A SIMULATION-BASED STUDY ON DISTRACTIONS AND BENEFITS OF SIGNAL LIGHT PROJECTIONS WITH DIRECTIONAL INDICATORS

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ABSTRACT

To prevent accidents, the signaling function of automotive exterior lighting is essential to provide other road users with information on the presence of the vehicle and/or changes in its moving direction. Recently, dynamic turn signal indicators, backup indicators, and other light projections with directional indicators have been proposed and studies are being conducted to evaluate their safety enhancement and visibility in different lighting conditions. However, previous studies had limitations since most of them had not been studied or verified under dynamic driving situations. In addition, there aren't any studies on the distraction caused by turn signal projection lamps. Therefore, it is necessary to provide an assessment of the distraction and benefits of turn signal projection lamps under several dynamic scenarios. For this reason, we investigated whether the signal projection lamps, which work simultaneously with directional indicators and project a simple geometric pattern of a certain color and size on the left and right road surfaces in front of the vehicle, are beneficial or distracting to other drivers and VRUs (Vulnerable Road Users) such as cyclists and pedestrians. Twenty participants participated in the experiment. The results showed that the signal projection lamp hardly distracts drivers, cyclists, and pedestrians, but rather helps predict the presence of oncoming vehicles and the moving direction of the vehicles. Particularly with the signal projection lamp, the cyclist test showed a 14% and 9% decrease in detection time when the vehicle turned right and left, respectively. These differences were statistically significant. Our results suggest that a signal projection lamp is more beneficial than a distraction to drivers, cyclists, and pedestrians.

INTRODUCTION

Driving at night has many visual limitations to maintaining safe driving. If the turning of the vehicle cannot be properly predicted, it can cause accidents. Therefore, to prevent accidents, the signaling function of automotive exterior lighting is essential to provide other road users with information on the presence of the vehicle and/or changes in its moving direction. Projection lamps on the road have enabled new interactions between vehicles and VRUs (Vulnerable Road Users). Therefore, the projection lamp can make a positive contribution to the VRU.

According to the previous study, visibility improved when using turn signal projection lamps for both young and middle-aged participants [1]. The backup guide lamp, which implements a guideline in the form of a dotted line pattern on the rear road surface when reversing after parking, improves safety [2, 3] and is already applied to commercial vehicles. There is also a light that projects a bicycle-shaped image forward to improve cyclist safety [4]. Currently, studies on the effect of projection distance and contrast on people's acceptance [5], safety improvements by lighting for pedestrians and cyclists [6], and the requirement of the performance of road projection lamps [7] are also being conducted.

However, previous studies have limitations since most of them have not been studied or verified under dynamic driving situations. We evaluated scenarios where the multiple signal lights of nearby vehicles projected a pattern on the road surface or the signal light of a passing vehicle is projected to the driving path and the effects they had on the drivers of vehicles passing through the intersection, the cyclists following the cycle path, and the pedestrians crossing the crosswalk.

In this experiment, three situations one for the drivers, one for the cyclists, and one for the pedestrians were created. The situations were all intersections and T-junction roads under dynamic conditions. These situations were implemented with a VR head-mounted display using a driving simulator, a bicycle riding simulator, and a

locomotion simulator by walking pad. Each situation had two different scenarios with different conditions. The result shows the statistically significant benefits and limited distractions of signal projection lamps.

METHODS

This experiment was conducted to evaluate the effect of a projection lamp in a VR environment. A driving simulation program was used to implement the road environment, and HMD (Head Mounted Display) was used to show the actual road environment to the participants. In addition, we investigated the interaction between the vehicle and the VRU by applying different simulators according to driving, riding, and walking situations.

Experimental set-up

We implemented the intersection with the driving simulation program SCANeR studio 2022. To select the proper cases of cyclist and pedestrian scenarios, cases with a high number of accidents were selected by referring to the case-by-case analysis of car-to-cyclist and car-to-pedestrian accidents in Germany by the EU-funded project PROSPECT (Proactive Safety for Pedestrians and Cyclists) [8]. Six scenarios were configured according to two driving conditions (left turn and straight in the intersection scene, turn left and right in the T-junction scene) with three kinds of road users (driver, cyclist, and pedestrian). For each scenario, we evaluate the performance of the test driver, cyclist, and pedestrian with/without turn signal projection lamp conditions.

