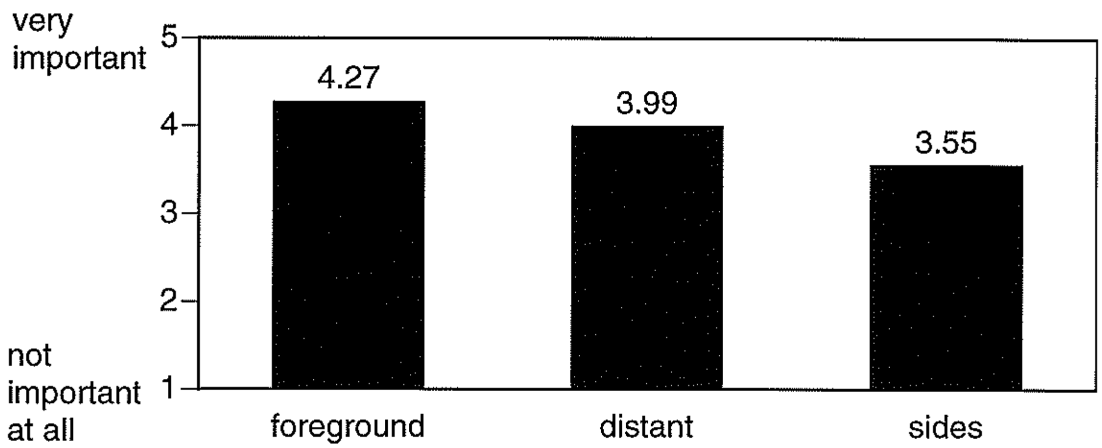

Figure 2. Importance of different beam-pattern areas for judging overall uniformity.

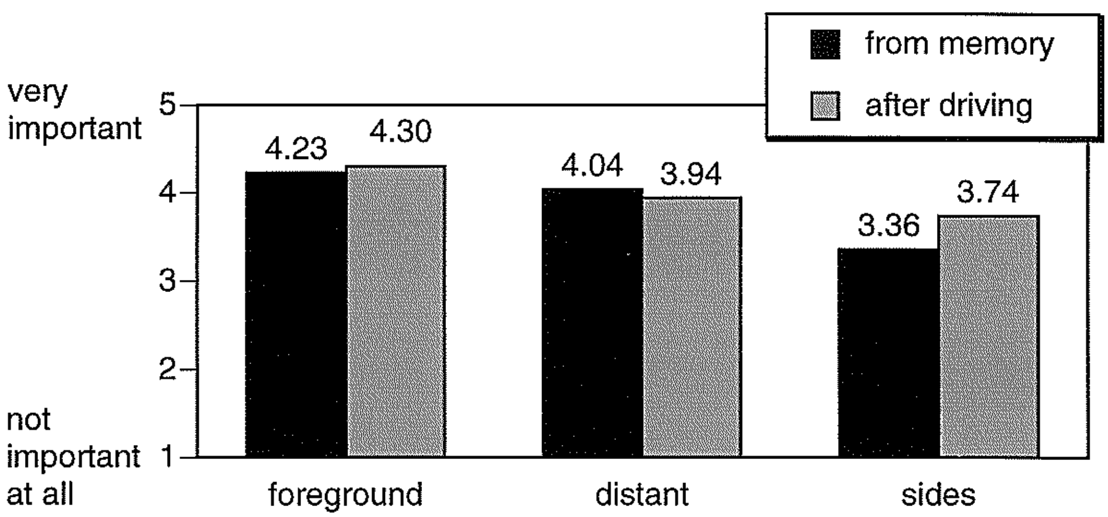

Figure 3. Importance of different areas for judging uniformity, from memory and after nighttime driving.

