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Study on the Improvement of Pedestrian and Vehicle Visibility by Geometric Patterns Projection Lighting

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Abstract

The proportion of pedestrian fatalities due to traffic accidents is higher at night than during the day. Drivers can more easily recognize pedestrians by setting their headlights to high beam, but use of high beam poses the issue of increasing glare for pedestrians. This study proposes a lighting technology that increases the noticeability of pedestrians for drivers and the noticeability of approaching vehicles for pedestrians while at the same time helping to reduce glare for pedestrians. The newly designed lighting enables geometric patterns projection lighting that makes use of projection technology. This geometric pattern projection lighting was compared with conventional low beam and high beam headlights to verify the effectiveness. Tests were conducted on a closed course with the participation of 20 drivers to evaluate the functionality of each headlight type. In these tests, subjects performed specific tasks such as evaluation of pedestrian visibility from the driver's point of view, and noticeability of approaching vehicles and glare from the pedestrian's point of view. Human subject tests used an experimental design in which study subjects experienced all three types of headlights in multiple trials. The results showed that while high beam provided the longest visibility distance, the glare was also the greatest. Geometric patterns projection lighting was shown to be better than low beam in both pedestrian visibility distance and distance at which an approaching vehicle is noticed. Overall, geometric patterns projection lighting was able to achieve a good balance between visibility distance and lower glare, and was verified to be a promising means of increasing visibility for drivers at night.

Introduction

Accidents involving pedestrian fatalities account for 18% of traffic accidents in the United States, and 75% of such accidents are in road situations other than intersections, as shown in Fig. 1. Accidents involving pedestrian fatalities are also more likely at night, with 19% during the day and 78% at night, as shown in Fig. 2. [1]

Development of nighttime lighting technologies is underway, such as a headlight system that detects the presence of surrounding vehicles and automatically switches between high beam and low beam (Auto High Beam), and a variable light distribution-type headlight system that detects the positions of surrounding vehicles and masks the light to help prevent glare (Adaptive Driving Beam).

These conventional systems have the following issues. Low beams are designed with a light distribution that prevents glare for oncoming drivers, and the light does not reach pedestrians walking on the sidewalk on the opposite side of the road, making them difficult to

FIGURE 1 Locations of accidents involving pedestrian fatalities in North America in 2022

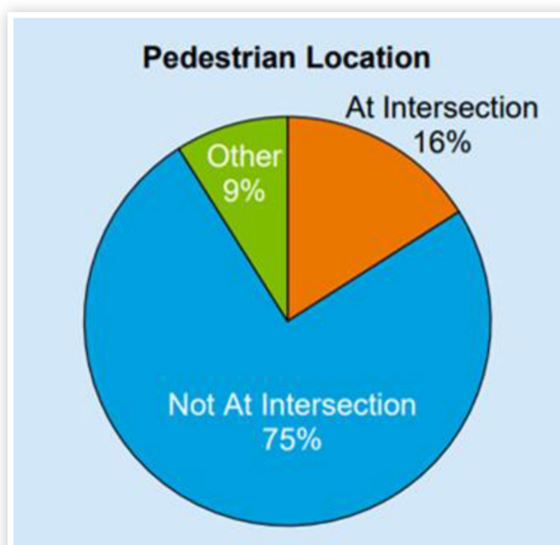
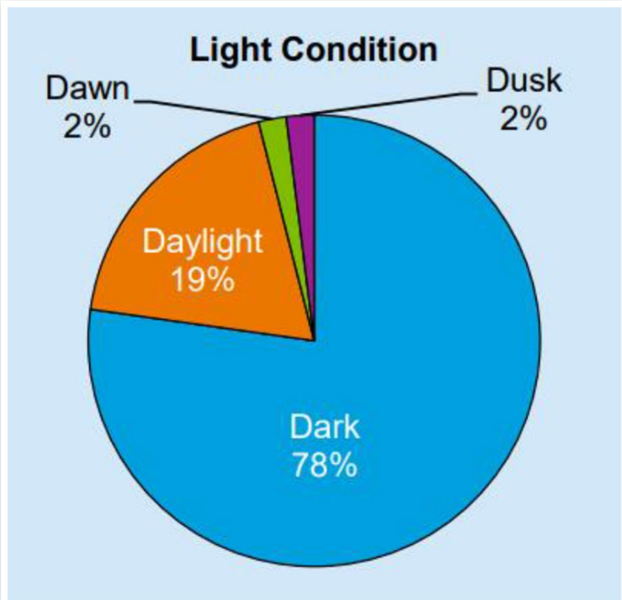


FIGURE 2 Time periods of accidents involving pedestrian fatalities in North America in 2022



see. In addition, auto high beams and adaptive driving beams illuminate pedestrians, but do not take glare into consideration. Therefore, geometric patterns lighting that makes use of projection technology was devised and its effectiveness was clarified.