Figure 1 shows examples of experiment environments from the participant's perspective. In the driver situation (scenario 1&2), five vehicles with turn signals stopped at the intersection, and the participant becomes the driver, following the preceding test vehicle and waiting for the signal to turn left or go straight. In the cyclist situation (scenario 3&4), a test vehicle approaches a cyclist with the turn signals on. In the pedestrian situation (scenario 5&5-1), the test vehicle approaches the participant's walking path with turn signals on as he/she crosses the crosswalk.

Figure 1. Examples of experiment environments in the participant's perspective. Scenario 1: driver test, left turn (left), Scenario 4: cyclist test, right turn (center), Scenario 5: pedestrian test, right turn (right).

Data collection

A driving simulator, a bicycle riding simulator, and a locomotion simulator were connected to the driver, cyclist, and pedestrian scenarios, respectively, to collect participants' data.

In the driver situations, the average speed, passing time of the ego vehicle, and time required for the ego vehicle to brake after the preceding vehicle brakes were analyzed. In the cyclist situation, participants are riding on a bicycle path and were ordered to press a button when they recognize a vehicle turning left or right to enter in front of their path. The speed of the bicycle was calculated by measuring the number of wheel rotations using a pedaling cadence sensor from Giant™. The horizontal distance between the cyclist and the vehicle, the time which is taken to press the button after detection of entering the vehicle (detection time), TTC (Time to Collision), and the distance from the cyclist to the vehicle when the button is pressed were analyzed. In pedestrian situations, participants crossed the crosswalk and pressed a button when they recognize a vehicle approaching the crosswalk. The pedestrian speed was fixed at 3.5km/h by the fixed constant speed of the walking pad. The horizontal distance between the pedestrian and the vehicle, TTC, the remaining time to the

accident, and the distance from the pedestrian to the vehicle when the button was pressed were analyzed. Figure 2 shows typical experiment scenes on simulators in different experimental situations.

Figure 2. Participant driving a vehicle using a driving simulator (left), riding a bicycle on a bicycle simulator (center), walking on the walking pad (right).

Experimental procedure

Participants practice the experiment environment with simplified scenarios for about 5 minutes before the driver, cyclist, and pedestrian situation test. The experiment was continued according to the following procedure:

1) In the driver situation, the participant becomes the driver, stops at an intersection and follows the proceeding vehicle to go straight or turn left.

2) In the cyclist situation, the participant becomes a cyclist and rides on a bicycle path as a test vehicle passes. Presses the button which is mounted on the handle of the bicycle when starting off, and press the button again when recognizing the approaching vehicle.

3) In the pedestrian situation, the participant walks and waits while facing the front, then presses the start button when the experiment starts and presses the end button as soon as he/she recognizes an approaching test vehicle while walking on the crosswalk.

All sessions of each scenario were randomized to minimize order effects. It took approximately 1 hour to complete each situation, including the time to complete the questionnaire, with additional break time whenever participants requested.

Participants

Twenty undergraduate and graduate students from Yeungnam University (male: 11, female: 19, average age: 24.6 years) participated in this experiment. All participants in the experiment were Korean, had a driver's license, had visual acuity of 0.7 or higher, and self-reported with no color blindness or color weakness. They wore an HMD during the experiment. Experiments with wearing HMD for more than 1 hour may cause other effects. Therefore, the experiment was performed for each situation separately. Each participant come to the test site three times.

RESULTS

The experimental data were analyzed using ANOVA and t-test using IBM SPSS Statistics (ver. 25).