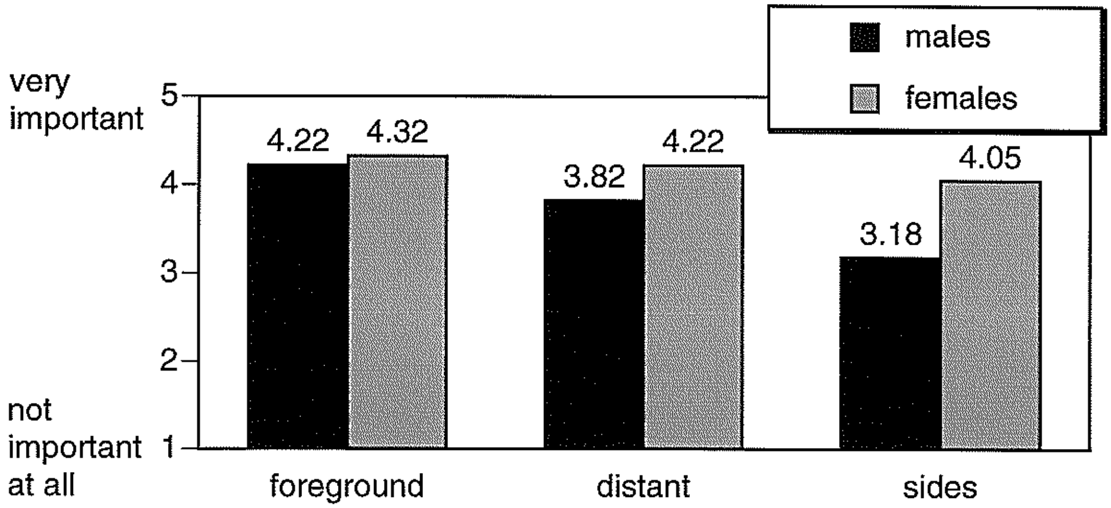

Figure 4. Importance of different areas for judging uniformity as a function of the sex of the respondent.

Prior attention to uniformity

One of the questions asked the respondents to indicate how much attention they had paid to headlight beam-pattern uniformity prior to participating in this study. The two extremes on the 5-point response scale were "none" and "very much." Only 12.5% (6 out of 48) respondents indicated that they paid "very much" attention to uniformity . On the other hand, 12.5% of respondents labeled their level of prior interest in uniformity as "none." Some respondents even commented that they either were not aware of beam-pattern uniformity (e.g., "If you pay attention it is evident that the non-uniformity creates the impression of shadows that I had assumed were due to the road environment."), or that they did not evaluate beam-pattern uniformity by itself, but only in combination with other aspects of headlighting ("I don't think I ever concerned myself with the uniformity per se of the lights: I evaluate the overall 'efficiency' of the illumination.").

There was a nonsignificant tendency for the degree of prior attention to uniformity to correlate negatively with the ratings of uniformity, $r(45) = -.11, p = .45$. This is the pattern that might be expected if those who spontaneously paid attention to uniformity did so because they noticed nonuniformity and therefore gave low uniformity ratings.

Discussion

Consistent with previous research (Wang et al., 1996), the foreground in the lane of travel was rated as the most important area when judging the uniformity of headlight beam patterns. Because foreground, as defined in this study, included the brightest part of the beam pattern on the road, it is not clear whether this finding reflects the inherent importance of the foreground for uniformity judgments, or whether it demonstrates the importance of brightness.

The side areas (i.e., the oncoming lane and the right shoulder) were considered to be more important for uniformity than the distant area. However, additional clarification of the relative importance of the two parts forming the side areas in this study (the oncoming lane and the right shoulder) would be desirable.

Males tended to rate the beam patterns on their own vehicles as being less uniform than did females. This difference could be a consequence of the greater overall annual mileage of males (Massie, Campbell, and Williams, 1995), and thus their greater exposure to nighttime driving. It is possible that the greater exposure to nighttime driving leads to a more critical examination of the beam-pattern properties.

Ratings of uniformity from memory were similar to those made after actual nighttime driving. Analogously, ratings from memory of the importance of the different areas of the beam pattern for uniformity tended to be similar to those made after driving.

In terms of attention to uniformity prior to this study, 12.5% of the respondents indicated that they "never" paid any attention (by selecting one extreme of the 5-point response scale) and 12.5% of the respondents indicated that they paid "much attention" (by selecting the other extreme of the scale). Furthermore, it was apparent that some respondents considered uniformity to be produced by a combination of the inherent uniformity of the beam pattern and the reflectance properties of the road surface. This uncertainty about the concept of uniformity calls for a more limiting definition. In future research, it should be made clear that uniformity is being considered independently of the roadway environment or of other salient aspects of the beam pattern (such as brightness).

EXPERIMENT 2: A FIELD EVALUATION

Based on the results of the survey in Experiment 1, a controlled field experiment was designed to obtain additional information about beam-pattern uniformity for two specific beam patterns. As was the case with the survey, this experiment also consisted of two parts: a part in which uniformity was evaluated from memory, and a part in which uniformity was evaluated directly while viewing a beam pattern.

