Can Eyes on a Car Reduce Traffic Accidents?

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ABSTRACT

Various car manufacturers and researchers have explored the idea of adding eyes to a car as an additional communication modality. A previous study demonstrated that autonomous vehicles' (AVs) eyes help pedestrians make faster street-crossing decisions. In this study, we examine a more critical question, "can eyes reduce traffic accidents?" To answer this question, we consider a critical street-crossing situation in which a pedestrian is in a hurry to cross the street. If the car is not looking at the pedestrian, this implies that the car does not recognize the pedestrian. Thus, pedestrians can judge that they should not cross the street, thereby avoiding potential traffic accidents. We conducted an empirical study using 360-degree video shooting of an actual car with robotic eyes. The results showed that the eyes can reduce potential traffic accidents and that gaze direction can increase pedestrians' subjective feelings of safety and danger. In addition, the results showed gender differences in critical and noncritical scenarios in AV-to-pedestrian interaction.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); HCI design and evaluation methods; User studies.

KEYWORDS

Autonomous Vehicles, Vehicle-to-Pedestrian Interaction, Gaze Directions, Real Car Prototype, Empirical Study

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1 INTRODUCTION

Autonomous vehicles (AVs) provide significant opportunities and challenges to our daily lives on roads. One of the challenges is the design of interaction methods (i.e., unclear interactions) between AVs and pedestrians [1]. AV-to-pedestrian interaction is very different from the interaction between human-driven vehicles and pedestrians. The existing external human-machine interfaces (eHMI) on human-driven vehicles are insufficient to afford novel interactions between AVs and pedestrians. For example, there is no way for autonomous vehicles to notice pedestrians that they recognized. Many conceptual communication modalities have been proposed for AV-to-pedestrian interactions [5, 17, 18, 21, 42], including the use of eyes on an AV to interact with pedestrians [4, 40]. A previous study showed that eyes on an AV can help pedestrians make faster street-crossing decisions in a scenario where a pedestrian is standing to cross the street [4]. However, slightly faster or slower road crossings are not as critical as traffic accidents (i.e., injury or death). It is much more important to reduce traffic accidents (i.e., making right decisions) than to help people decide quickly. In this study, we attempt to answer the research question of whether car eyes reduce traffic accidents.

We consider a critical street-crossing scenario in which a pedestrian walks in a hurry to cross a street. If the car (eyes) is not looking at the pedestrian, it implies that the car does not recognize the pedestrian. Thus, pedestrians can judge that they should not cross the street, thereby avoiding potential traffic accidents. However, if the car (eyes) is looking at the pedestrian, it implies that the car recognizes the pedestrian. Using this assumption, pedestrians can judge whether it is safe to cross the street.

We conducted an empirical study to investigate the benefits of the eyes with 18 participants. We built a real car prototype (i.e., mounted physical robotic eyes on an autonomous cart), shot 360-degree videos of the car in a real traffic environment, and imported them into a virtual reality (VR) environment. We compared a no-eyes car (normal-looking car) and our eyes car in the critical street-crossing scenario for the four conditions (Figure 1). The participants were the walking pedestrians in the VR and made street-crossing decisions. We measured the error rates of the participants' decisions.

The most notable result was that eyes could reduce potential traffic accidents for male pedestrians. The error rate in the critical condition where an accident can occur was significantly lower for male participants, but not for female participants. On the other