Geometric Patterns Projection Lighting

This study examined the use of projection technology, which is continuing to advance, to enhance pedestrian visibility while at the same time helping to prevent glare to pedestrians by projecting light with geometric patterns.

Regarding geometric patterns, the following three patterns were studied.

The first pattern, as shown in Fig. 3, illuminates with vertically banded light in order to reduce glare. When pedestrians cross through an area that is illuminated with vertically banded light, the light in the bright lines in the banding is a powerful stimulus, whereas the stimulus of light in the dark lines is weakened. It was confirmed that movement is made more conspicuous by this variation in light stimulus. Since the bright lines in the vertical banding are emphasized, however, it was found that pedestrians appear like sticks and are not easily recognized as pedestrians.

Therefore the second pattern studied as a way to enhance the visibility of pedestrians was a grid pattern, as shown in Fig. 4, that adds horizontal bands to the first pattern. It was confirmed that the visibility of pedestrians was enhanced over the first pattern because the light is in a grid pattern. However, depending on the body type of the pedestrian, this pattern ends up continuing to shine the powerful light into the pedestrian’s eyes with the horizontal bands, so it was found that this pattern was not able to reduce the glare.

The third pattern studied as a way of enhancing the visibility of pedestrians, therefore, was the diamond-shaped pattern made up of diagonal lines shown in Fig. 5. This would reduce the amount of light on pedestrians regardless of differences in their body type. As a result, it was found that this could emphasize the movement of pedestrians, enhance the visibility of pedestrians, and reduce the glare on pedestrians, as shown in Fig. 6.

The geometric patterns used a diamond-shaped pattern that enhances visibility by emphasizing the

FIGURE 3 Vertically banded pattern

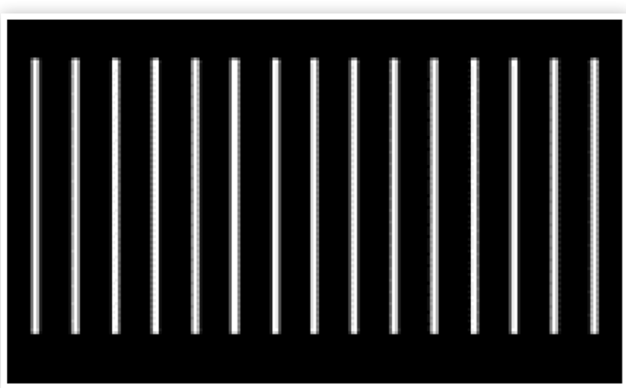


FIGURE 4 Grid pattern

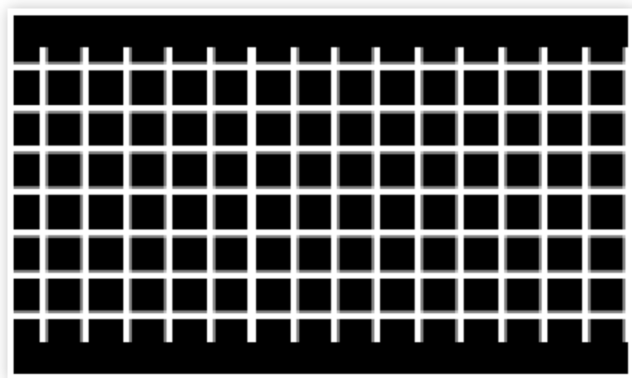


FIGURE 5 Diamond-shaped pattern

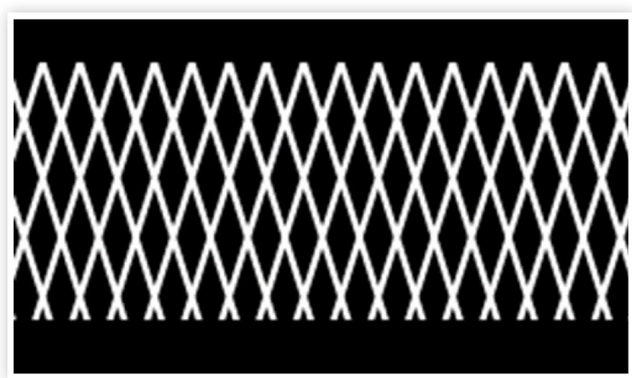


FIGURE 6 Emphasized pedestrians

movement of pedestrians regardless of pedestrian body type.[2]

The brightness of the diamond-shaped pattern is 2.0 lux in front of the eye at a distance of 40 m from the test vehicle. At the same position, the low beam is 0.2 lux, and the high beam is 5.0 lux.