Scenario 1: driver test, left turn

The average driving speed, passing time, and brake response time of participants with the projection lamp was 17.08 ± 1.20 km/h, 5.69 ± 0.33 sec, and 0.58 ± 0.25 sec. And they were 14.23 ± 2.06 km/h, 6.99 ± 0.93 sec, and 0.95 ± 0.53 sec respectively without the projection lamp. In scenario 1, the average speed with the projection lamp was 2.85 km/h, which is statistically significantly faster [t(19)=5.644, p=.000] than without the projection lamp. The passing time of 1.30 sec with the projection lamp was statistically significantly faster [t(19)=-6.101, p=.000] than that without the projection lamp (see Figure 3).
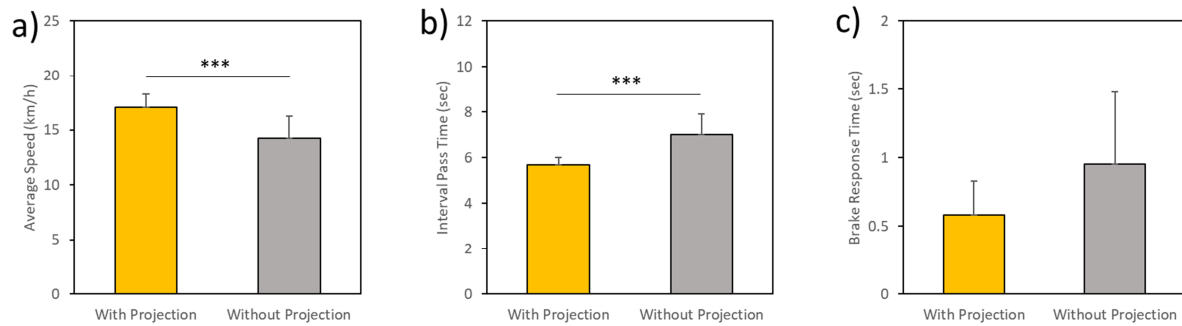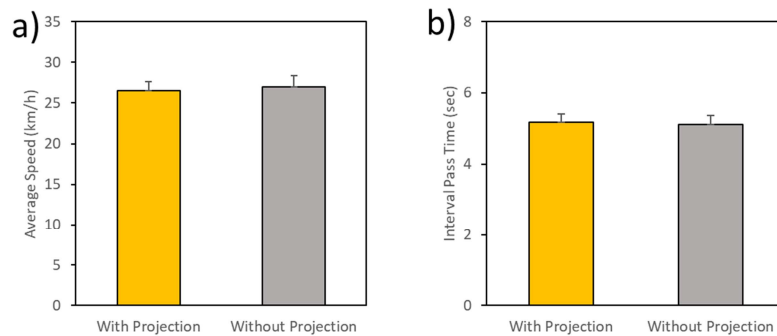

*Figure 3. Data for scenario 1. a) Average driving speed. b) Passing time. c) Response time which is the braking time interval of the ego vehicle after breaking the test vehicle. ***p<.001.*

Scenario 2: driver test, straight

Figure 4 show the average driving speed and passing time with and without the projection lamp. The average driving speed, and passing time were 26.48 ± 1.15 km/h and 5.18 ± 0.22 sec with the projection lamp. And they

were 26.99 ± 1.34 km/h and 5.11 ± 0.26 sec without the projection lamp. There were no significant differences.

Figure 4. Data for scenario 2. a) Average driving speed. b) Passing time from starting point to finishing point.

Scenario 3: cyclist test, left turn

Detection time is the time when the participant detects an oncoming vehicle that is going to make a left turn and, TTC is computed assuming that the vehicle and cycle keep the current speed at the detection time, and the distance between the vehicle and the participant was also computed when the vehicle was detected. They were 8.65 ± 0.81 sec, 1.86 ± 1.12 sec, and 4.03 ± 2.24 m respective with the projection lamp and 9.45 ± 0.38 sec, 0.97 ± 0.38 sec and 5.30 ± 0.53 m without the projection lamp (see Figure 5). With the projection lamp, detection time was significantly faster [t(19)=-9.792, p=.000] than without the projection lamp. TTC with the projection