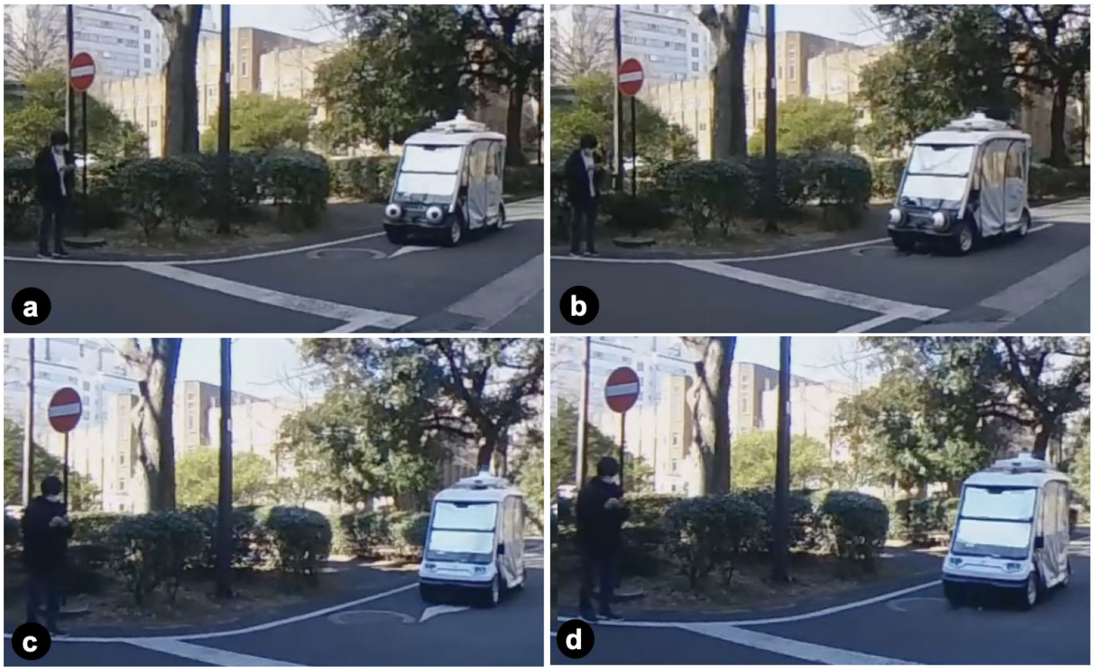

Figure 1: A participant view in the empirical study. (a) eyes on a car looking at the participant (car intends to yield), (b) eyes on a car looking at another side (car intends not to yield), (c) no-eyes car intends to yield, and (d) no-eyes car intends not to yield.

hand, we found that eyes could increase traffic efficiency for female pedestrians. For example, the error rate in non-critical conditions was significantly lower with eyes for female participants. In addition, the results showed that when the eye's gaze direction is away from the pedestrians, it can increase both male and female pedestrians' subjective feelings of "danger" when they cross a street. Finally, we discussed the pedestrians' preference for eyes on a car concept for AV-to-pedestrian interaction and their opinions about AVs. The three main contributions of this study are as follows.

- An empirical study with 18 participants comparing an eyes car and a no-eyes car in a critical street-crossing scenario showed that the eyes can reduce potential traffic accidents for male pedestrians.
- Discussion of gender differences between a dangerous and a safe street-crossing scenario in AV-to-pedestrian interaction.
- A real car prototype including the development of the robotic eyes on an autonomous cart, to represent the car's intentions.

From our findings, we found that robotic eyes on a car can reduce traffic accidents under certain conditions. In this paper, we discuss our prototype design for real robotic eyes and our scenarios with exact timelines, in addition to our discussion on gender effects on the eyes.

2 RELATED WORK

2.1 AV-to-Pedestrian Interaction

Vehicle and driver cues are two types of information that help pedestrians make street-crossing decisions when a vehicle approaches [5]. Vehicle cues include acceleration, deceleration, speed, and distance of the vehicle [9–11], while driver cues include eye contact, gestures, and postures [12, 13]. However, the interactions between AVs and pedestrians differ from those of human-driven vehicles. For example, there may be no driver inside an AV, or the driver may be doing something else (e.g., reading a book). In recent years, AV-to-pedestrian interaction has been widely explored, and many studies have proposed various communication modalities for an AV to interact with pedestrians. For example, using an external display on an AV is a popular solution for AV-to-pedestrian interactions [16–20]. The display presents text or symbols to communicate with pedestrians [8]. In addition, several studies have investigated different colors and animations of light on an external human-machine interface (eHMI) for AV-to-pedestrian interaction [21–25] and projections of various objects [15, 26]. In addition, human-like communication interfaces have been investigated, such as using "eyes" [4, 15, 26, 38, 40] and "smiles" [15, 16, 18] on cars to interact with pedestrians. Chang et al. [4] proposed the concept of having "eyes" on an AV and showed that the eyes can help pedestrians make quick street-crossing decisions in a non-critical traffic scenario where a pedestrian stands and is about to cross a street. Jaguar Land Rover [40] proposed a similar concept called "virtual eyes" on an AV and explored pedestrians' trust in self-driving technologies. In addition, a study [38] proposed the concept of using multiple gaze directions to indicate a car's moving direction. Unlike previous studies, in this study, we focused on a critical traffic scenario where a walking pedestrian is in a hurry to cross a street and uses gaze directions to imply a car's recognition of surrounding pedestrians.

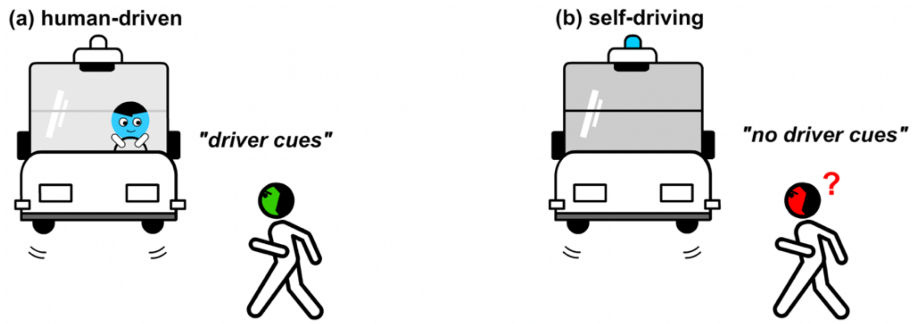

Figure 2: (a) interaction between a human-driven car and a pedestrian and (b) interaction between a self-driving car and a pedestrian.