When the diamond-shaped pattern is illuminated with 100% illuminance from the feet to the head of a pedestrian, glare to the pedestrian becomes an issue. In addition, illumination that does not reach above the chest of the pedestrian can reduce glare, but the driver's ability to detect the pedestrian decreases. By setting the illumination from the feet to the chest at 100% and the illuminance from the chest and above at 50%, it is possible to reduce glare on the pedestrian and improve the driver's ability to detect the pedestrian. Diamond-shaped pattern that reduces glare is shown in Fig. 7.

Figure 8 shows the illuminating area of this diamond-shaped pattern projection lighting. Assuming a scenario where a driver driving a vehicle at a speed of 40 to 60 km/h (25 to 37.5 mph) notices a pedestrian attempting to cross the road and stops, the lighting was set to illuminate the sidewalk 40 m to 80 m ahead. This enabled illumination of the pedestrian’s entire body with a diamond-shaped pattern, as shown in Fig. 9.

General human subject verification was performed using this diamond-shaped pattern projection lighting to confirm the effect.

FIGURE 7 Glare-reducing diamond-shaped pattern

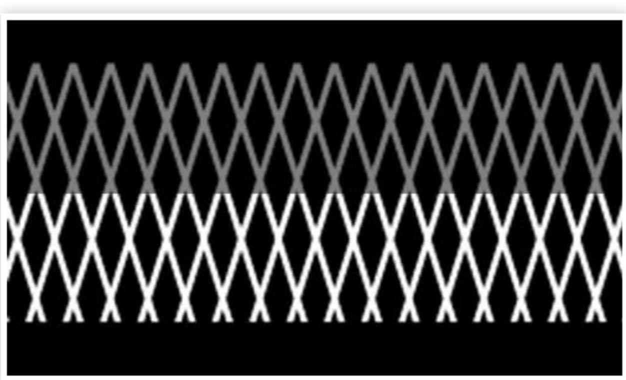


FIGURE 8 Illuminating area

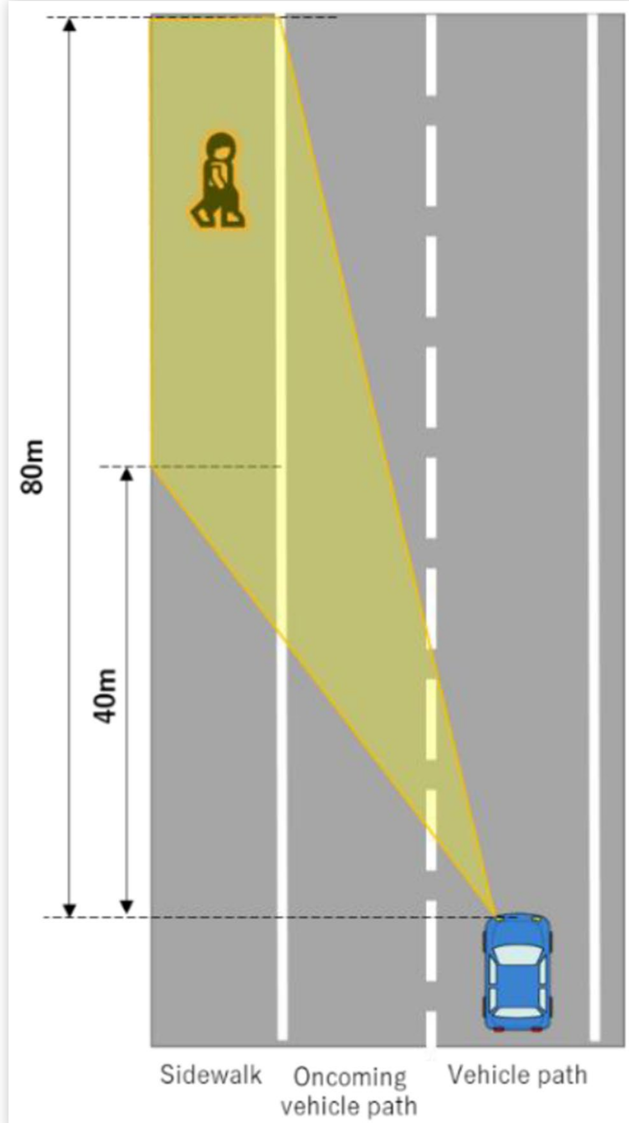
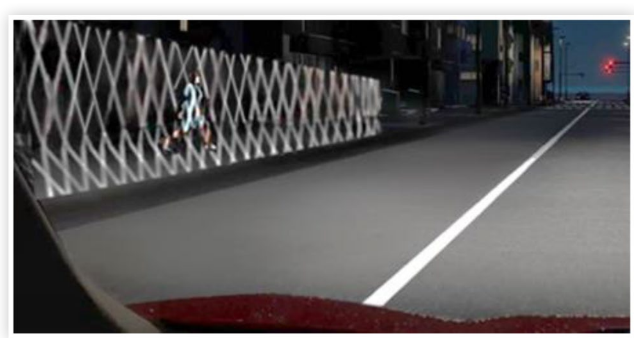


FIGURE 9 Diamond-shaped pattern illumination



Test Contents

Evaluation Method

The following three tests were conducted using geometric patterns projection lighting that makes use of projection technology.

