EVALUATION OF AN ACTIVE HEADLIGHT SYSTEM

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15. Abstract

This study evaluated an active headlight (AH) system, developed by Honda R&D and Stanley Electric. The AH system delivers a low-beam pattern using two lamps on each side of a vehicle. The inboard lamps are fixed and the outboard lamps can be turned horizontally. An onboard computer selects a horizontal angle for the rotatable lamps based on three factors: steering-wheel angle, vehicle speed, and position of the turn-signal switch.

In the first of three experiments, pedestrian visibility was assessed on left and right curves. The subject was seated in a stationary vehicle at the start of a curve, and a dark-clad pedestrian moved either toward or away from the subject's vehicle. On the curves tested (with radii of approximately 90 m), the AH system, in comparison to a standard headlight system, provided extra visibility of 7.5 m (additional 14%) on the left curve and extra visibility of 1 m (additional 2%) on the right curve. (The vehicle and its position on the roadway were configured for U.S./European right-hand traffic.)

In the second experiment, discomfort glare for the oncoming drivers was evaluated on the same curves as in the first experiment. The subject was seated in a stationary vehicle at the start of a curve, and rated discomfort glare experienced from an oncoming car (equipped with either the AH or a standard system) by using the deBoer discomfort-glare scale. The results indicate that on the left curve (from the perspective of the glare car) there was an increase in discomfort glare when the AH system was on, but the resulting glare was less discomforting than the glare on the right curve with a standard system. In contrast to the findings for the left curve, on the right curve there was a tendency for a decrease in discomfort glare when the AH system was on.

The third experiment evaluated impressions of specific aspects of headlamp performance and overall preference after two 30-km in-traffic driving experiences, one with each system. Subjects liked the increased lateral illumination provided by the AH system on curves, at intersections, and while changing lanes. Complaints about the AH system included perceived jerkiness of the movement of the light, slow return of the light to the straight-ahead position, and a dark area between the fixed and rotatable beams. There were no significant differences between the two systems on any of the specific aspects, nor in overall preference between the two systems. However, individual subjects tended to have strong preferences either for the AH system or for the standard system, and those preferences were systematically related to the evaluations of specific aspects of performance.

Overall, the findings of this study imply that dynamically controllable headlamps, as embodied in the AH system, are likely to provide increased visibility for low-contrast objects on curves and at intersections, along with an acceptable increase in discomfort glare for oncoming drivers. Driver acceptance of, and preference for, such a system will likely depend on modifying the light distributions provided by the component lamps and changing certain aspects of the movement of the rotatable beams.

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CONTENTS

INTRODUCTION

A majority of research concerning the low (passing) beam of vehicle headlamps has dealt with attempts to develop a single optimal beam pattern. The hope was that such a beam pattern would provide satisfactory visibility of all important targets (such as pedestrians, delineation, and traffic signs), under all relevant conditions (including varieties of road geometries, during rain, snow, and fog), for all drivers (young and old), and, at the same time, not be glaring for the oncoming traffic.

However, despite all of the recent advances in headlamp design, the current low beams (whether in the U.S., Europe, or Japan) fall short in meeting many of the important functions expected from them (Sivak, Helmers, Owens, and Flannagan, 1992). For example, the current low beams do not provide sufficiently long visibility for low-contrast objects, resulting in visibility distances that are shorter than the stopping distances from normal travel speeds (Johansson and Rumar, 1963; Olson and Sivak, 1983).

Another specific concern is that the current standards do not regulate headlamp illumination in the periphery. For example, the widest controlled angle is 15° in the U.S. and Japan (15° left and right at 1.5° down [FMVSS, 1993; JIS, 1984]), and 9° in Europe (9° left and right at 1.5° down [ECE, 1992]). Consequently, there is a concern that the current headlamps might not provide sufficient lateral-spread illumination for driving on curves and at intersections.

There are two types of approaches to providing increased lateral illumination. One type involves *constant* additional illumination supplied by the standard low beams or supplemental beams. Another type involves *dynamically controllable low beams*, responsive to the changing requirements of the environment. The approach taken by Honda R&D and Stanley Electric, in developing the Active Headlight (AH) system, is of the later type.

The present study, consisting of three experiments, was performed to evaluate the potential benefits and drawbacks of the AH headlamp system by comparing the AH system with a standard system. The first experiment dealt with visibility of pedestrians on curves. The second experiment evaluated discomfort glare experienced by oncoming drivers on curves. The third experiment assessed subjective opinions concerning various aspects of headlamp performance.

DESCRIPTION OF THE HEADLIGHT SYSTEMS

AH system

The AH system delivers a low-beam pattern by two lamps on each side of a vehicle. The inboard lamps are fixed and the outboard lamps can be turned horizontally. The horizontal aim (rotation angle) of the rotatable lamps is under the control of an onboard computer that considers three factors in selecting the horizontal angle for these rotatable lamps: steering-wheel angle, vehicle speed, and position of the turn-signal switch. In general, the lamp angle increases with an increase in the steering-wheel angle, and is greater when the turn signal is on. When the turn signal is on, the lamp angle generally decreases with an increase in speed. Conversely, when the turn signal is not on, the lamp angle generally increases with an increase in speed. (However, this applies only for low speeds. Additional increases in speed, beyond a certain low speed, do not lead to a further increase of the lamp angle.) When the steering wheel is turned to the left, only the left outboard lamp is moved; conversely, when the steering wheel is turned to the right, only the right outboard lamp is moved. A schematic of the AH system is shown in Figure 1.
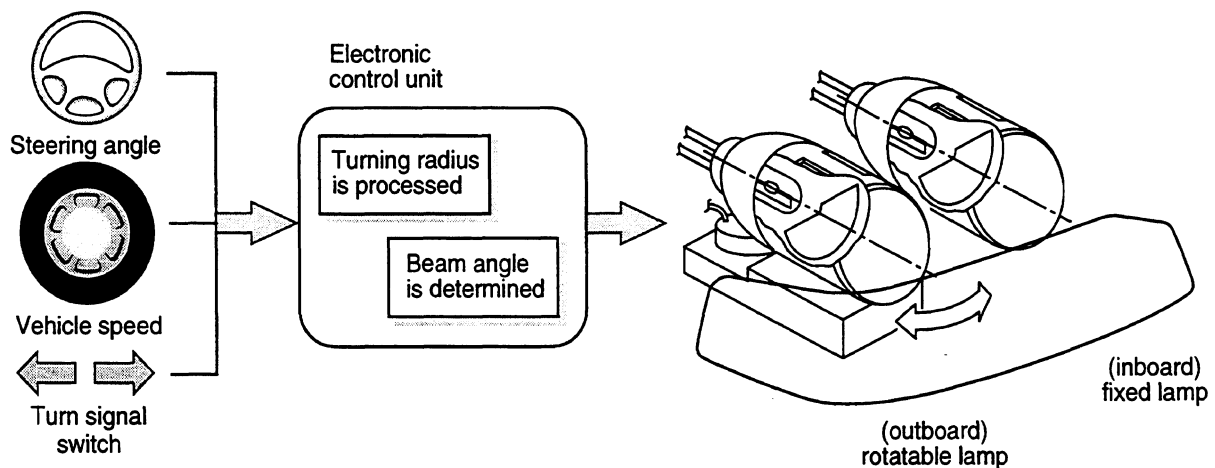

Figure 1. A schematic diagram of the AH system.

Isocandela diagrams for the individual four lamps that were tested are shown in Figures 2 and 3. Isolux diagrams of the total beam pattern (from all four lamps) projected on the roadway are shown in Figures 4 through 7 for the total beam pattern with the lateral angle of the rotatable lamp at 0°, ±15°, ±30°, and ±45°, respectively. (These isolux diagrams were generated based on the mounting height and lateral separations of the lamps approximating those on the test car used in this study.)