Subjects

Sixteen paid subjects, all licensed drivers, participated in this experiment. Eight subjects were between the ages of 22 and 33 (mean of 30), and eight were between the ages of 70 and 79 (mean of 74). There was an equal number of males and females in each age group. Subjects were recruited from lists of potentially interested subjects maintained at UMTRI. Subjects wore the same eyewear, if any, that they would normally wear when driving at night.

Experimental setup

The study was performed on a straight, flat, asphalt-paved road adjacent to the UMTRI parking lot. Subjects were seated in a 1993 midsize car, which was parked in the middle of a 3.66 m (12 feet) wide lane. Figure 5 shows a schematic diagram of the view from the driver's position. This diagram was used during the experiment for rating the importance of different parts of the beam pattern for judgments of uniformity.

The experimental car was equipped with two sets of properly aimed headlights that could be turned on independently during the experiment. One set of headlamps had a U.S. beam pattern, while the other set had an ECE (European) beam pattern. Figures 6 and 7 present isolux diagrams of the illuminance on the road surface from the two sets of headlamps, given the actual mounting height and lateral separation of the headlamps. The headlamps were connected to an external power source in order to keep the voltage constant during the entire experiment.

The experiment was conducted at night on dry pavement, with the low-beam headlights as the only source of nearby illumination.

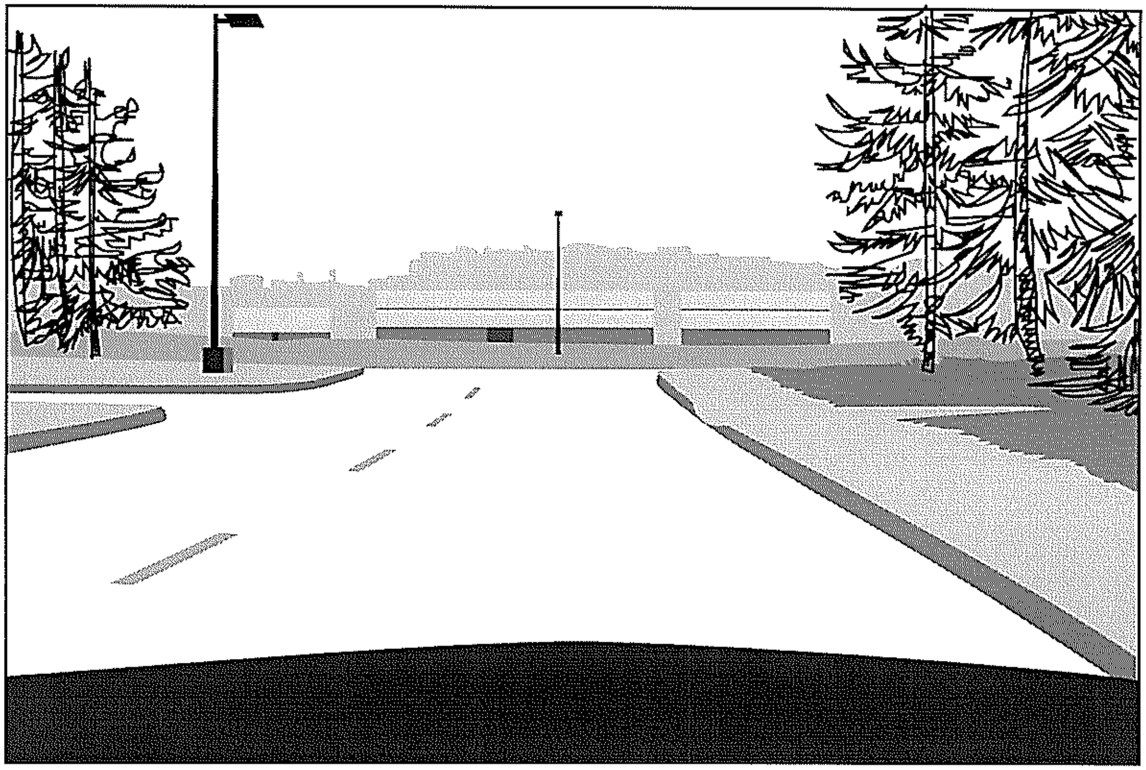

Figure 5. A schematic diagram of the view from the driver's position.