Test 1 obtained the distance at which the test vehicle driver recognizes a pedestrian crossing the road from the left. This visibility distance was used as a parameter to judge the visibility quality.

Test 2 obtained the distance at which a pedestrian on the sidewalk noticed an approaching vehicle. This noticing distance was used as a parameter to judge the noticeability quality.

Test 3 conducted sensory evaluation of the glare from low beam, high beam, and geometric patterns projection lighting.

For convenience, geometric patterns projection lighting that makes use of projection technology is referred to hereinafter as projection lighting.

Study Subjects and Informed Consent

The study subjects consisted of 20 male and female subjects aged 18 to 66 years old selected randomly from general drivers in the U.S. Table 1 shows the age breakdown. The study subjects were voluntary participants, and the test supervisor provided thorough oral and written explanations of the purpose and content of this study as well as the right to participate, and obtained written consent to participate in advance.

Test Environment and Equipment

The test was conducted on a closed course after sunset, once it became dark enough, and only in clear weather. A 2018 Honda CR-V equipped with projection lighting was prepared as the test vehicle, and two GPS transceivers (for the vehicle and for the pedestrian) were prepared for distance measurement.

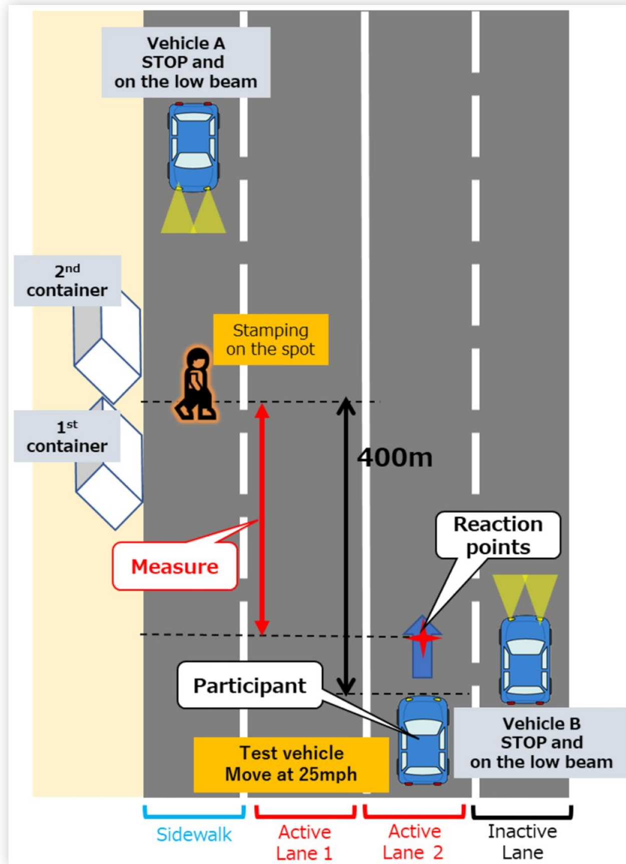
Test 1 Procedure

The test course used a 1,000 m section of straight road, and the vehicles, roadside objects, and pedestrian were arranged as shown in Fig. 10. The low beam headlights of vehicles A and B were lit to help keep the test vehicle from standing out. White containers that simulated houses were located as roadside objects, and a pedestrian marched in place on the sidewalk. The study subjects rode in the test vehicle as the driver, and the test was started with a distance between the test vehicle and the pedestrian of 400 m or more. The study subjects drove in their lane at 40 km/h (25 mph), and signaled when they recognized something moving. The vehicle speed was set to a constant speed of 40 km/h (25 mph) using Adaptive Cruise Control. The tester measured the distance to the pedestrian from the point where the study subjects noticed something moving. To help keep the study subjects from guessing the pedestrian position, the pedestrian marched in place in the three positions A, B, and C, as shown in Fig. 11. Randomization was performed by varying the order of the pedestrian positions and the lighting modes for each group as shown in Table 2. Testing was conducted with the two pedestrian clothing color patterns of white and black for the three lighting modes shown in Table 3.