2.2 Empirical Study in AV-to-Pedestrian Interaction

Conducting an empirical study with autonomous systems (i.e., self-driving cars) in a real environment is challenging owing to cost and safety issues [32]. Various simulation platforms have been proposed to address these issues, with VR simulation being a common approach [33]. Many studies have used 3DCG to present their proposed eHMI concepts and evaluated them for AV-to-pedestrian interaction in a VR environment [27–31]. Conducting an empirical study using VR simulation has many benefits [41]. However, a 3DCG car model in a VR environment can be very different from a real car in a real environment, especially people's subjective feeling of being in danger from a 3DCG (game-like) car and a real car. Video experiments for evaluating AV-to-pedestrian interactions are another common approach [15, 23, 34, 35]. Researchers shot videos with a real car in a real environment based on the proposed traffic scenarios, and asked participants to watch the videos and complete the given tasks (e.g., making a street-crossing decision). Several empirical studies have been conducted with a real car in a real environment (i.e., university campuses) despite the cost and lengthy preparation for safety [36, 37]. In this study, we designed a mixed method (real-world and VR) for our study of AV-to-pedestrian interactions. We first built a real car prototype and shot 360-degree videos from the perspective of a walking pedestrian in a real environment. We imported the videos into a VR environment for our empirical study. A similar mixed method was used to evaluate AV-to-pedestrian interaction [32]. We believe that this mixed method can provide a balance between a real world and a VR environment (i.e., improve safety in the real world and solve unrealistic issues in VR).

3 RESEARCH QUESTION

This section describes our research question together with the assumptions behind the study and the scenario.

3.1 Assumption

Figure 2 shows the problem (no driver cures) in AV-to-pedestrian interaction. We assume that the eyes on a car indicate the car's attention (i.e., replace the driver's gaze). If a car recognizes a pedestrian, it looks at the pedestrian. This implies that the car may stop when the pedestrian attempts to cross the street in front of it. However, if the car does not look at a pedestrian, it implies that the car may not recognize the pedestrian at all. From the pedestrian's perspective, this means that the car may not stop when they start crossing the street.

3.2 Scenario

In this study, we focused on a critical street-crossing scenario in which a pedestrian is in a hurry and walks to cross a crosswalk without traffic lights. This is a typical case where traffic accidents occur, according to a survey [39], more than 90% of drivers do not stop at crosswalks without traffic lights even if pedestrians are waiting to cross. In such cases, pedestrians rely only on vehicle cues to make street-crossing decisions in order to avoid dangerous situations (i.e., injury or death). We believe that this scenario of pedestrians already walking to cross is much more important than a non-critical scenario where a pedestrian stands and is about to cross a street, as in [4].
Figure 3 shows our scenario: a walking pedestrian in a hurry is about to cross a street and suddenly notice an approaching car. Pedestrians must judge whether the car will stop. If the pedestrian judges that the car will stop, they can continue crossing the street without stopping. However, if the pedestrian judges that the car will not stop, then the pedestrian must stop for their own safety. We consider two decisions as errors: (1) if the car stops but the pedestrian also stops, it is an error, and (2) if the car does not stop but the pedestrian continues walking, it is an error.

3.2.1 Research Question. Our main research question was whether the eyes on a car can reduce potential traffic accidents. More specifically, it is unclear whether eyes can reduce errors in a critical situation. Another question is whether eyes can improve efficiency, that is, whether eyes can reduce errors in a non-critical situation. We also wanted to know how people perceive robotic eyes on a car.

4 EMPIRICAL STUDY

This section describes the details of the empirical user study that we conducted to answer the research question described in the previous section. We compared cars with and without eyes in the critical street-crossing scenario. We built a real car prototype and shot 360-degree videos of the car for this study.

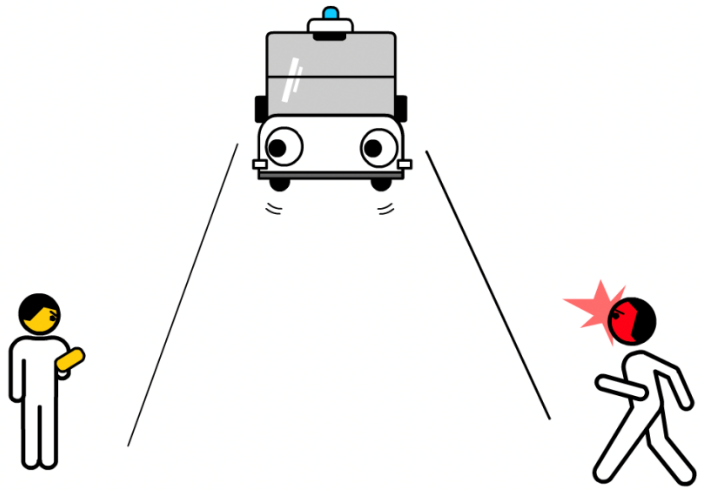

Figure 3: Eyes on a car in a critical street-crossing scenario.