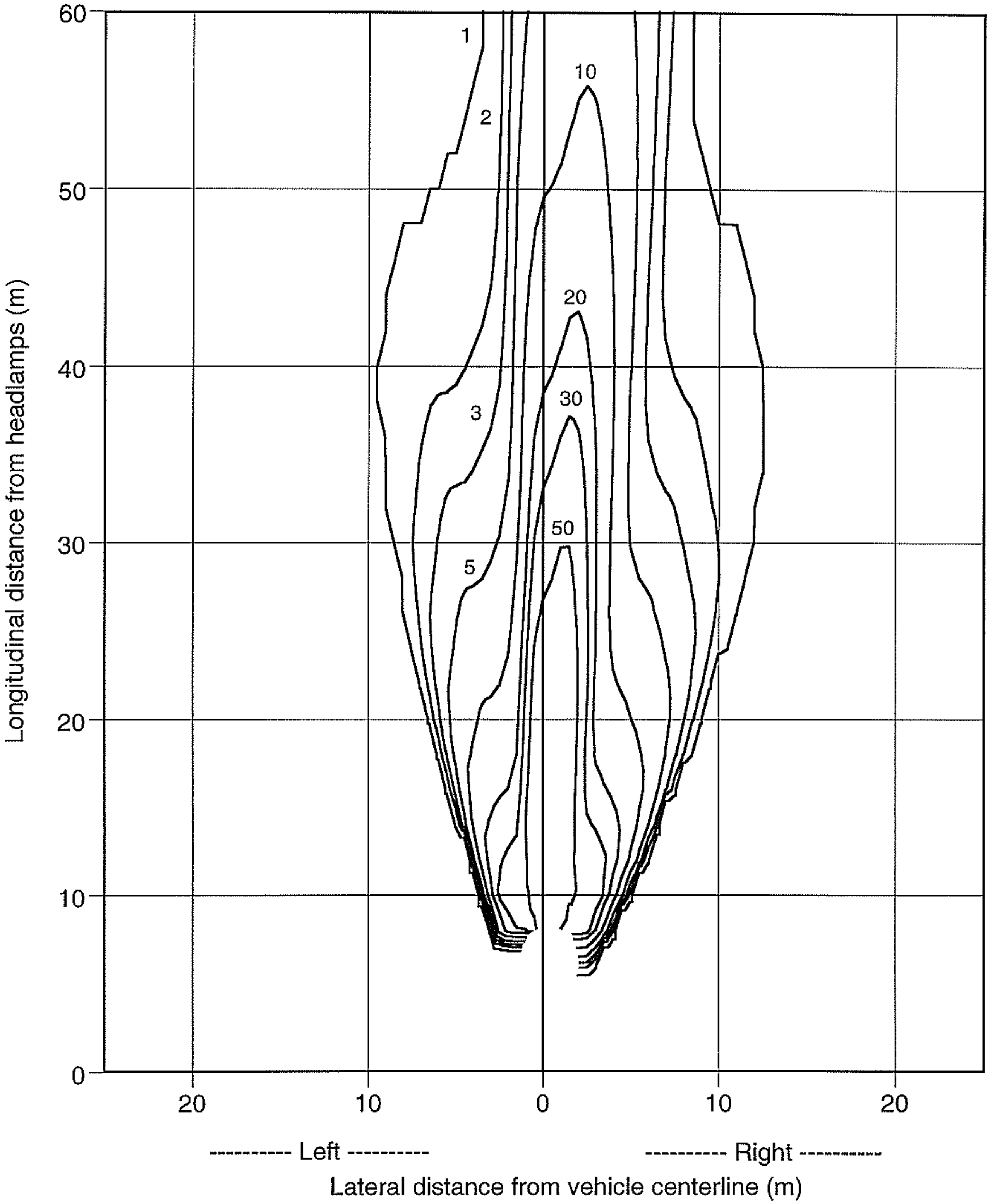

Figure 6. Isoilluminance diagram (in vertical lux) at the road surface from the pair of lamps having a U.S. beam pattern.