For any angle of the rotatable lamps, the two lamps on each side met the U.S. standard for low-beam headlamps (FMVSS, 1993). The luminous intensities at the U.S. test points are listed in Table 1 for the four individual lamps (with the rotatable lamps at 0°), as well as for the combined lamps on each side.

The AH system, as installed in the test vehicle for this study, could be operated in two modes. In the automatic mode, the onboard computer selected the angles for the rotatable lamps. In the manual mode, these angles were set manually.

Standard system

In this study, the beam pattern provided by the AH system was evaluated in comparison to the beam pattern delivered by the AH system with the rotatable lamps set at 0°. This system will be referred to as the standard system. The isocandela diagrams for the four lamps (Figures 2 and 3) and the total isolux diagram with the rotatable lamps at 0° (Figure 4) characterize the beam pattern generated by the standard system in this study.

Figure 2. Isocandela diagram for the left fixed lamp (top panel) and the left rotatable lamp (bottom panel). (The axes are in degrees.)
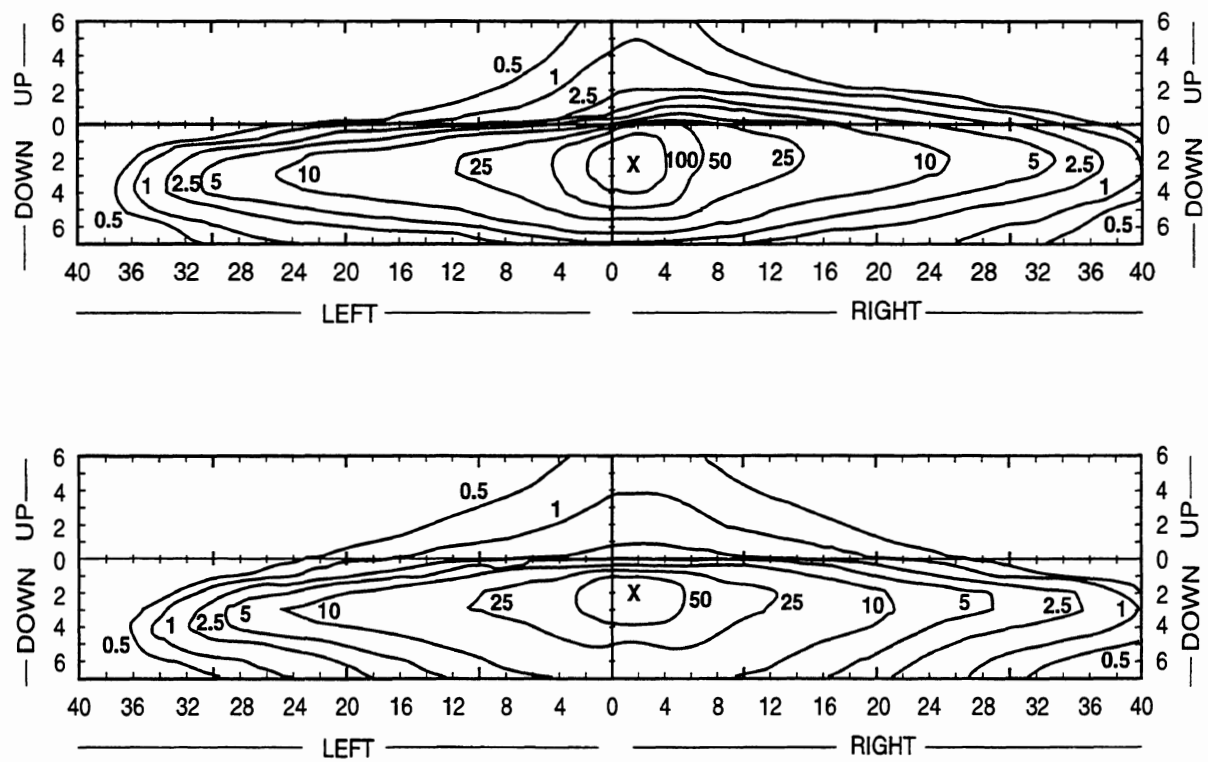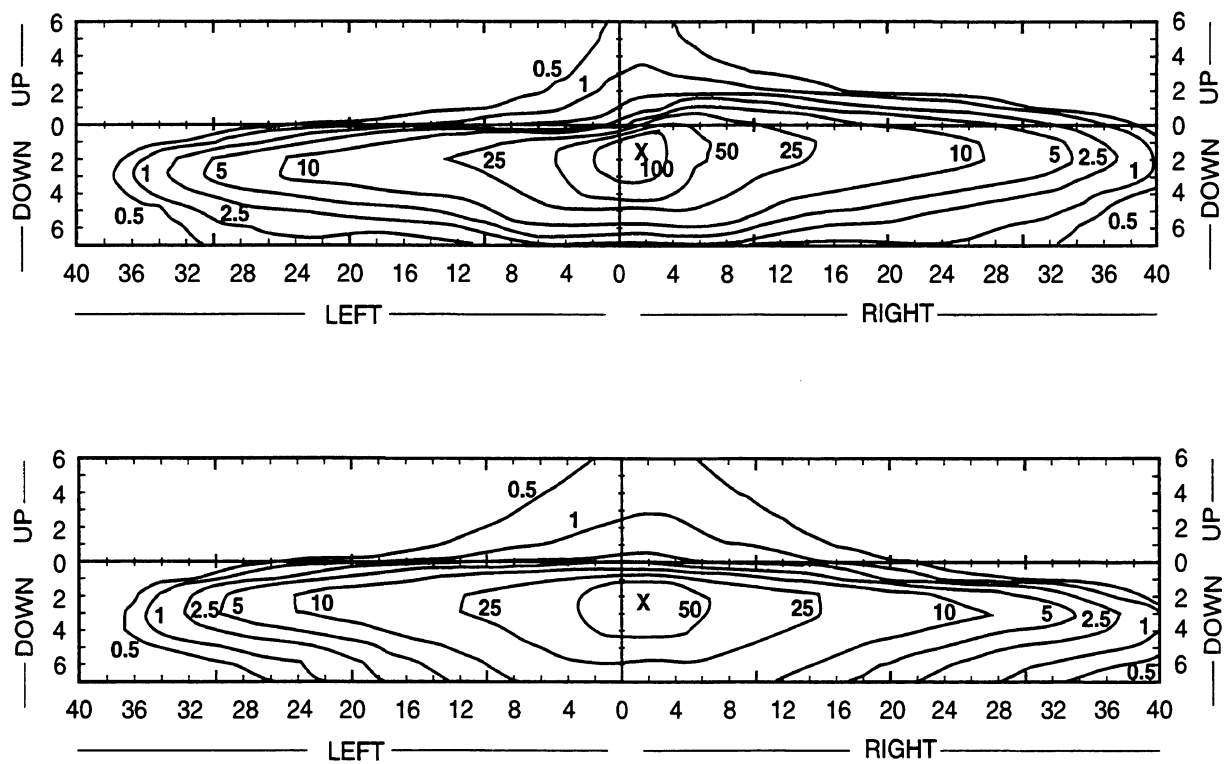
Figure 3. Isocandela diagram for the right fixed lamp (top panel) and the right rotatable lamp (bottom panel). (The axes are in degrees.)
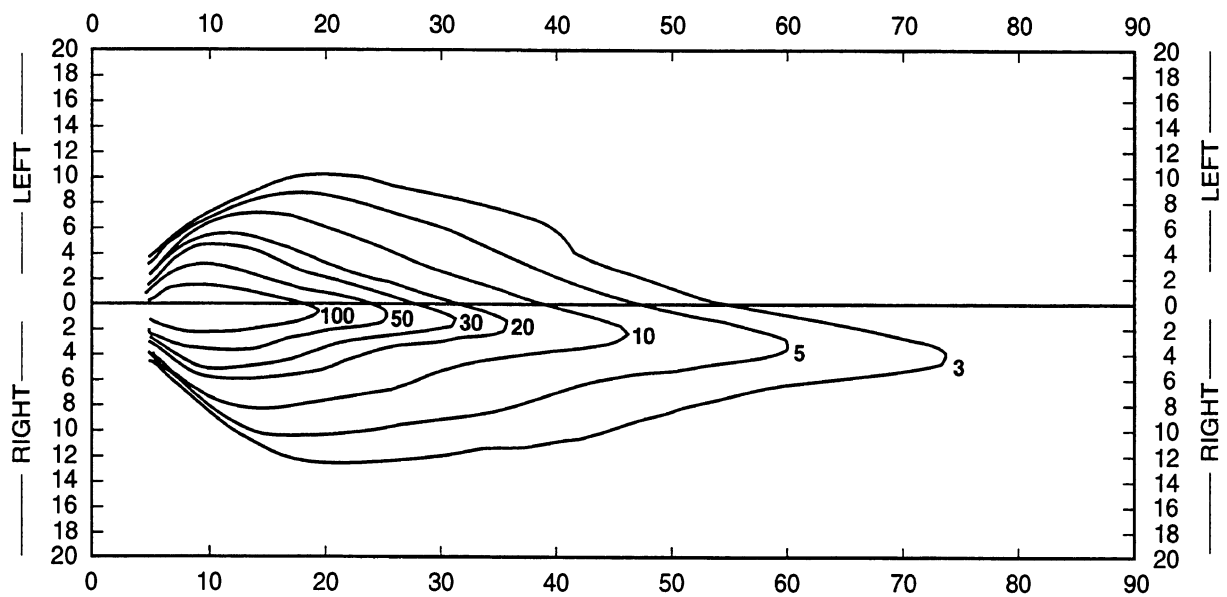
Figure 4. Isolux diagram of the combined beam pattern from all four lamps, projected on a road surface. Both rotatable lamps are at 0°. (The axes are in meters.)