Figure 4: A real car prototype. Controllable robotic eyes on an autonomous cart, which contain three gaze directions (look left, look straight, and look right).

4.1 A Real Car Prototype

We built "controllable" robotic eyes on an autonomous cart (produced by YAMAHA), as shown in Figure 4. The robotic eyes contain three gaze directions (left, straight, and right) that can be manually controlled using arrow keys (physical buttons). Although this cart has full self-driving capability, we drove the cart manually during our user study owing to safety issues. Smoked glass sheets were pasted on the windshield and side windows to pretend that the car was self-driving (i.e., the driver in the cart could not be seen while driving the cart). The same golf cart with robotic eyes was used in [38].

4.2 VR Study with 360-degree Videos

We shot 360-degree videos in a real environment with the proposed pedestrian street-crossing situation. While recording the videos, we held a 360-degree camera (RICOH THETA Z1) with a gimbal and walked as a pedestrian to cross the street. Meanwhile, our car approached the crosswalk. Figure 5 shows the pedestrian street-crossing environment and conditions. Figure 5(a): The pedestrian (the person who held the camera) started walking on a sidewalk from this location and was about to cross the street. First, the pedestrian was blocked by an obstacle (i.e., bicycles and a building), and the pedestrian was unable to see the complete road condition (i.e., could not see the car). Figure 5(b) shows that the pedestrian kept walking, passed the obstacle, and suddenly saw an approaching car. Figure 5(c) shows that the pedestrian kept walking and needed to decide whether to cross the street before going onto the road (i.e., the car lane). The videos contained environmental, and vehicle sounds (the cart was quiet, as it was an electric vehicle).

4.3 Car Behaviors

The videos contain four car behaviors: (1) a "no-eyes" car intends not to yield to the pedestrian (critical cases), (2) a no-eyes car intends to yield to the pedestrian (non-critical cases), (3) an "eyes" car not looking at the pedestrian and intends not to yield to the pedestrian (critical cases), and (4) an "eyes" car looking at the pedestrian and intends to yield to the pedestrian (non-critical cases). See Figure 6

If the car intends to yield to the pedestrian (conditions 2 and 4), the speed of the car is slightly slower than that of the car without yielding intention (conditions 1 and 3). However, the difference was minor and difficult to be noticed by people to judge the cars' intentions (stop or stop). We expected the participants to make street-crossing decisions based on their eyes, in the empirical study.

Figure 5: 360-degree videos in a real environment.

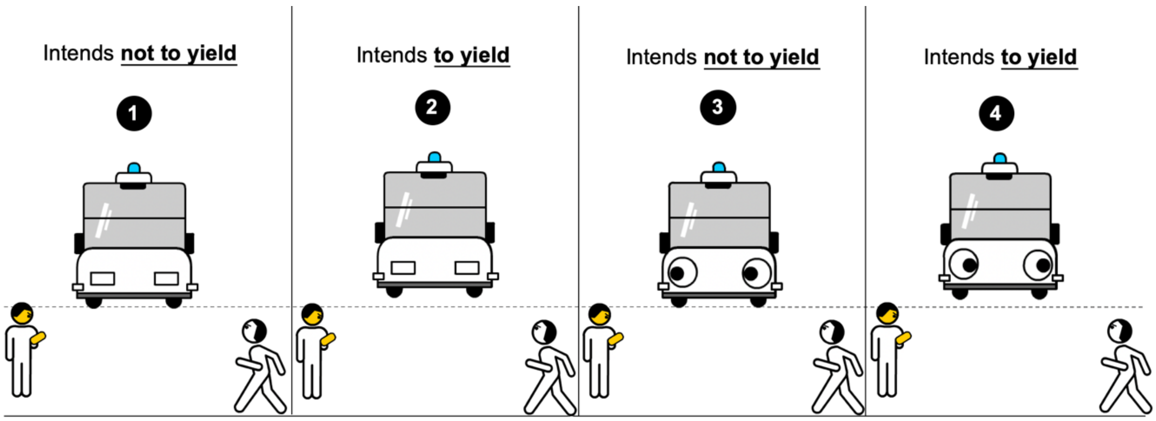

Figure 6: Four conditions of the car behaviors.

4.4 Participants

We recruited 18 participants (9 men and 9 women, aged 18–49 years) to our lab for the user study. The user study was conducted from 15th of February to 10th of March 2022. The recruitment process was outsourced. The total cost, including the processing fees and honorariums, was approximately \$2,160 (about \$120 per participant).

4.5 Task and Conditions

For our empirical study, we placed the videos in a VR environment. The participants were asked to wear an HMD and act as walking pedestrians, about to cross the street. The task of the participants was to observe the surrounding traffic conditions and make street-crossing decisions. More specifically, the participants needed to make a "STOP" crossing decision if they felt any danger to cross the street (i.e., to avoid collision). However, if they felt safe crossing the street, they did not need to do anything. A within-subjects method was used in the empirical study, and each participant was asked to make street-crossing decisions 40 times (10 times for each condition; Figure 6). The order of the four conditions was randomized for each participant.