TABLE 1 Breakdown of study subjects

Age Breakdown	Male	Female
18-24	2	2
25-35	2	2
36-45	2	2
46-55	2	2
56+	2	2

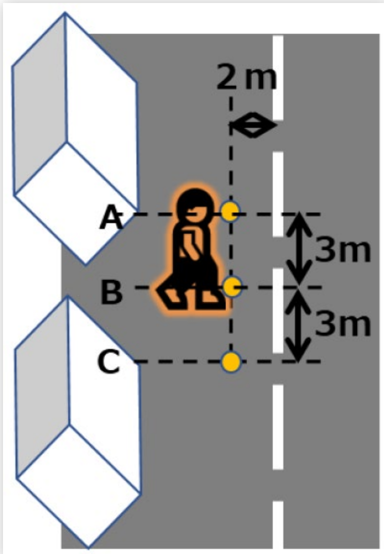
FIGURE 10 Test 1 layout



Test 2 Procedure

The test course used a 1,000 m section of straight road, and the test layout had the relative positions shown in Fig. 12. The low beam headlights of vehicles A and B were lit to help keep the test vehicle from standing out. The study subjects stood on the sidewalk as pedestrians, and

FIGURE 11 Pedestrian position



faced the direction to cross the road while looking at a smartphone. The study subjects were asked to pay attention to the sidewalk on the opposite side of the road. Vehicles came from both the left and right directions, but the study subjects wore headphones in both ears and listened to music so that they could not hear the running sound of the test vehicle. The test was started with a distance between the test vehicle and the study subject of 400 m or more. The tester rode in the driver's seat of the test vehicle and drove in their lane at 40 km/h (25 mph). The vehicle speed was set to the constant speed of 40 km/h (25 mph) using Adaptive Cruise Control. The study subjects (pedestrians) signaled when they noticed the approaching vehicle. The tester measured the distance to the study subjects from the point where the study subjects noticed something moving. Testing was conducted with the test vehicle lighting modes specified for Tests 1 to 6, as shown in Fig. 12. To help keep the study subjects from guessing the direction from which the test vehicle would come, randomization was performed so that the test vehicle came from the left or right of the study subjects. However, measurement was actually performed only for Tests 2, 3, 5, and 6 in which the test vehicle came from the right of the study subjects. Table 4 shows the driving conditions. In addition, sensory evaluation was conducted to compare the noticeability of the approaching vehicle for each lighting mode. The test was conducted with the three lighting modes shown in Table 3.

Test 3 Procedure

The test course used a 1,000 m section of straight road, and the test layout had the relative positions shown in Fig. 13. The low beam headlights of vehicles A and B were lit to help keep the test vehicle from standing out. The study subjects stood on the sidewalk as pedestrians, and faced the direction to cross the road. The test was started with a distance between the test vehicle and the pedestrian of

TABLE 2 Test 1 group conditions

	Order	Pedestrian Position	Lighting mode
GROUP A	1	Null	Low beam
	2	Null	Projection lighting
	3	A	High beam
	4	Null	High beam
	5	B	Projection lighting
	6	C	Low beam
GROUP B	1	Null	High beam
	2	Null	Projection lighting
	3	B	Low beam
	4	Null	Low beam
	5	A	Projection lighting
	6	C	High beam
GROUP C	1	Null	Low beam
	2	Null	Projection lighting
	3	B	High beam
	4	Null	High beam
	5	C	Projection lighting
	6	A	Low beam
GROUP D	1	Null	High beam
	2	Null	Projection lighting
	3	C	Low beam
	4	Null	Low beam
	5	A	Projection lighting
	6	B	High beam
GROUP E	1	Null	Low beam
	2	Null	Projection lighting
	3	A	High beam
	4	Null	High beam
	5	C	Projection lighting
	6	B	Low beam

TABLE 3 Lighting modes

Lighting mode	①Low beam
	②Low beam + Geometric patterns projection lighting
	③Low beam + High beam

400 m or more. The tester rode in the driver's seat of the test vehicle and drove in their lane at 40 km/h (25 mph). The vehicle speed was set to the constant speed of 40 km/h (25 mph) using Adaptive Cruise Control. After the test vehicle had passed in front of them, the study subjects evaluated the glare using the de Boer scale. The test was conducted with the three lighting modes shown in Table 3.

Test Results

Test 1 Results

The distance at which the study subjects (drivers) recognized a pedestrian dressed in white was measured, and