Figure 5. Isolux diagrams of the combined beam pattern from all four lamps, projected on a road surface. The top panel is for the left rotatable lamp at -15° and the right rotatable lamp at 0°, while the bottom panel is for the left rotatable lamp at 0°, and the right rotatable lamp at +15°. (The axes are in meters.)

Figure 6. Isolux diagrams of the combined beam pattern from all four lamps, projected on a road surface. The top panel is for the left rotatable lamp at -30° and the right rotatable lamp at 0°, while the bottom panel is for the left rotatable lamp at 0°, and the right rotatable lamp at +30°. (The axes are in meters.)

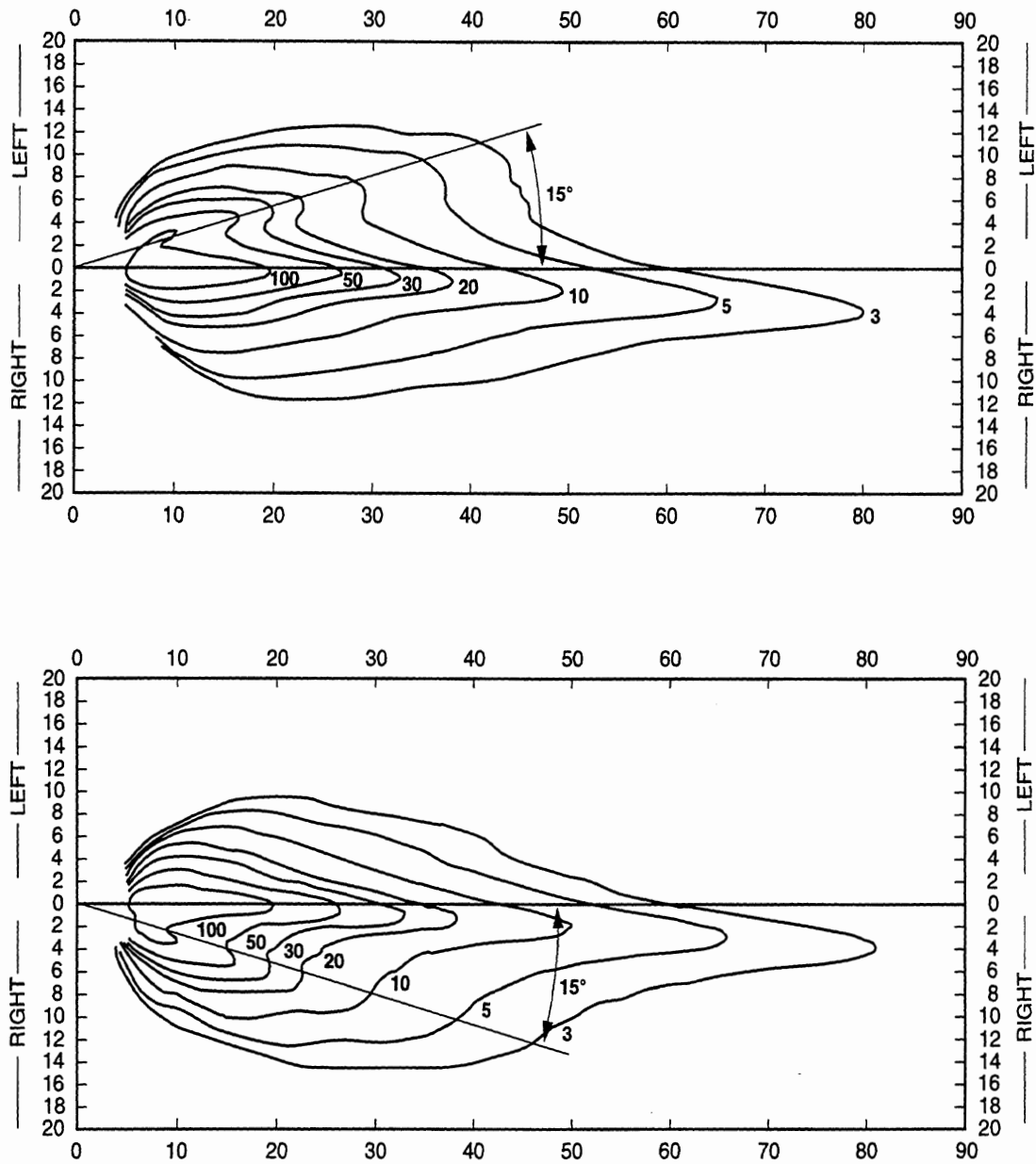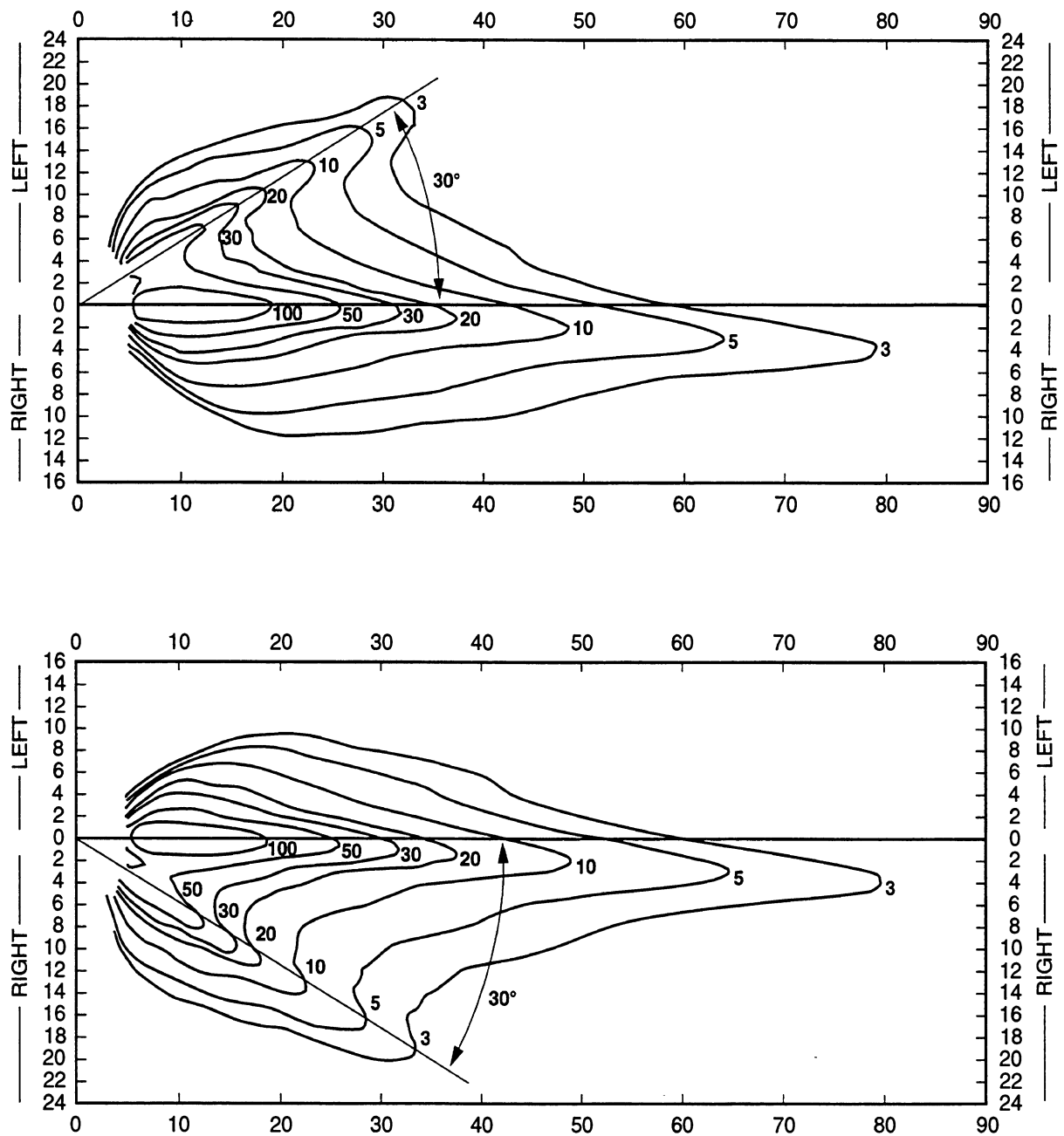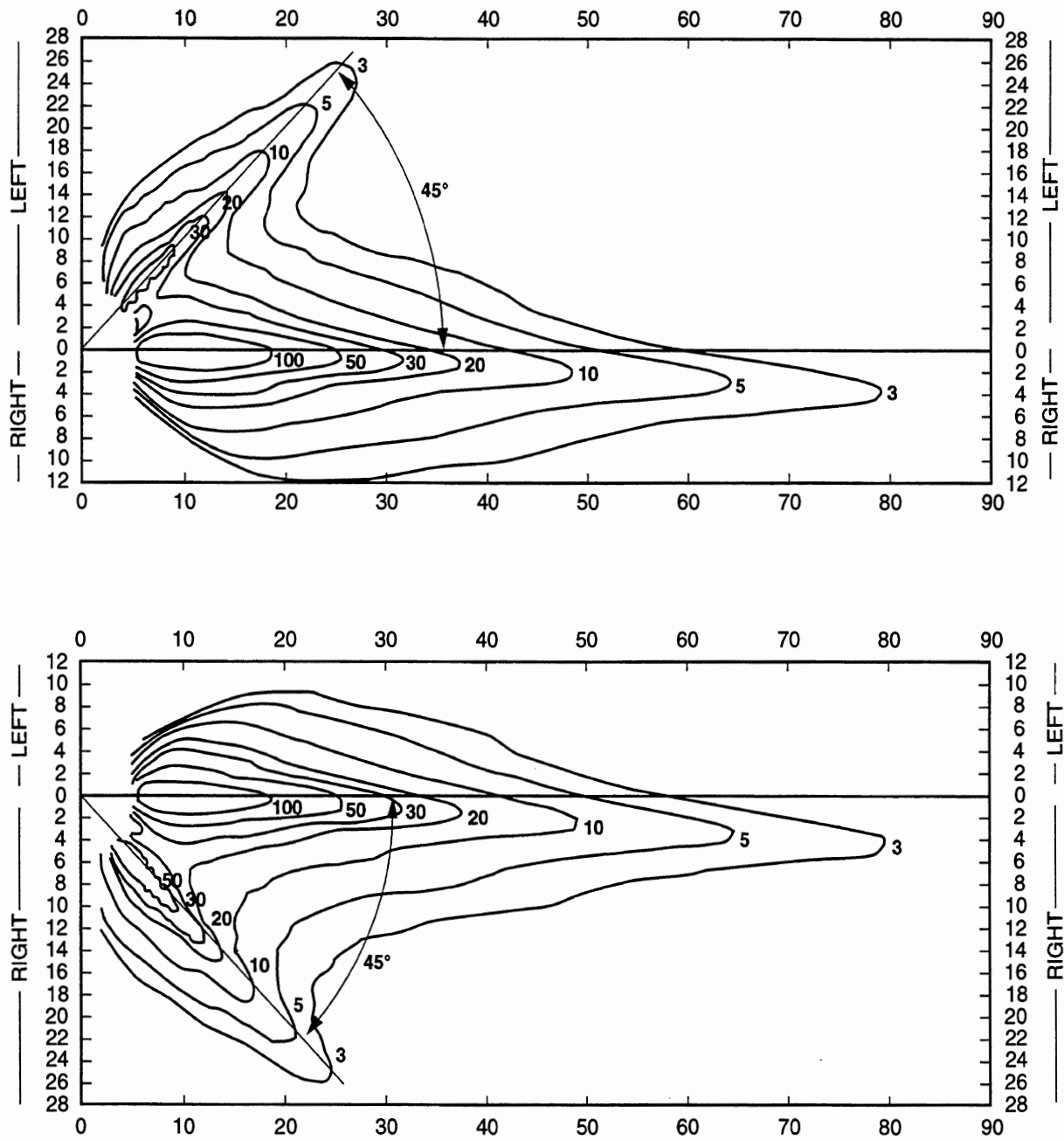Figure 7. Isolux diagrams of the combined beam pattern from all four lamps, projected on a road surface. The top panel is for the left rotatable lamp at -45° and the right rotatable lamp at 0°, while the bottom panel is for the left rotatable lamp at 0°, and the right rotatable lamp at +45°. (The axes are in meters.)

Table 1
Luminous intensities produced by the lamps at the U.S. test points. (The rotatable lamps are at 0°.)