4.6 Procedure

The participants were invited to a room where we set up a VR environment with 360-degree videos (Figure 7). We provided an oral overview and detailed instructions to the participants. The evaluation itself consisted of three parts: instruction and trial (10–15 min), VR task (15–25 min), and questionnaire (5 min). The entire evaluation process was completed within 30–40 minutes.

The instruction for the VR evaluation was as below:

"In the VR, you are a walking pedestrian in a hurry and about to cross a street (no traffic lights). First, you are blocked by an obstacle (bicycle & building) so you cannot see complete road conditions (i.e., see a car is approaching). However, you keep walking to pass the obstacle and suddenly you see a car is approaching. The car may or may not yield to you. You need to make a "STOP" crossing decision if you feel it is dangerous to cross.

Two steps for completing the given task in the VR evaluation.

Step 1: Press "Start" button to start the task. *After pressing the "start" button, you do not need to move (walk), the video will play such as you are walking forward in the VR.*

Step 2: Press "Stop" button to stop crossing the street*. You need to make a stop-crossing decision (by pressing a button using a motion controller) if you feel it is dangerous to cross. However, you don't need to do anything if you feel it is safe to cross. For making the "stop" crossing decision, you will hear a 3-seconds audio countdown and you need to make the decision right after the countdown ends. If you don't make the decision within 1 seconds after the countdown ends, it means you decide to cross the street."*

Figure 8 shows three related locations of the car's behaviors and pedestrian's movement in the VR environment. ***Location a:***

Figure 7: Photograph of our empirical study.

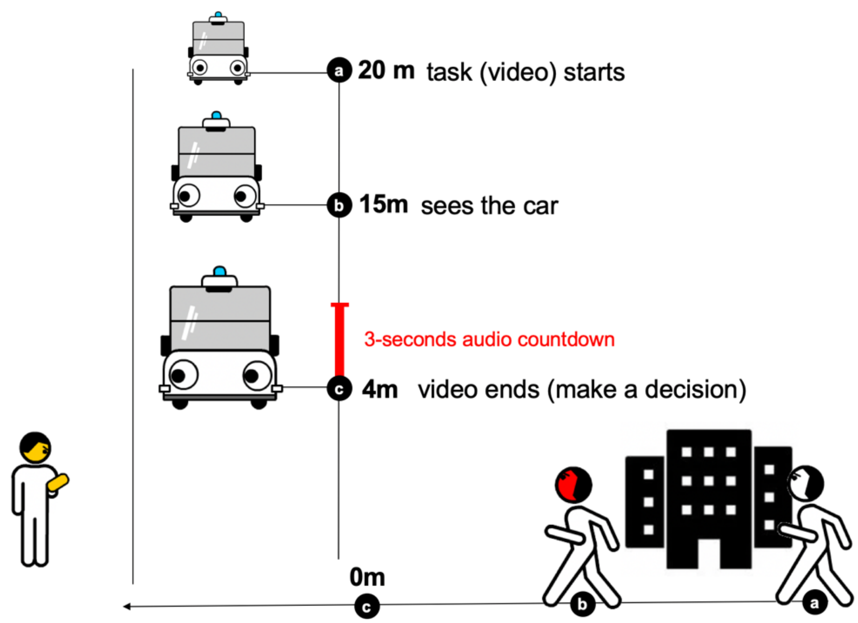

Figure 8: Car's behaviors and pedestrian's movement in the VR environment.

The car and the pedestrian start moving from this location when the task starts. At this location, the pedestrian cannot see the car. ***Location b:*** The car and the pedestrian continue moving forward to the Location b. When the car and the pedestrian reach this location, the pedestrian can see the. ***Location c:*** The car and the pedestrian continue moving forward to Location c. There is a 3-seconds audio countdown before the car and the pedestrian arrive at this location. The participants need to make a street-crossing decision right after the countdown ends.

4.7 Measurement

We counted the errors in the street-crossing decisions. Under conditions 2 and 4 (non-critical conditions), the stop decision is counted as an error. However, in conditions 1 and 3 (critical conditions), the cross decision was counted as an error. Following the VR evaluation, we administered a post-study questionnaire in which participants answered the following seven questions:

Q1. Do you agree that you "feel safe" when the approaching car (eyes) is looking at you?

Q2. Do you agree that you "feel dangerous" when the approaching car (eyes) is not looking at you?

Q3. Do you agree that the eyes (gaze directions) on the car affect your street-crossing decision-making?

Q4. Do you agree that "knowing a car is self-driving" affects affect your street-crossing decision-making?

Q5. Why?

Q6. How much do you like the "eyes" on the car?

Q7. Why?