FIGURE 12 Test 2 layout

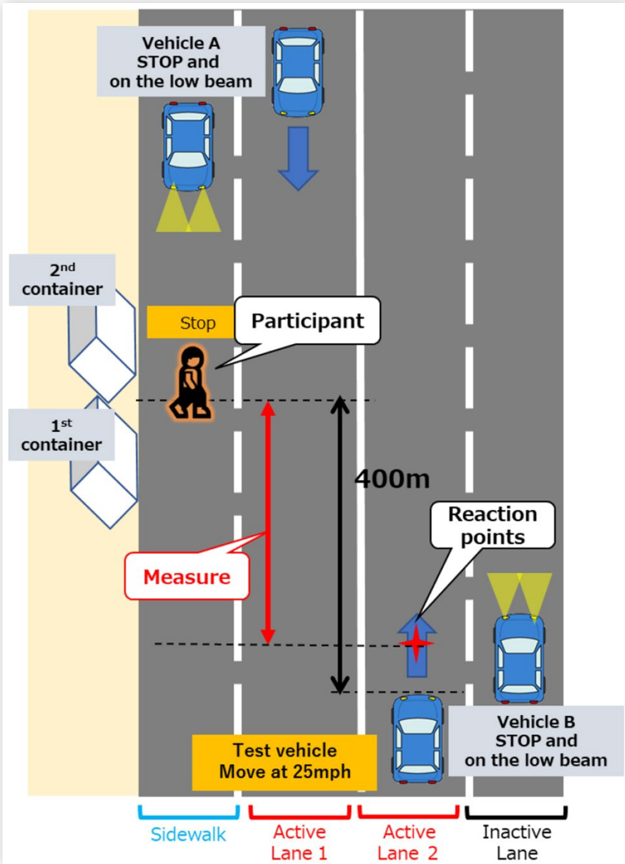


FIGURE 13 Test 3 layout

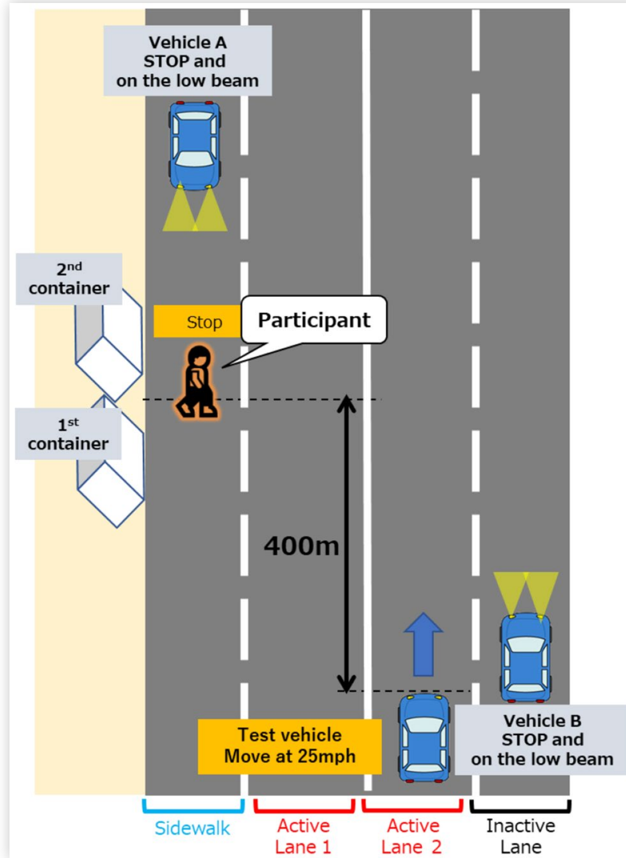


TABLE 4 Driving condition

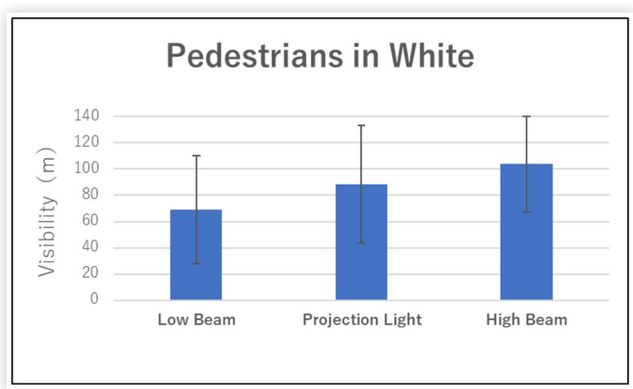
	Traveling Lane	Function
Test 1	Active Lane 1	Low beam
Test 2	Active Lane 2	Low beam
Test 3	Active Lane 2	Projection
Test 4	Active Lane 1	Low beam
Test 5	Active Lane 2	Projection
Test 6	Active Lane 2	High beam

the average value of the results was calculated. Figure 14 shows the results.

From Fig. 14, the average for projection lighting was 88.2 m compared to an average of 69.0 m for low beam, which is an increase in visibility distance of 19.2 m or 28%. The average distance for high beam was 103.8 m. This result was recognized as a significant difference based on the significance test.