Test Point	Limit (cd)		Left Lamps (cd)			Right Lamps (cd)		
	Min	Max	Fixed	Rotatable	Total	Fixed	Rotatable	Total
10U to 90U		125	56	46	102	56	50	106
1.5U, 1R to R		1400	354	207	561	312	137	449
1U, 1.5L to L		700	239	194	433	161	146	307
0.5U, 1.5L to L		1000	337	250	587	236	188	424
0.5U, 1R to 3R		2700	1310	332	1642	1300	216	1516
0.5D, 1.5L to L		3000	1780	850	2630	1860	860	2720
0.5D, 1.5R	10000	20000	10470	1170	11640	11590	1040	12630
1D, 6L	1000		2250	1800	4050	2940	2170	5110
1.5D, 2R	15000		16740	6990	23730	15670	6690	22360
1.5D, 9R	1000		3880	2630	6510	4240	2750	6990
1.5D, 9L	1000		2570	2030	4600	3200	2380	5580
2D, 15R	850		2400	1830	4230	2270	2530	4800
2D, 15L	850		1950	1690	3640	2050	1850	3900
4D, 4R		12500	7840	4130	11970	5350	5670	11020

EXPERIMENT 1: VISIBILITY

Method

Task. The task in this experiment was to detect a pedestrian walking from darkness into the light provided by the test vehicle, or to detect the disappearance of a pedestrian walking from the light provided by the test vehicle into darkness.

Test site. The test site was the approach roadway located at the entrance to The University of Michigan Matthaei Botanical Gardens. The surface of the two-lane road was asphalt (7.1 m wide), with no lane markings. The roadway had a relatively constant elevation and the radius of the curve was approximately 90 m (see Figure 8). The shoulder on either side of the roadway consisted of short grass and was clear of obstructions so that the roadway was clearly visible from all points along the curve in the range tested.

Repeated passes were made on the test road while the vehicle equipped with the AH system was in the automatic mode. A safe and reasonable top speed for the roadway was determined to be about 40 km/hr (25 mph). Under these conditions, the maximum angle of the AH system varied only slightly, and averaged 15°. Thus, 15° was selected as the appropriate AH system angle for this curve. This angle was used in the manual mode for the left hand outboard lamp on the left curve, and for the right outboard lamp on the right curve.

The experiment was conducted in November 1993, only on nights without visible moonlight (either when the moon was new, had not yet risen above the horizon, or was occluded by clouds), without active precipitation, and without water on the road surface. The experiment began at least one hour after sunset. The test site was free of lighting from street lamps and building lights. A minimal amount of traffic was encountered during the experiment. When other traffic was present, the experiment was temporarily halted and data collection was resumed only when the roadway was free of traffic.

Test vehicle. The subjects were seated in the driver's seat of a 1993 Honda Accord that was equipped with the AH system. The vehicle and its position on the roadway were configured for U.S./European right-hand traffic.

Subjects. Sixteen paid subjects participated in the experiment. Eight subjects were between the ages of 19 and 24 (with the mean of 21.9), and eight were between the ages of 62 and 72 (with a mean of 67.0). There were four males and four females in each age group. All subjects were licensed drivers.
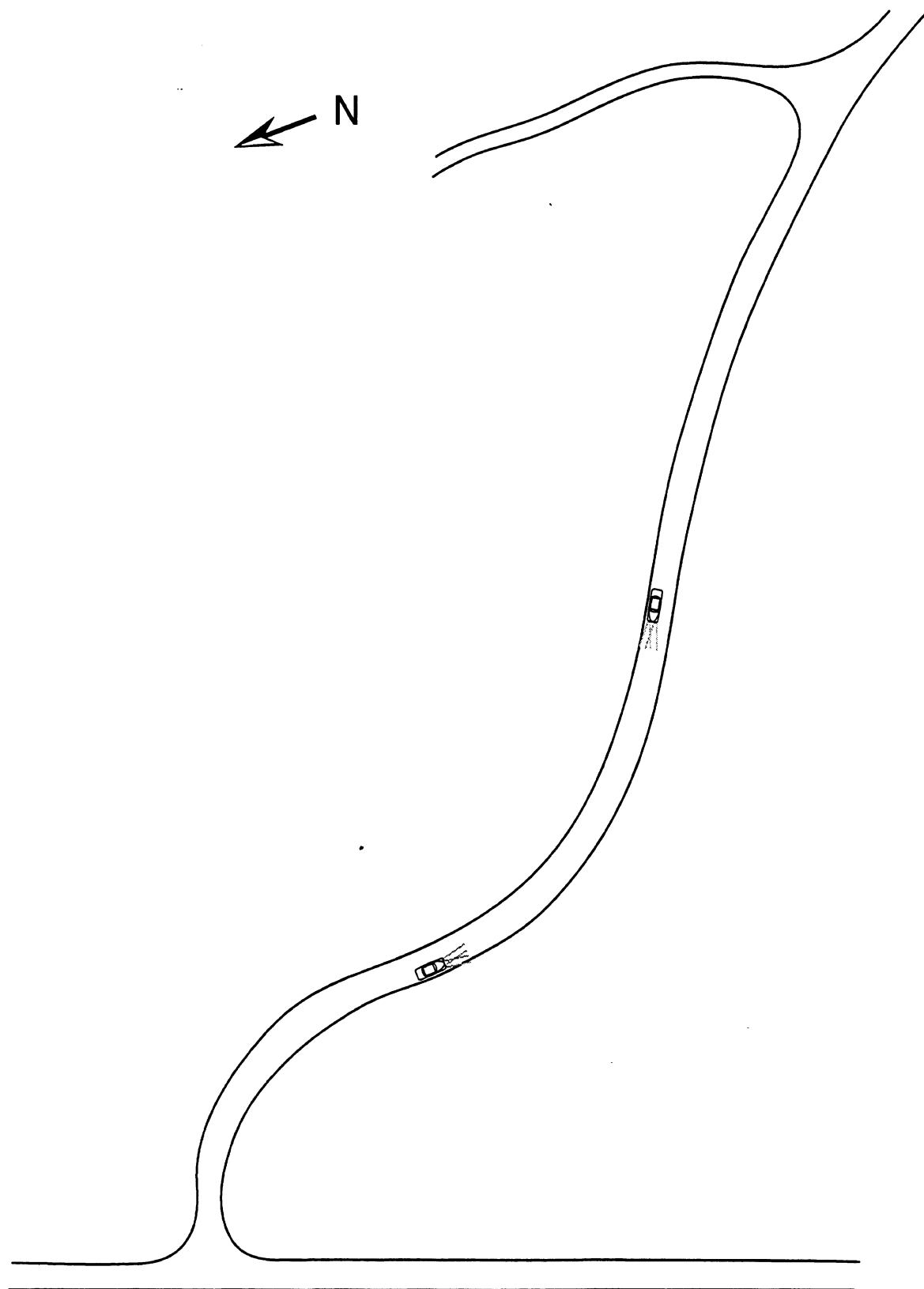
Figure 8. A schematic of the test site, showing the two positions of the test vehicle.

Design. There were 16 trials for each subject, eight trials each for the left- and right-hand directions of the same curve. During four trials the pedestrian walked toward the vehicle (i.e., out of the darkness and into the light), and during four trials the pedestrian walked away (i.e., out of the light and into the darkness). For each direction of the movement of the pedestrian, the AH system was "on" for two trials and "off" for two trials. The system "on" was represented by manually setting the angle for either the left or the right rotatable lamp (depending on the direction of the curve) at 15°, and system "off" by setting the angles for both of the rotatable lamps at 0°. There were two practice trials for each direction of the curve, one each with the pedestrian walking toward and away from the vehicle.