5 RESULTS

5.1 Task Performance

Error Rates

Figure 9 shows the total error rates. The overall error rate was 50.56% in the no-eyes car and 29.44% in the eyes car. The analysis of error rates using a paired t-test showed that the difference between the two car types was statistically significant ($p < 0.01$). This indicates that an eyes car can help pedestrians make street-crossing decisions more correctly than a no-eyes car in general. Figure 10 shows the error rates for the critical and noncritical cases. In the critical cases, the error rate was 37.22% in the no-eyes car and 24.44% in the eyes car. Analysis of error rates using a paired t-test showed that the difference was statistically insignificant ($p > 0.05$). In the non-critical cases, the error rate was 63.89% for the cars and 35% for the non-eyes cars. The analysis of error rates using a paired t-test showed that the difference between the two car types was statistically significant ($p < 0.01$).

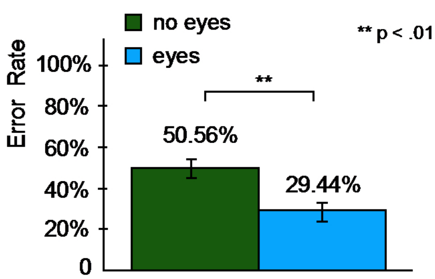

Figure 9: Overall error rates. no eyes: mean = 50.56; SD = 13.81; eyes: mean = 29.44; SD = 14.54.

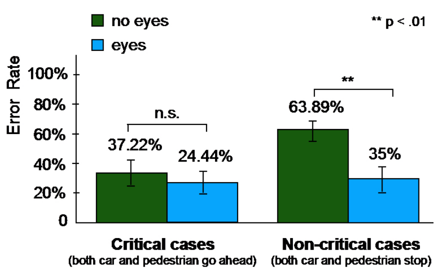

Figure 10: Error rates in the critical and non-critical cases. Critical cases. no eyes: mean = 37.22; SD = 28.45; eyes: mean = 24.44; SD = 24.79. Non-critical cases. no eyes: mean = 63.89; SD = 23.3; eyes: mean = 35; SD = 28.75.

Error Rates in Male and Female Participants

Figures 11 shows the error rates of the male participants. In the critical cases, the error rate of the male participants was 48.89% in the no-eyes car and 17.78% in the eyes car. Paired t-test analysis showed that the difference was statistically significant ($p < 0.05$). However, the error rate was 55.56% in the no-eyes car and 35.56% in the eyes car in the non-critical cases, which showed no statistically significant difference ($p > 0.05$). These results indicate that the eyes contributed to safety, but not efficiency, for male participants.

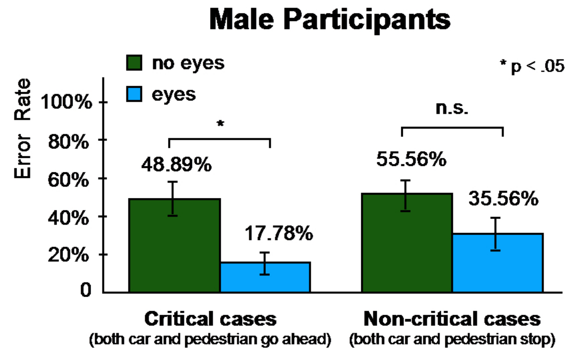

Figure 11: Error rates of male participants in the critical and non-critical cases. Critical case. no eyes: mean = 48.89; SD = 31.4; eyes: mean = 17.78; SD = 17.87. Non-critical case. no eyes: mean = 55.56; SD = 26.03; eyes: mean = 35.56; SD = 27.44.

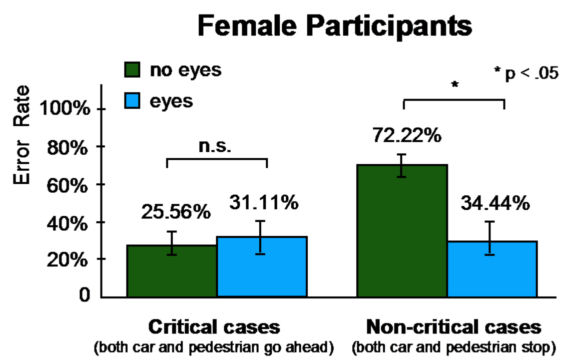

Figure 12: Error rates of female participants in the critical and non-critical cases. Critical cases. no eyes: mean = 25.56; SD = 20.68; eyes: mean = 31.11; SD = 29.77. Non-critical case. no eyes: mean = 72.22; SD = 17.87; eyes: mean = 34.44; SD = 31.67.

Figures 12 shows the error rates of the female participants. In the critical cases, the error rate was 25.56% in the no-eyes car and 31.11% in the eyes car. Paired t-test analysis showed that the difference was statistically insignificant ($p > 0.05$). On the other hand, in the non-critical cases, the error rate was 72.22% in the no-eyes car and 34.44% in the eyes car, which showed a statistically significant difference ($p < 0.05$) between the two types of cars. These results indicate that the eyes contributed to efficiency, but not safety, for female participants.