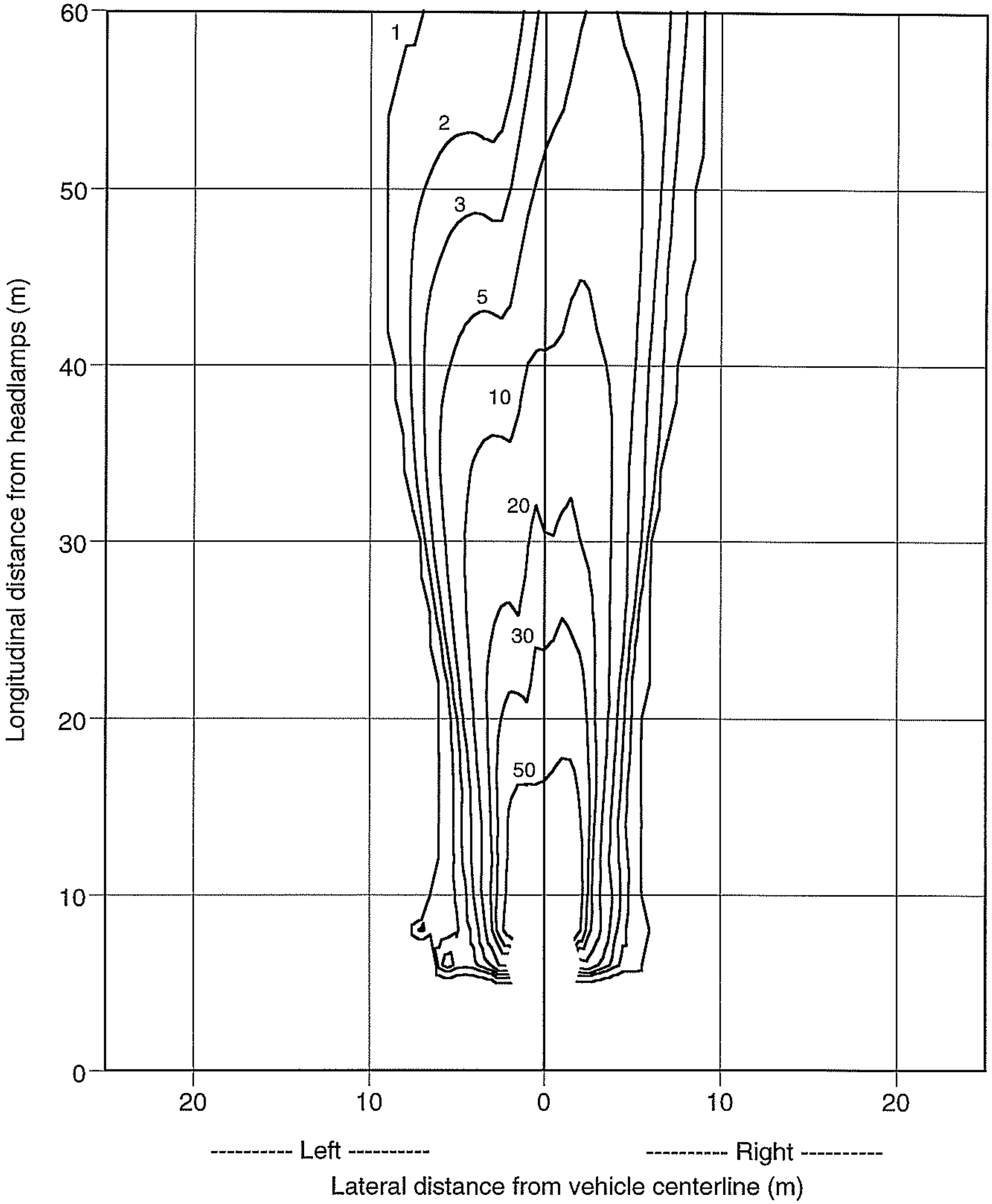

Figure 7. Isoilluminance diagram (in vertical lux) at the road surface from the pair of lamps having an ECE beam pattern.

Experimental tasks

Rating of uniformity from memory

First, subjects were given a brief identification task lasting about eight minutes. Specifically, they were asked to identify targets on the road ahead that were placed at three different distances (9 m, 18 m, and 27 m ahead of the car) and at three different locations (2 m to the right of the right road edge, at the center stripes, and on the left road edge; see Figure 5). Each target displayed a series of five letter "Cs," which varied in orientation of the gap (left, right, top, or bottom) and size. The task was to identify the direction of the gap in each letter "C." Data for this identification task were not analyzed, because this task was given only to draw the subjects' attention to the road ahead, which was illuminated only by the low-beam headlights. At the end of the identification task, the targets were removed and the car's headlights were turned off. Of the 16 subjects, eight performed the identification task using the U.S. beam pattern (see Figure 6), and eight using the ECE beam pattern (see Figure 7).