lamp was also significantly faster [t(19)=9.792, p=.000], and the distance was significantly longer than without the projection lamp[t(19)=-5.170, p=.000] (see Figure 5).
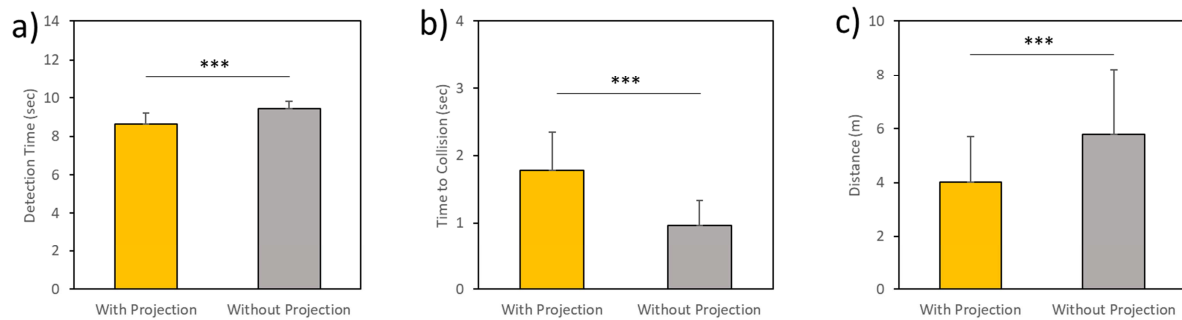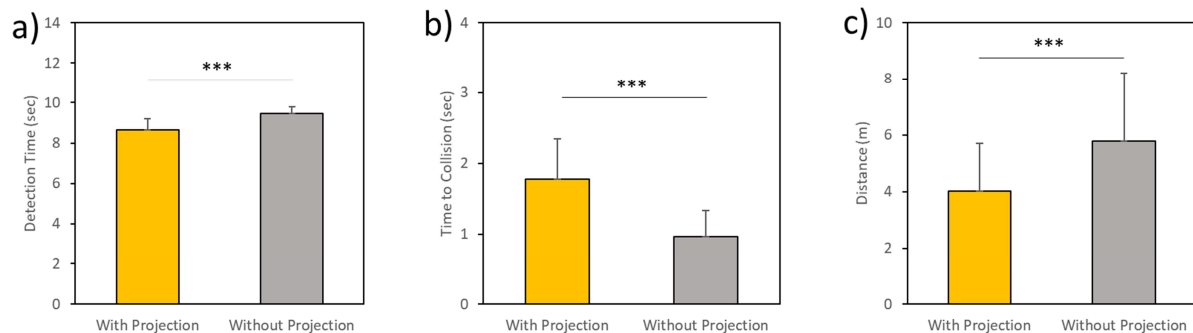

Figure 5. Data for scenario 3. a) Detection time for the participant to recognize the test vehicle turning after the experiment started. b) TTC. c) Distance from the cyclist to the detected vehicle. ***p<.001.

Scenario 4: cyclist test, right turn

In scenario 4, the detection time is the time when the participant detects that an oncoming vehicle is going to make a right turn. The detection time, TTC, and distance were 6.12 ± 0.49 sec, 3.93 ± 0.49sec, and 1.77 ± 1.28 m with projection lamp. And they were 7.15 ± 0.69 sec, 2.90 ± 0.69 sec, and 4.15 ± 1.55 m without projection lamp (see Figure 6). With the projection lamp, detection time was significantly faster [t(19)=-14.454, p=.000], TTC was significantly faster [t(19)=14.454, p=.000], and distance was significantly longer [t(19)=8.783, p=.000] than without the projection lamp (see Figure 6).

Figure 6. Data for scenario 4. a) Detection time for the participant to recognize the test vehicle turning after the experiment started. b) TTC. c) Distance from the cyclist to the detected vehicle. ***p<.001.

Scenario 5: pedestrian test, left turn, pedestrian & vehicle in the same direction