In addition to the compression of different scenarios (critical and non-critical) for male and female pedestrians separately, we analyzed gender differences (i.e., error rates) via ANOVA. The results showed that the difference between the male and female participants was statistically significant ($F(7, 64) = 4.195$, $p = 0.0007$). This indicates that male and female pedestrians exhibit different street-crossing behaviors when interacting with an AV with their eyes.

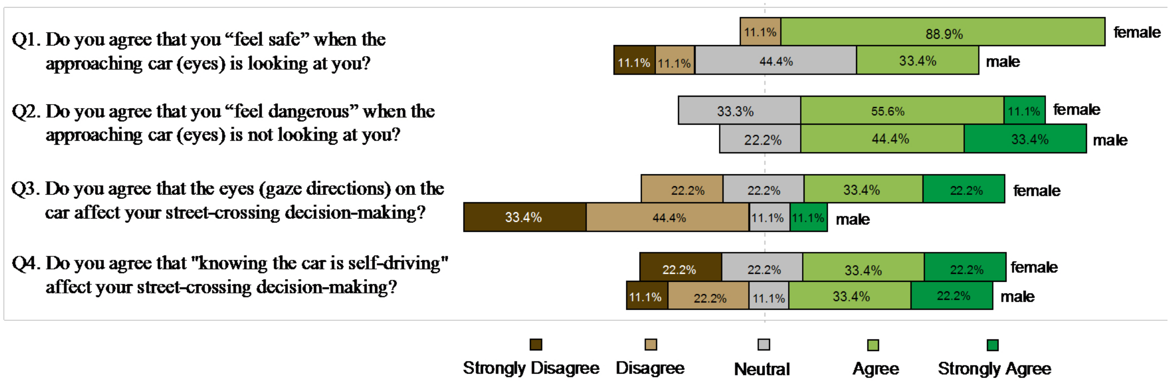

Figure 13: Questionnaire results.

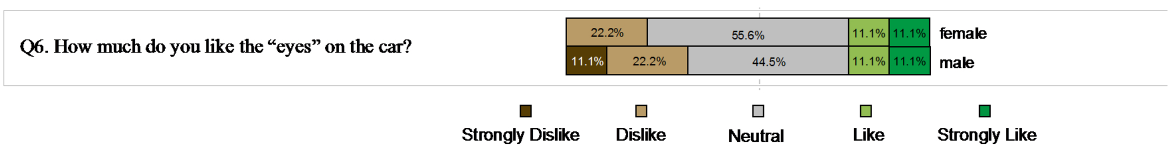

Figure 14: Preference of the "eyes" on the car.

5.2 Questionnaire

Figure 13 shows the questionnaire results. The results (Q1) show that 88.9% of the female participants felt "safe" if the approaching car (eyes) was looking at them when they were about to cross a street. However, only 33.4% of male participants felt "safe" in the same street-crossing situation. On the other hand, the results (Q2) show that 66.7% of the female participants and 77.8% of the male participants felt "dangerous" if the approaching car (eyes) did not look at them. This indicates that both female and male pedestrians feel dangerous if the car (eyes) does not look at them. Furthermore, the results (Q3) show that 55.6% of the female participants agreed that eyes (gaze directions) can affect them to make a street-crossing decision, while only 11.1% of the male participants agreed. Furthermore, the results (Q4) show that 55.6% of the participants (both male and female are equal) agreed that knowing the car is self-driving affects their street-crossing decision making. Figure 14 shows the preference of the "eyes" for the car. The results showed that four participants liked it and five participants disliked it.

6 DISCUSSION

6.1 Eyes on a Car can Reduce Potential Traffic Accidents for Male Pedestrians

It is unclear how pedestrians interact with an AV, because interacting with an AV may be very different from a human-driven vehicle (i.e., no driver cues) [5]. This study has shown that a with-eyes car might be able to help pedestrians make a street-crossing decision more correctly than a no-eyes car (i.e., a normal-looking car) in a critical street-crossing situation, where a walking-in-a-hurry pedestrian is about to cross the street. More specifically, we found that the eyes of a car (i.e., when the gaze direction is away from the pedestrian) can reduce potential traffic accidents (i.e., in a dangerous street-crossing situation) for male pedestrians. The results showed that, in the critical cases (i.e., the car intended not to yield to the pedestrian), the error rate of the male participants was significantly improved from the no-eyes car condition to the with-eyes car condition. However, the results showed that the eyes could not reduce potential traffic accidents for female pedestrians. We believe that this is a significant improvement for male pedestrians because many studies have shown that male pedestrians have a higher traffic accident death rate than female pedestrians [2, 6, 7].