After the headlamps were extinguished, subjects were introduced for the first time to the issue of uniformity. Beam-pattern uniformity was defined in the instructions as "how evenly the light is distributed by the low-beam headlights on the ground ahead of the car." Subjects had to rate the uniformity of the beam pattern they just experienced in the identification task by using a 9-point rating scale. The scale had three verbal anchors, one at each of the two extremes ("very spotty" and "very uniform") and one in the middle of the scale ("neither"). After the rating, subjects had to identify the part(s) of the beam pattern their rating was based on, by marking the area(s) in a diagram that showed the view ahead (see Figure 5).

Rating of uniformity during actual viewing

In this part of the study, the two low-beam headlighting patterns were shown to the subjects for one minute each. At the end of each presentation the subjects had to rate the pattern using the 9-point rating scale described above. There were four presentations of each of the two beam patterns, for a total of eight trials. The trials were randomized, with the constraint that the last two trials involved a presentation of each of the two beam patterns. During these last two trials, in addition to rating the uniformity, the subjects also rated the importance of the different areas of the beam pattern for uniformity.

Procedure

Two subjects were tested at a time, one seated in the driver position, and one in the right-front passenger position. The seating configuration was balanced across subjects by age and sex. An experimenter, seated in the back seat, supervised and controlled the experiment.

At the beginning of the experiment, while the subjects were given instructions for the identification task, the car's low-beam headlights were on to allow the subjects to adapt to the prevailing light level. The entire experiment was completed in about 35 minutes.

Results

Uniformity ratings

Two analyses of variance were performed. To evaluate whether the ratings from memory and during viewing differed from each other, the first analysis included the ratings from memory and the ratings during viewing for the same beam pattern as in the memory condition. (Each subject experienced only one of the two beam patterns in the memory condition. For the beam pattern that the subject did not experience in the memory condition, the ratings during viewing were not included in this analysis.) The results indicate the following two interesting tendencies, albeit neither of them was statistically significant. First, uniformity tended to be greater during viewing than from memory (Figure 8). Second, in agreement with a similar nonsignificant tendency in the data from Experiment 1, males tended to assign lower uniformity than did females (Figure 9).

The effect of the beam pattern was tested in the second analysis of variance. This analysis included all of the ratings made during viewing; the ratings from memory were not included. The effect of the beam pattern was statistically significant, $F(1, 12) = 7.59$, $p = .02$, with the ECE beam pattern being rated as more uniform than the U.S. beam pattern (see Figure 10). (The ratings from memory also showed a trend in the same direction [U.S. = 4.75, ECE = 5.75], but the effect was not statistically significant.) A breakdown of the data by age indicates that there was a tendency for this effect to be greater for younger than for older subjects (see Figure 11). However, this interaction between lamp and age failed to reach statistical significance, $F(1, 12) = 3.47$, $p = .09$.

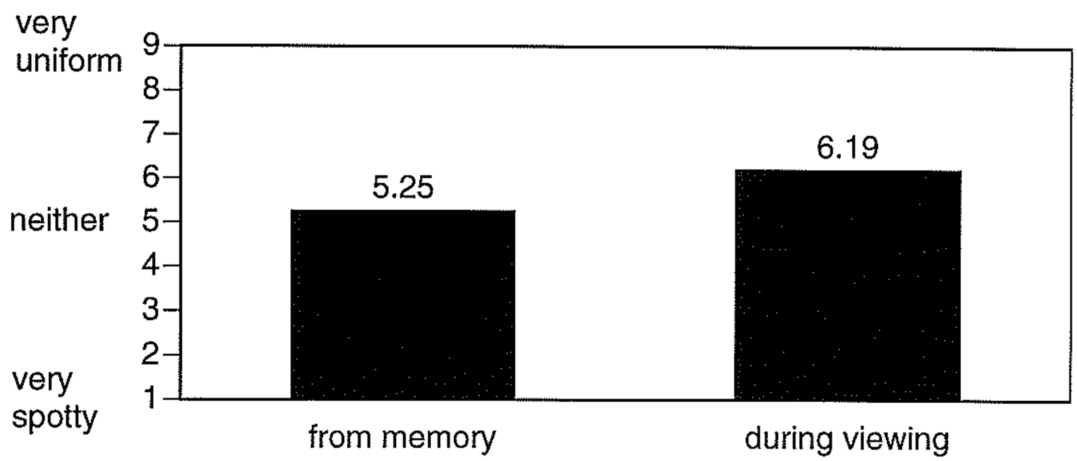

Figure 8. Uniformity ratings from memory and during viewing.