The repeated measures analysis of variance (ANOVA) with one within-subjects factor was conducted for each comparison to examine whether there was a significant difference between the headlight types. The repeated measures ANOVA revealed a significant main effect of headlight type on the distance at which participants detected the pedestrian wearing white, $F(2, 38) = 11.979$, $p < .001$, $\eta^2 = .387$. A significant difference was found between low beam and projection lighting, indicating that

FIGURE 14 Average value of visibility distance of pedestrians dressed in white

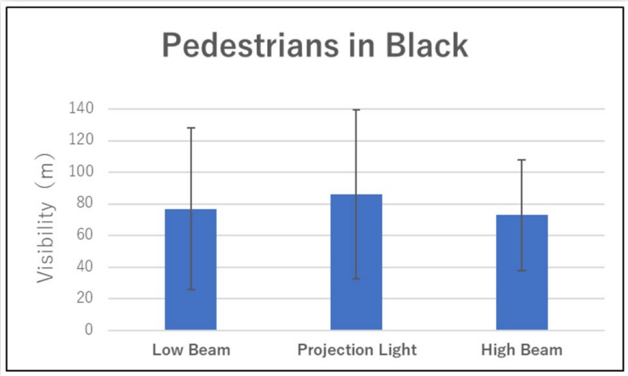


projection lighting is more effective than low beam for detecting pedestrians wearing white clothing.

The distance at which the study subjects (drivers) recognized a pedestrian dressed in black was measured, and the average value of the results was calculated. Figure 15 shows the results.

From Fig. 15, the average for projection lighting was 86.1 m compared to an average of 77.0 m for low beam, which is an increase in visibility distance of 9.1 m or 12%. The average for high beam was 73.0 m. This result was

FIGURE 15 Average value of visibility distance of pedestrians dressed in black



not recognized as a significant difference based on the significance test.

The repeated measures analysis of variance (ANOVA) with one within-subjects factor was conducted for each comparison to examine whether there was a significant difference between the headlight types. The repeated measures ANOVA revealed a nonsignificant main effect of headlight type on the distance at which participants detected the pedestrian wearing black, $F(2, 38) = 0.628$, $p = .539$, $\eta^2 = .032$.

Test 2 Results

The distance at which the study subjects (pedestrians) noticed the approaching vehicle was measured, and the average value of the results was calculated. Figure 16 shows the results.

From Fig. 16, the average value for projection lighting was 56.9 m, which means that the presence of an approaching vehicle could be noticed 17.5 m or 44% farther away than the average value of 39.4 m for low beam. The average value for high beam was 225.8 m. This result was recognized as a significant difference based on the significance test.

The repeated measures ANOVA, with Greenhouse-Geisser correction was conducted for each comparison to examine whether there was a significant difference between the headlight types. The repeated measures ANOVA, with Greenhouse-Geisser correction, revealed a significant main effect of headlight type on the distance at which participants noticed the car approaching, $F(1.036, 19.685) = 41.279$, $p < .001$, $\eta^2 = .685$. Since significant differences were found between all headlights, the order of effectiveness in terms of visibility distance was shown to be high beam, projection lighting, and low beam.

In addition, Fig. 17 and Fig. 18 show the sensory evaluation results.

From Fig. 17, when comparing low beam and projection lighting in terms of noticeability of approaching vehicles, 85% of study subjects responded that projection lighting was better.

From Fig. 18, when comparing projection lighting and high beam in terms of noticeability of approaching vehicles, 65% of study subjects responded that high beam was better.

FIGURE 16 Average value of distance at which an approaching vehicle is noticed

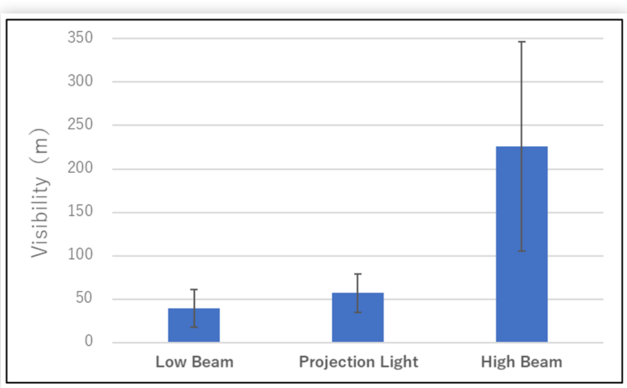


FIGURE 17 Sensory evaluation of noticeability of approaching vehicle - Comparison of LOW BEAM and PROJECTION LIGHT

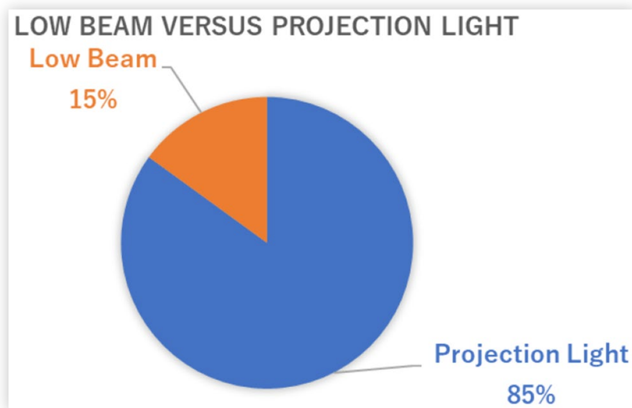


FIGURE 18 Sensory evaluation of noticeability of approaching vehicle - Comparison of PROJECTION LIGHT and HIGH BEAM