6.2 Eyes on a Car can Increase Traffic Efficiency for Female Pedestrians

Safety (i.e., avoiding traffic collisions) may be the most important issue in pedestrian interactions. However, "efficiency" may also be an important part of AV-to-pedestrian interaction, as the original concept of an AV allows us to save driving time. The results showed that the eye could not reduce traffic accidents involving female pedestrians. However, eyes (when looking at pedestrians) can increase the traffic efficiency of female pedestrians. For example, in the safe street-crossing scenario (i.e., the car intends to yield to the pedestrian), it is safe to cross, but female pedestrians always "stop" crossing the street. The error rate (i.e., safe to cross but didn't cross) of the female participants was relatively high (72.22%) in comparison with the male participants (55.56%). Although safe, it is inefficient, especially when a walking pedestrian is in a hurry to cross the street. The results showed that the eyes could solve this inefficiency issue, as the error rate was statistically significantly ($p < 0.05$) improved from 72.22% (no-eyes car) to 34.44% (eyes car) in the female participants. However, the improvement was not statistically significant in male participants.

6.3 Gaze Directions can Increase Pedestrians' Subjective Feelings of "Danger" and "Safe"

Eighty-four percent of pedestrians seek eye contact with drivers when they cross a street [3]. However, driver cues may not be available when a car is self-driving [5]. This study showed that the eyes can not only help pedestrians make their street-crossing decisions more correctly but also increase their subjective feelings when crossing a street. The results showed that when the eyes are away from the pedestrians, it can increase both female and male pedestrians' subjective feeling of "dangerous" when they are walking to cross a street (66.7% of the female and 77.8% of the male participants agreed with it). We believe that increasing pedestrians' subjective feelings of danger is important and can reduce traffic accidents, even if the pedestrians are not fully confident about the car's intentions (i.e., yield to you or not). The study results showed that the subjective feeling of danger only helps male pedestrians reduce traffic accidents. On the other hand, when the eyes were looking at the pedestrians, it increases female pedestrians' subjective feeling of "safe" (88.9% and 33.4% of the female and male participants agreed with it). This shows a difference in the subjective feeling of safety between female and male pedestrians.

6.4 Pedestrians' Preference and Opinions of the Eyes Concept and AVs

Although the results of this study have shown some benefits of the eyes in AV-to-pedestrian interaction, the subjective preference of the eyes were mixed. 22.2 % Of the participants (male and female equally) liked (or strongly liked) the eyes concept. A female participant indicated "*the eyes are very cute and I felt reliable when the eyes are looking at me*," while a male participant mentioned the size and position of the eyes, he indicated "*the eyes are large and the position of the eyes is easy to recognize*." On the other hand, 22.2 % of the female participants disliked the eyes and 33.3% of the male participants disliked (or strongly disliked) it. A female participant explained that one reason for the dislike was that she felt someone was looking at her and felt a bit creepy, while a male participant had a similar opinion that he felt the eyes were scary and not cute. In addition, more than half of both male and female participants agreed (or strongly agreed) that knowing a car is self-driving may affect their street-crossing decision. Some participants indicated that an AV is safer than a human-driven car, while others had a contrary opinion.

7 LIMITATION AND FUTURE WORK

A limitation of the eyes is that they are only visible from the front of a car. If pedestrians are next to or behind the car, they cannot see the eyes. A limitation of our study is that it evaluated only one critical street-crossing scenario. We believe that a systematic evaluation of typical accident scenarios (situations) is worthy of further investigation. In addition, testing a critical traffic scenario in a VR environment can be significantly different from testing it in a realistic traffic environment. This is because participants know that they are always safe in a VR environment, even if they make an incorrect decision to cross a street (i.e., traffic collision never occurs in real life during the study).

In the future, we would like to integrate a real AV engine (AI) with the eyes and control eye gaze according to the internal state of the AI. For example, different algorithms can be developed to control the eyes differently (i.e., different self-driving modes) in order to accommodate different traffic situations. Furthermore, it might be useful to develop technologies to recognize pedestrians' gender and change AVs' behaviors, as this study has shown interesting gender differences between critical and non-critical cases in AV-to-pedestrian interaction. In addition to pedestrians' gender, we also plan to investigate different road users (e.g., children and the elderly), as we believe that different road users may need different ways to interact with AVs. For VR evaluation, we would like to answer the following research question: How can users perceive real-world traffic danger in a VR environment?

8 CONCLUSION

'Unlike previous studies that showed that eyes can help pedestrians make faster street-crossing decisions [4], this study shows that it might be possible to reduce traffic accidents with eyes in some situations. We built a real car prototype with robotic eyes and conducted an empirical study to compare a car with and without eyes in a critical street-crossing scenario. The results showed that the eyes can reduce potential traffic accidents for male pedestrians (in critical cases) and increase traffic efficiency for female pedestrians (in non-critical cases). In addition, the gaze direction of the eyes can increase pedestrians' subjective feelings of "safe" (car is looking at you) and "danger" (car is not looking at you) when crossing a street. This study discussed the gender differences between critical (both car and pedestrian go ahead) and non-critical (both car and pedestrian stop) cases in AV-to-pedestrian interaction. These findings provide useful insights and interesting directions for the future development of AV-to-pedestrian interactions.

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