In Scenario 5, the detection time is the time when the participant detects an oncoming vehicle to make a left turn. The detection time, the TTC, and the distance between the vehicle and the participant when the vehicle was detected were 8.15 ± 0.74 sec, 1.28 ± 0.74 sec, and 12.24 ± 1.46 m with the projection lamp. And they were 8.44 ± 1.08 sec, 0.99 ± 1.08 sec, and 11.60 ± 1.89 m without the projection lamp (see Figure 7). With the projection lamp, the distance when the participant found the test vehicle was 0.64 m faster, and this difference was statistically significant [t(19)=2.397, p=.027].
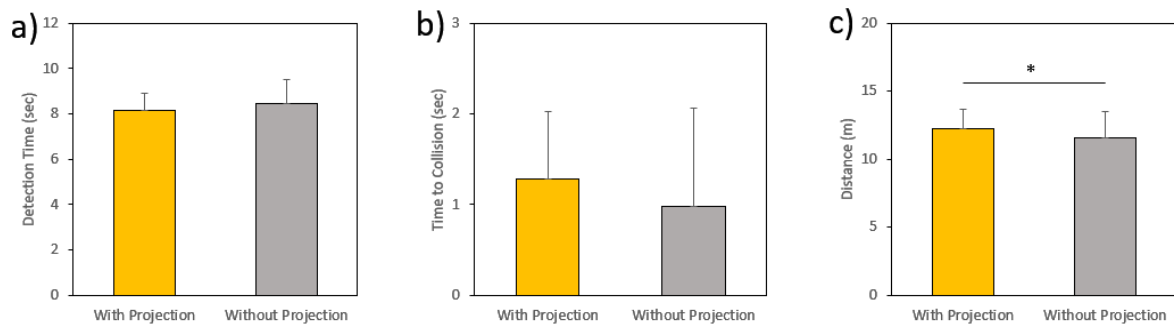
*Figure 7. Data for scenario 5. a) Detection time for the participant to recognize the test vehicle turning after the experiment started. b) TTC. c) Distance from the pedestrian to the detected vehicle. *p<.05.*

Scenario 5-1: pedestrian test, left turn, oncoming vehicle

In Scenario 5-1, the detection time, TTC, and the distance between the vehicle and the participant when the vehicle was detected was 7.51 ± 1.33 sec, 2.02 ± 1.33 sec, and 13.91 ± 6.14 m with the projection lamp. And they were 7.74 ± 1.24 sec, 1.79 ± 1.24 sec, and 12.96 ± 5.54 m without the projection lamp (see Figure 8). There was no significant difference.
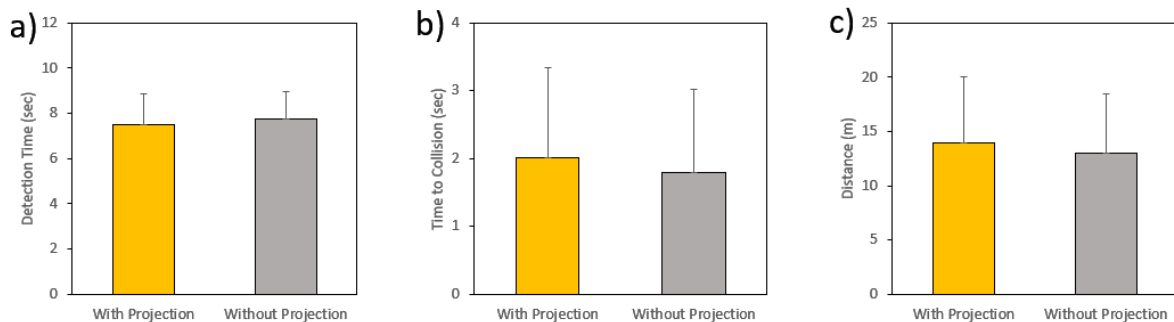

Figure 8. Data for scenario 5-1. a) Detection time for the participant to recognize the test vehicle turning after the experiment started. b) TTC. c) Distance from the pedestrian to the detected vehicle.

CONCLUSION

In this experiment, evaluations were performed by six scenarios for drivers, cyclists, and pedestrians situations. The result shows that the driver's driving speed and brake response time were faster with the projection lamp than without the projection lamp, and it was found that the detection time of the approaching vehicle was also decreased for cyclists and pedestrians.

This experiment result will be helpful to develop a safer road environment tailored to road users in the future by providing quantitative data showing significant benefits and limited distraction of turn signal projection lamps. Further study may be necessary to find the proper length or direction of the projection lamp to minimize distraction and maximize visibility. In addition, this study was conducted in the evening of a sunny day, additional research under adverse weather conditions or daytime seems to be necessary.

Since the results of our study were not obtained from field studies such as actual driving and walking situations, sufficient discussion and review will be required in the actual application process. Nevertheless, these results will be an important empirical basis for determining whether to adopt signal projection lamps for automotive lighting in the future.

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