Procedure. The pedestrian, dressed completely in dark clothing (shirt, pants, shoes, gloves, and hat), walked on the right-hand edge of the roadway. The pedestrian started at a distance of 80 m when walking toward the vehicle, and at 20 m when walking away from the vehicle. All distances were measured in the center of the lane from the position of the subject seated in the AH- equipped vehicle, and were marked on the edge of the roadway. Successive trials alternated the direction of pedestrian travel.

Each subject was tested individually, and the experiment lasted approximately 40 minutes. The vehicle was positioned so that the right wheels were approximately 0.5 m from the right edge of the roadway. Subjects were seated in the driver's seat of the stationary, AH-equipped vehicle. One experimenter sat in the right front seat of the vehicle and provided the subjects with instructions. A second experimenter sat in the left rear seat of the vehicle and manually controlled the AH system. A third experimenter acted as the pedestrian walking along the edge of the roadway. Subjects were instructed that the pedestrian would be walking both toward and away from the stationary vehicle. Participants honked the car's horn when they were able to detect the presence of the pedestrian walking toward the test vehicle, and when the pedestrian was no longer detectable walking away from the test vehicle. The location of the pedestrian when the subject honked the vehicle horn was recorded by the "pedestrian" experimenter.

Results

A preliminary analysis showed that, although there was a slight tendency for the visibility distance to be longer when the pedestrian walked away from the subject (59.6 m) than when he walked toward the subject (59.3 m), the effect was not statistically significant. Consequently, the two directions of the movement of the pedestrian were collapsed in the main analysis, which investigated the effects of lamp system, curve direction, subject age, and subject sex.

The effect of lamp system was statistically significant, $F(1, 12) = 65.2, p < 0.001$, with longer visibility distances when the AH system was on (61.6 m) than when the system was off

(57.3 m). The effect of curve direction was also statistically significant, F (1, 12) = 6.3, $p < .05$, with longer visibility distances on the right curve (60.9 m) than on the left curve (58.0 m).

The interaction of the lamp system with the direction of the curve (see Table 2) was also statistically significant, F (1, 12) = 19.2, $p < 0.001$. (No other main effect or interaction was statistically significant.)

Table 2
Mean visibility distance (m).

AH System	Left Curve	Right Curve
Off	54.3	60.4
On	61.8	61.4

Discussion

One way of summarizing the data is to say that on the left curve the AH system provided extra visibility of 7.5 m (additional 14%), while on the right curve the benefit was 1.0 m (additional 2%). In both cases the increases in the visibility distance were statistically significant, and the increase on the left curve is of practical significance, as well. For example, at 40 km/hr, the extra 7.5 m of visibility distance translates into additional 0.68 seconds in which to make a decision.

There are at least two reasons for the greater benefit on the left curve. First, the low beam is inherently asymmetrical, providing more light to the right than to the left (see Figure 4). Second, the standard beam tested had a relatively gradual gradient to the right (see Figure 4). Thus, the increment in light to the right provided by the rotatable beams was in addition to an already substantial illumination.

14

EXPERIMENT 2: DISCOMFORT GLARE

Method

Task. The task in this experiment was to rate the amount of discomfort glare experienced from a test vehicle as it passed. The subjects used the so-called de Boer discomfort-glare scale (de Boer, 1967). It is a 9-point scale with qualifiers for only the odd points (see Table 3).

Table 3
The de Boer discomfort-glare scale.

Scale Value	Qualifier
1	unbearable
2	
3	disturbing
4	
5	just acceptable
6	
7	satisfactory
8	
9	just noticeable

Test site. The same test site was used as in Experiment 1. The positions of the subject's vehicle were the same as in Experiment 1 (see Figure 8).

Test vehicles. The subjects were seated in a 1992 Nissan Altima. The oncoming car (with the AH system on or off) was the same car as in Experiment 1 (a 1993 Honda Accord).

Subjects. Sixteen subjects were tested. They were the same persons who participated in Experiment 1.

Design. There were eight trials for each subject, four trials each for the left- and the right-hand directions of the same curve. During two of the trials the AH system was on (in its automatic mode). For the remaining two trials the AH system was off. Participants were given two practice trials for each direction of the curve, once each with the system on and off.

Procedure. Participants sat in the driver's seat of a parked vehicle, at the locations indicated in Figure 8, while the test vehicle drove past the parked vehicle with the subject. The starting distance of the glare vehicle was about 185 m away on the left curve, and 217 m on the right curve. This permitted ample distance and time for the AH vehicle to reach, and maintain, 40 km/hr.

Each subject was tested individually after completing Experiment 1. One experimenter sat in the right front seat of the subject's vehicle and provided the subject with instructions, while a second experimenter drove the test vehicle. Subjects were instructed to rate the amount of discomfort glare they felt from the passing vehicle's headlamps on a scale of 1 to 9, by calling out the number that most appropriately identified the amount of discomfort they experienced. They were told not to look directly into the oncoming car's headlamps, but to look forward as if actually driving. Subjects were given a laminated page that showed the de Boer scale. Each subject's participation lasted approximately 20 minutes.

Results

The effects of the following variables were of interest: lamp system, curve direction, subject age, and subject sex. The effect of the AH system was statistically significant, $F (1, 12) = 7.2, p < 0.05$, but small, with the system on yielding somewhat more discomforting responses, indicated by numerically *lower* de Boer ratings (5.3) than with the system off (5.7). The effect of the direction of the curve was also statistically significant, $F (1, 12) = 36.2, p < 0.001$, with the glare car on the right curve yielding more discomforting responses (4.7) than on the left curve (6.4). (The left and right curves are from the point of view of the vehicle with the headlamps to be evaluated—the same point of view as in Experiment 1.)

The interaction of the lamp system with the direction of the curve (see Table 4) was also statistically significant, $F (1, 12) = 13.4, p < .01$. On the left curve, there was a statistically significant increase in glare when the AH system was on. On the right curve there was a tendency for *less* glare with the system, but the effect was not statistically significant.

Table 4

Mean discomfort glare on the de Boer scale (lower numbers indicate more glare). The left and right curves are from the point of view of the vehicle with the headlamps to be evaluated.

AH System	Left Curve	Right Curve
Off	7.0	4.5
On	5.8	4.9

The effects of sex and age of the subjects were not statistically significant. Also, none of the interactions was statistically significant (except for lamp system by curve direction, as discussed above).

Discussion

On the left curve (from the perspective of the glare car) there was in increase in discomfort glare when the AH system was on. However, even with the AH system on, the glare on the left curve was less discomforting than the glare on the right curve without the AH system. Furthermore, the de Boer rating on the left curve for the AH system was better than "just acceptable" (scale point 5).

In contrast to the findings for the left curve, on the right curve there was a tendency for a decrease in discomfort glare when the AH system was on. These differential glare findings on the two curves are consistent with the asymmetry of the low-beam pattern and the geometry of the situation.

EXPERIMENT 3: SUBJECTIVE EVALUATIONS

Method

Task. Subjects were asked to provide subjective evaluations of several aspects of in-traffic driving experience with the AH system and a standard system.

Test route. The test route consisted of a 29.9 km route on public roads in the city of Ann Arbor, Michigan, and it took about 50 minutes to traverse. The route contained three different types of roads:

- two-lane residential streets (19.7 km)
- four-lane rural divided roadways without limited access (8.1 km)
- five-lane suburban nondivided roadways (2.1 km)

In general, the residential streets had less street lighting than the other two types of roads. The density of street lighting varied from 0 to 11 luminaires per km, and averaged 6.6 luminaires per km.