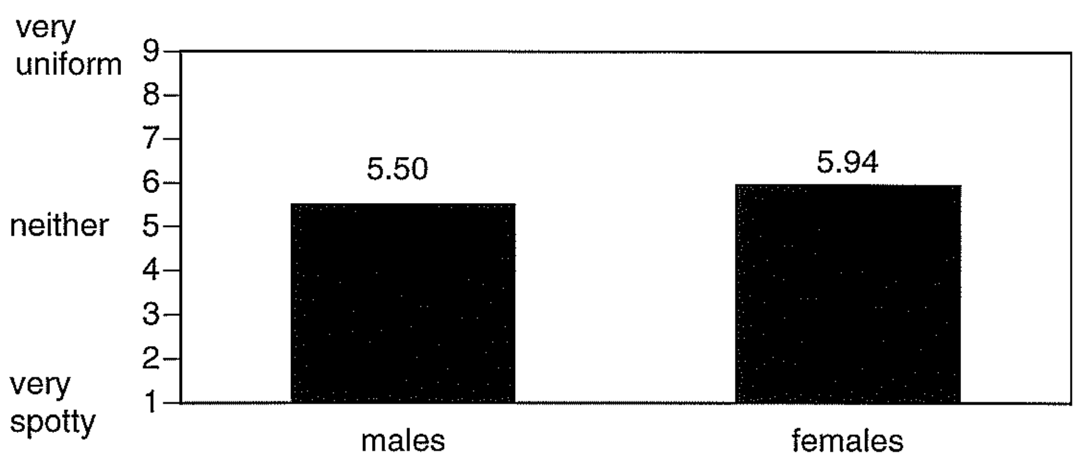

Figure 9. Uniformity ratings by sex for a combined set of ratings from memory and during viewing.

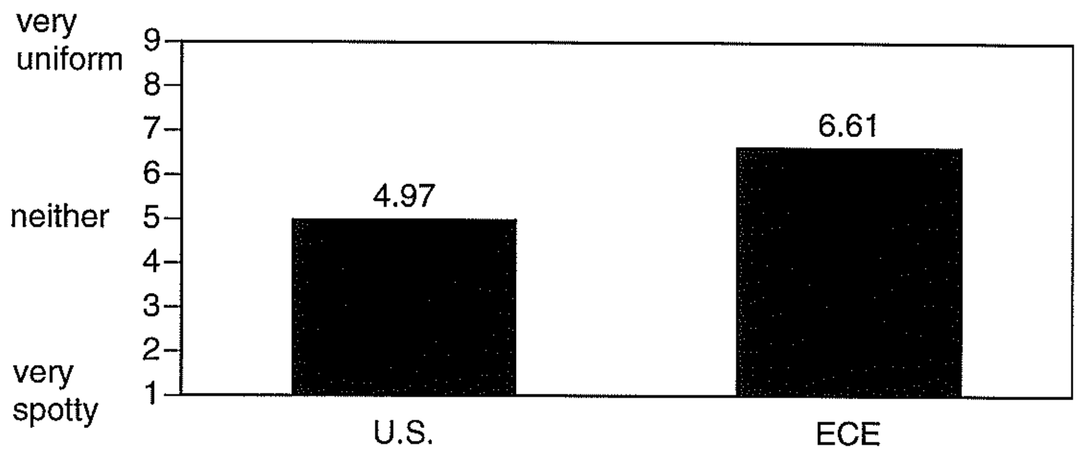

Figure 10. Uniformity ratings of the U.S. and ECE beam patterns during viewing.