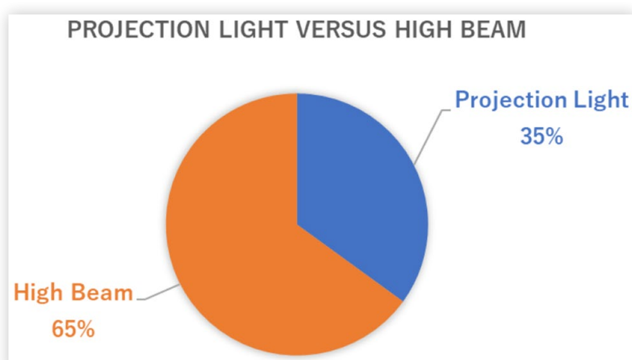
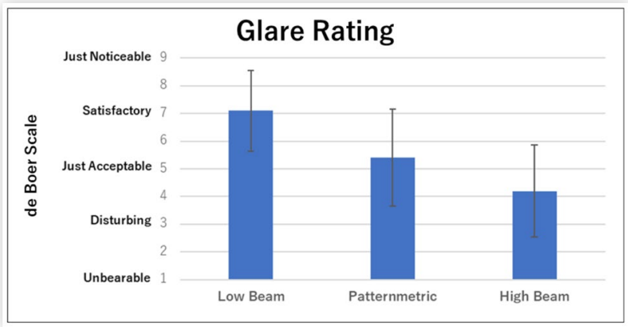


FIGURE 19 Average value of glare evaluation results



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Test 3 Results

Sensory evaluation was conducted using the de Boer scale to evaluate the glare when a test vehicle illuminating the verification function passed in front of the study subjects (pedestrians). Figure 19 shows the average values of the results.

From Fig. 19, the average value for projection lighting was 5.4 points, which is a glare index enhancement of 1.2 points compared to the average value of 4.2 points for high beam. This result was recognized as a significant difference based on the significance test. Low beam had the best glare index, with an average value of 7.1 points. This result was recognized as a significant difference based on the significance test.

Wilcoxon signed rank test was conducted for each comparison to examine whether there was a significant difference between high beams and projection lighting. The results of the two-tailed Wilcoxon signed rank test were significant based on an alpha value of .05, V = 145.00, z = -2.03, p = .042. This indicates that the differences between high beam and projection lighting glare are not likely due to random variation. The difference between high beams and projection lighting was large, suggesting that high beams are perceived as brighter than projection lighting and cause discomfort.

Conclusions

The results of this study show that projection lighting improves the visibility of pedestrians and approaching vehicles. When comparing the visibility distance of a pedestrian dressed in white for low beam and projection lighting, the average visibility distance for low beam was 69.0 m, while the average visibility distance for projection lighting was 88.2 m, which is an increase in visibility distance of 19.2 m. The results indicate that projection lighting may enable drivers to notice pedestrians 1.73 seconds earlier than with low beam.

In the case of a pedestrian dressed in black, there was no significant difference in the visibility distance between low beam, projection lighting, and high beam.

The average visibility distance of projection lighted pedestrians dressed in white and black was roughly equivalent at 88.2 m and 86.1 m, respectively.

The average distance at which pedestrians noticed an approaching vehicle was 39.4 m for low beam, and this average noticing distance increased by 17.5 m to 56.9 m for projection lighting. The results indicate that projection lighting may enable pedestrians to notice approaching vehicles 1.6 seconds earlier than with low beam.

In addition, the results of sensory evaluation showed that 85% of study subjects judged that projection lighting increased the noticeability of approaching vehicles compared to low beam.

Pedestrians rated the glare of the three headlight types. As a result, projection lighting had an average glare index value of 5.4 points, which is an enhancement of 1.2 points over the average value of 4.2 points for high beam. Low beam had the best glare index, with an average value of 7.1 points.

Projection lighting was shown to be better than low beam in both pedestrian visibility distance and distance at which an approaching vehicle is noticed. High beam provided the longest visibility distance, but also had the least desirable glare evaluation results. Overall, projection lighting was able to achieve a good balance between visibility distance and lower glare, and was verified to be a promising means of increasing visibility for drivers at night.

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2. Masayoshi, T., Tsuchiya, Y., and Oshida, K., "Study on the Improvement of Pedestrian's Visibility by Geometric Patterns Projection Lighting," (Report/Paper Numbers: 23-0063), 2023.

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