The subjects made 30 right turns and 23 left turns at 53 intersections. In addition to turns made at intersections, there were a total of 13 measurable right curves and 22 measurable left curves. The route was divided into four segments. At the end of each segment, subjects were asked to pull off to the side of the road and answer three questions based on the previous driving segment (see Procedure). The first segment was somewhat longer than the other three segments (see Table 5), but because the posted speeds were higher on this segment, the differences in the amount of time to traverse each segment were not large. The majority of the route consisted of streets with a speed limit of 40 km/h (25 mph), which was also the lowest posted speed limit throughout the route. The highest posted speed limit was 72 km/h (45 mph). The average speed limit for each segment is given in Table 5. The experiment was conducted in May and June 1994.

Table 5
The length and the average speed limits by segments of the test route.

Test Route Segment	Length (km)	Average Speed Limit (km/hr)
1	11.3	51
2	6.5	43
3	6.5	40
4	5.6	46
Overall	29.9	45

Test vehicle. The test vehicle was the same 1993 Honda Accord used in Experiments 1 and 2.

Subjects. Twelve paid subjects participated in the experiment. Six subjects were between the ages of 19 and 23 (with a mean of 20.5), and six were between the ages of 61 and 78 (with a mean of 67.3). There were three males and three females in each age group. All subjects were licensed drivers.

Design. Each subject drove the test route twice, once with the AH system in the automatic mode ("on") and once with the system turned off ("off"). The order of the two headlight systems was counterbalanced so that for half the subjects in each age group the AH system was on in the first run, and for the other half the AH system was on in the second run.

Procedure. Each subject was tested individually. Two experimenters accompanied the subjects. One experimenter, in the back seat, monitored the equipment. The other experimenter, in the right front seat, provided instructions to the subjects about the route to be followed, and administered questions at the end of each route segment. The subjects were told that they would drive the same route twice, each time with a different headlight system. No specific information was provided concerning the nature of the two headlight systems. On most of the four- and five-lane roads, the subjects were asked to make as many lane changes as traffic conditions would allow. The actual frequency of lane changes ranged from 5 to 18 per each run, with a mean of 10.1.

Three questions (see Table 6) were administered four times, at the end of each route segment. Six questions (see Table 7) were given twice, after each run. Three questions (see Table 8) were given once, after the completion of both runs.

Table 6
The questions that were given four times per run, once after each segment of the route.

Please rate how the headlamps affected your **visual comfort** on the previous segment.

1   (very uncomfortable)

2

3

4   (about as comfortable as with headlamps on my own car)

5

6

7   (very comfortable)

Please rate how the headlamps affected your **visual fatigue** on the previous segment.

1   (great amount of fatigue)

2

3

4   (about as much fatigue as with headlamps on my own car)

5

6

7   (no fatigue)

Please rate how the headlamps affected your **driving confidence** on the previous segment.

1   (not confident)

2

3

4   (about as confident as with headlamps on my own car)

5

6

7   (confident)

Table 7
The questions that were given once after each run.

How well could you see on **curves**?
 	
    1   (very poorly)
 	
    2
 	
    3
 	
    4   (about as well as with headlamps in my own car)
 	
    5
 	
    6
 	
    7   (very well)

How well could you see at **intersections**? (The same response scale as above.)
How well could you see while **changing lanes**? (The same response scale as above.)
How well could you see **overall**? (The same response scale as above.)
Please indicate what you liked best about the headlighting system on the previous run.
Please indicate what you liked least about the headlighting system on the previous run.

Table 8
The questions that were given after the completion of both runs.

Please indicate your overall preference between the two headlighting systems that you have used on the two runs.

       1   (strong preference for headlighting system on the first run)

       2

       3

       4   (no preference between the two systems)

       5

       6

       7   (strong preference for headlighting system on the second run)

Please indicate below any further reactions that you have to either system.

Results

The effects of the headlight systems. There were no significant differences in the evaluations of the two headlight systems on any of the questions. This applies to questions administered after each route segment, after each run, and after completion of both runs. (Also, there were no statistically significant differences due to subject age and sex.) The mean ratings on the seven questions that evaluated different aspects of the performance of the headlight systems are shown in Table 9 for each headlight system. Table 10 summarizes the overall preferences between the two systems.

Table 9
Mean ratings on the seven questions that evaluated different aspects of the performance of the headlight systems. All seven questions used a 7-point rating scale, on which the value of 1 was the most negative, 4 comparable to the headlamps in one's own car, and 7 the most positive. (The entries for the first three questions are the means of answers given in four administrations of the questions, one at the end of each of the four route segments.)

Question	Aspect of performance	AH system	Standard system
1	Comfort	4.8	4.6
2	Fatigue	5.2	5.6
3	Confidence	5.2	5.1
4	Seeing on curves	5.4	5.2
5	Seeing at intersections	5.1	4.8
6	Seeing while changing lanes	5.6	5.2
7	Seeing overall	5.3	5.0

Table 10
Overall preference between the two headlight systems, by subject.

Scale point	Descriptor	Frequency
1	Strong preference for the AH system	4
2		1
3		1
4	No preference between the two systems	1
5		0
6		2
7	Strong preference for the standard system	3

What the subjects liked and did not like about the AH system

The subjects realized that the AH system provided a wider field of view through increased lateral illumination. Eleven out of twelve subjects indicated that they liked the wider field of view/increased lateral illumination provided by the AH system. According to the subjects' comments, the benefits of the AH system were evident primarily on curves, at intersections, and when changing lanes. Three older drivers pointed out that the AH system would improve the quality of (and confidence) in night driving, and increase one's nighttime mobility.

On the other hand, seven subjects commented that they found the moving light of the AH system distracting. Six subjects (including two of the seven who found the movement distracting) did not like the "jerkiness" (unevenness) of the movement. (Of the five subjects who preferred the standard system, four cited some aspect of the movement of the light by the AH system as a negative aspect.) One subject felt that the movement was too "slow," and two subjects did not like the dark area between the fixed and rotatable beams (evident at large angles of the rotatable beam).

Relation of the overall preference between the two systems to the subjective evaluation of the systems' performance. Subjects who tended to like various specific aspects of the AH system also tended to have an overall preference for the AH system over the standard system. The amounts of variance in overall preference accounted for by linear regressions on ratings of specific aspects are shown in Table 11. Figure 9 shows a scatter plot of the overall preferences and the mean differences in the specific evaluations, along with a best fitting regression line. Figure 10 plots the same data, but the lines are based on the assumptions that (1) if the absolute mean difference is greater than 1, subjects strongly prefer one system over the other, and (2) if the absolute mean difference is smaller than 1, the relation can be described by a linear function.

Table 11
The proportion of variance in individual subjects' overall preferences accounted for by the differences in their ratings of specific aspects of the two systems.

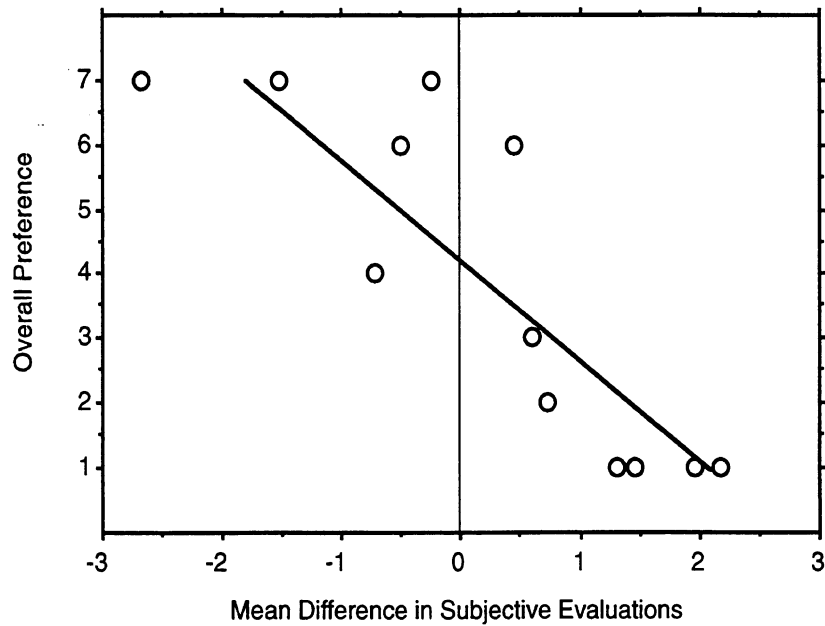| Aspect of performance	Proportion of variance accounted for
Comfort	.56
Fatigue	.68
Confidence	.62
Seeing on curves	.50
Seeing at intersections	.67
Seeing while changing lanes	.48
Seeing overall	.50
Mean of all aspects	.73