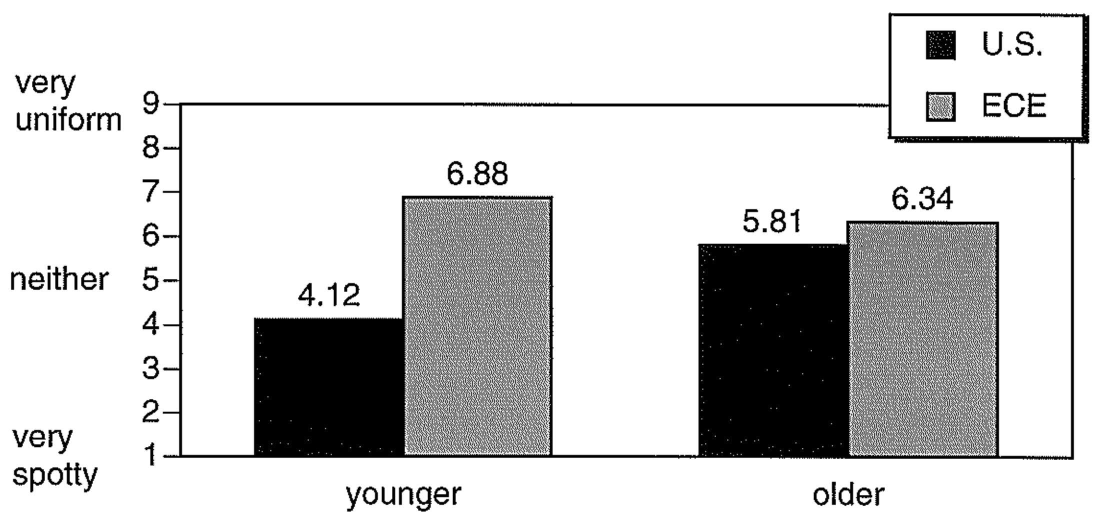

Figure 11. Uniformity ratings of the U.S. and ECE beam patterns during viewing, by age.

Relevant illumination area

On the last two trials of the experiment (one for each beam pattern), the subjects were asked (in addition to rating uniformity) to indicate the areas of the beam pattern that were important for uniformity. The subjects used the schematic diagram in Figure 5 to mark the important areas. The subjects' sketches of the important areas were coded for the analysis into three broad areas: the oncoming lane, one's own lane of travel, and the right road shoulder. Table 1 shows the frequencies with which subjects selected these areas in the beam pattern as important for uniformity. (The instructions allowed more than one area to be selected.) The results in Table 1 indicate that the majority of the uniformity ratings were based on the illumination in one's own lane, either alone or in combination with other areas of the beam pattern (69% of the responses for the U.S. beam pattern, and 88% of the responses for the ECE beam pattern).

The relation between the importance of different areas for uniformity and the rated uniformity was evaluated by computing (for each beam pattern separately) a correlation coefficient between the relative importance of one's own lane (100, 50, 33, or 0%—see column 4 in Table 1) and the corresponding uniformity rating. The results showed that there was a strong and statistically significant correlation for the U.S. beam pattern, $r(14) = .85$, $p < .001$, indicating that the greater the relative importance of the illumination in one's own lane for uniformity, the greater the rated uniformity. On the other hand, there was no relation between these two variables for the ECE beam pattern $r(14) = -.08$, $p = 78$.

Table 1
Frequency of selecting different areas of the beam pattern as important for uniformity.

Areas selected			Weighting of "own lane" among areas selected	Number of subjects	
Oncoming lane	Own lane	Right shoulder		U.S. pattern	ECE pattern
	X		100	3	5
X	X		50	4	3
	X	X	50	2	2
X	X	X	33	2	4
X			0	4	2
X		X	0	1	0
		X	0	0	0

Discussion

One of the main experimental manipulations in this study involved the nature of the uniformity ratings (from memory or during actual viewing). Although there was a tendency for subjects to assign higher uniformity ratings during viewing than from memory, this effect was not statistically significant.

Consistent with the results in Experiment 1, males tended to assign lower uniformity ratings than did females. As indicated above, a possible explanation for this effect is that, because of the greater exposure of males to nighttime driving, they are more critical concerning beam-pattern properties.

Uniformity ratings while viewing were greater for the ECE beam pattern than for the U.S. beam pattern. This effect was substantial (1.6 units on a 9-point scale), and also statistically significant. (A tendency for an effect in the same direction was also present in the ratings from memory, but this effect was not statistically significant.)

Ratings of the uniformity of the ECE beam pattern were not significantly related to the areas that were considered important for uniformity. On the other hand, for the U.S. beam pattern there was a strong positive relation between the relative importance of illumination in one's own lane of travel and uniformity (i.e., the greater the relative importance of the illumination in one's own lane for uniformity, the greater the rated uniformity). This finding implies that the U.S. beam pattern might be perceived as especially non-uniform outside of one's own lane of travel.

SUMMARY

This study consisted of two experiments. In the first experiment, a survey of driver opinions concerning beam-pattern uniformity was conducted. The questions dealt with the uniformity of one's own low-beam pattern (from memory and after nighttime driving), the important areas of the beam pattern for uniformity, and the degree of prior attention paid to uniformity. A total of 48 respondents returned the questionnaire. The main results of this experiment are as follows: (1) Ratings of uniformity from memory were similar to those made after driving. (2) Foreground in one's own lane was rated as the most important area for uniformity.

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