Figure 9. The relationship between overall preference and the mean difference in the evaluations of specific aspects of performance. The straight line is the best fitting regression equation. (The overall preference was recoded so that 1 = strong preference for the AH system, 4 = no preference between the two systems, and 7 = strong preference for the standard system. A positive difference in subjective evaluations indicates that the AH system was rated more positively than the standard system.)
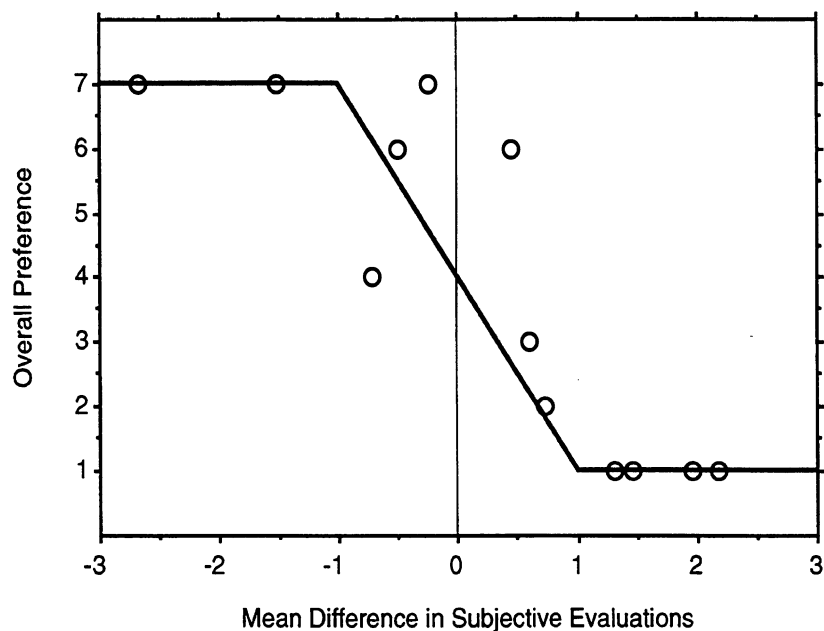

Figure 10. The relationship between overall preference and the mean difference in the evaluations of specific aspects of performance. The data points are the same as in Figure 9. The lines are based on the assumptions that (1) if the absolute mean difference is greater than 1, subjects strongly prefer one system over the other, and (2) if the absolute mean difference is smaller than 1, the relation can be described by a linear function.

Discussion

The results of this experiment indicate that, although as a group the subjects did not have a preference for one headlight system over the other, individual subjects did have strong preferences and those preferences were systematically related to their evaluations of various specific aspects of the two systems' performance. Using the means of the answers to the seven questions concerning specific aspects of performance, 73% of the variance in overall preference between the two systems can be accounted for.

The strength of individual subjects' preferences, some in one direction and some in the other, is shown in Table 10. Of 12 subjects, seven used the two extreme scale points on a 7-point response scale (points 1 and 7), with four strongly preferring the AH system, and three strongly preferring the standard system. Also, three subjects used the next two extreme scale points (points 2 and 6). Only one subject had no preference between the systems (point 4), and one subject had a slight preference for the AH system (point 3).

The subjects liked the wider field of view provided by the AH system. All but one of the subjects indicated that they liked this feature of the AH system. The 11 subjects who commented positively about the wide field of view included not only the six who indicated an overall preference for the AH system, but also four out of the five who preferred the standard system. According to the subjects, the wider field of view is especially beneficial on curves, at intersections, and for seeing objects in adjacent lanes.

Of the five subjects who preferred the standard system, four cited some aspect of the movement of the light by the AH system as a negative aspect. Although these results indicate a problem with how drivers perceive the movement of the headlamps, they do not indicate exactly what aspect of the movement they dislike. When subjects give unstructured descriptions of their subjective experience, they do not always choose the best words or fully isolate the aspects of a system that lead to their impressions. Perhaps future research should address the relationship between objective descriptions of the beam's movement and the subjective experiences of drivers. Other complaints included the dark area between the fixed beam and the rotatable beam (visible at large angles of the AH system), and a relatively slow return of the rotatable beam to the straight-ahead position.

SUMMARY AND CONCLUSIONS

This study evaluated several performance aspects of the Active Headlight (AH) system, developed by Honda R&D and Stanley Electric. The AH system delivers a low-beam pattern by means of two lamps on each side of a vehicle. The inboard lamps are fixed and the outboard lamps can be turned horizontally. An onboard computer determines the horizontal angle of the rotatable lamps based on three factors: steering-wheel angle, speed, and position of the turn-signal switch.

In the first of three experiments, pedestrian visibility was assessed on left and right curves. The subject was seated in a stationary vehicle at the start of the curve, and a dark-clad pedestrian moved either toward or away from the subject's vehicle. For the particular curve radius tested (approximately 90 m), the AH system, in comparison to a standard headlight system, provided on the left curve extra visibility of 7.5 m (additional 14%), while on the right curve the benefit was 1 m (additional 2%). In both cases the increases were statistically significant, and the increase on the left curve is of practical significance as well.

In the second experiment, discomfort glare for the oncoming drivers was evaluated on the same curves as in the first experiment. The subject was seated in a stationary vehicle at the start of a curve, and rated discomfort glare experienced from an oncoming car by using the deBoer discomfort-glare scale. The results indicate that on the left curve (from the perspective of the glare car) there was in increase in discomfort glare when the AH system was on. However, even with the AH system on, the glare on the left curve was less discomforting than the glare on the right curve with the standard system. In contrast, on the right curve there was a (statistically non-significant) tendency for a decrease in discomfort glare when the AH system was on. The differential glare findings on the two curves are consistent with the asymmetry of the beam and the geometry of the situation.

The third experiment evaluated subjective impressions of headlamp performance and overall preference after a 30-km, in-traffic driving experience with the AH system and a standard system. The performance aspects of interest included seeing on curves, at intersections, while changing lanes, and overall; as well as comfort, fatigue, and confidence. There were no statistically significant differences between the two systems on any of the specific aspects of performance, nor in overall preference between the two systems. However, individual subjects tended to have strong preferences—either for the AH system or for the standard system—and those preferences were systematically related to their evaluations of specific aspects of performance. The subjects liked the increased lateral illumination provided by the AH system on curves, at intersections, and while changing lanes. The complaints about the AH system included perceived jerkiness of the movement of the light, slow return of the light, and the dark area between the fixed and rotatable beams.

Overall, the findings of this study imply that dynamically controllable headlamps, as embodied in the AH system, are likely to provide increased visibility for low-contrast objects on curves and at intersections, along with an acceptable increase in discomfort glare for oncoming drivers. Driver acceptance of, and preference for, such a system will likely depend on modifying the light distributions provided by the component lamps and changing certain aspects of the movement of the rotatable beams.

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