A Field Study on Pedestrians' Thoughts toward a Car with Gazing Eyes

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Figure 1: A car with eyes gazes at a pedestrian waving their hand (left) and the operating interface in the car (right).

ABSTRACT

It is promising to apply eye-gaze techniques in designing an external human-machine interface (eHMI) for a self-driving car. We can find several prior "eye" studies; however, due to the difficulty of running a study in a real environment, prior research was often evaluated in a controlled VR environment. It is unclear how physical eyes on the car affect pedestrians' thoughts in the real-world outdoor environment. To answer the question, we built and mounted a set of physical eyes of suitable size for a real car, drove the car in a public open space, activated the physical eyes, and performed the eye-gaze interaction with pedestrians without providing them any prior explanation. We administered a questionnaire to collect pedestrians' thoughts and conducted a thematic (inductive) analysis. By comparing our findings to the previous results through a literature review, we highlighted the significance of physical implementation of the "eye concept" for future research.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**.

KEYWORDS

Physical anthropomorphic eHMI design, Uncontrolled field study

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1 INTRODUCTION

Eye contact is one of the effective nonverbal human communication methods. Because of this, the application of the eye-gazing approach has gained popularity in advanced human-computer interaction, including human-robot interaction [1, 14], and tracking for detection [34]. As such, we believe that eye contact could be used for a self-driving car's external human-machine interface (eHMI) design.

A significant challenge with the "car with eyes" concept is the design of ecologically valid evaluation methods. The technique of implementation is the first consideration. There are numerous current methods, including 2D displays [30], blinking headlights [47], and 3D mechanized robotics [19, 25]. The evaluation environment is the second consideration. To ensure participant safety, VR has become the mainstream method [8]. However, the immersive experience is not the same as experiencing the eyes on the car in the real world. The bias of the participants' awareness (Hawthorne effect [28]) may impact the overall results and lead to an argument pointing out the possibility of inaccurate findings.

In our field study, we posed the research question, "How do pedestrians perceive the physical eyes on the car as a communication mode in an uncontrolled real-world setting?" To answer the question, we need to meet three requirements: the "eye" concept must be physically implemented, the experience must take place in an open outdoor area (i.e., in the appropriate context), and the pedestrian must interact with the car-with-eyes without any prior knowledge of our experiment. We built a pair of 30-cm diameter robotic eyes attached to a bug-shaped self-driving car (Figure 1). We conducted our evaluation in the real environment to explore pedestrians' thoughts toward a car with eyes. While providing the autonomous look and feel using the Wizard-of-Oz method [38], we drove the car along a fixed route and activated the eye movement to look at an approaching pedestrian continuously following their movement. Another onsite experimenter followed the car, observed the encounters, and handed a paper with a QR code to access a questionnaire to the pedestrians who are interested. In our field study, participants were unaware of the evaluation when they encounter the car and the paper (questionnaire) is handed afterward by another experimenter. We aimed to gather their honest feedback of seeing the car with eyes. We distributed the paper to 50 pedestrians and received 39 fully answered responses. We summed up the data thematically [2] and generated five key findings. We discussed our key findings with previous research results. We found that the previous results are not always valid when "physical factors" are introduced to eHMI, even if they share the same concepts (2D eyes on display and 3D mechanical eyes).

The field study aimed to generate hypotheses about physical eyes on cars in an uncontrolled outdoor environment through inductive analysis. We reported the field study results, and these can be used to design follow-up study. In conclusion, our research provided three key contributions:

- We conducted the uncontrolled study with the physical-eyes-on-the-real-car in a public context.
- We thematically analyzed and concluded five key findings for car with eyes research based on questionnaire.
- We compared our findings to those past results, pointed out differences, and emphasized the worth of testing physical eyes in a real-world environment in future research.

2 RELATED WORK

Using eye expressions as a communication modality is not a novel concept. While it was not trendy in the past research, it has gained its traction in eHMI designs in recent years. The eye-based eHMI concept was first brought up by Matsumura in 2005 [31]. The research provided a preliminary relationship between the robot's motions and their corresponding expressions in human-robot communication. Following this idea, Ochiai et al. [33] mounted a pair of eyes on a car and rotated the eyes tracked by the driver's head pose to express the driver's intention in 2011. With the rapid development of self-driving cars, the requirements for additional communication channels in eHMI have increased. That is, the eye-based eHMI concept entered the car's eHMI designer's consideration. In 2017, Chang et al. [8] built the CG-model eyes on the car. In this project, the eyes' role shifts from conveying the driver's thoughts [46] to disclosing information about the self-driving car itself. One year later, the automaker Jaguar Land Rover developed an intelligent pod with mounted "virtual eye" displaying car's recognizing perception to provide pedestrians with a sense of security [41].

As eye-based eHMI becomes more popular, researchers began to evaluate how well eye contact functions as a communication medium in self-driving cars. However, past research showed inconsistent results. When the eye is a proposed method and the efficiency of each type of information delivery is assessed separately, the effect of the eye is positive, for example, on the direction capacity [21], the risk alarm [6], the intention interpreter [19], and the parking status [36]. But when the eyes are compared among other modalities (textual, audio, color, and anthropomorphic) [3, 15, 26, 30], the effects are frequently disappointing. Results indicated that using the eye was ineffective [7, 17], even resulting in the pedestrian's slowest response time [45], and that understanding the information was difficult [15].

The first reason could be the implementation methods. The "physical factor" should matter. Past "eye research" have used a variety of low-fidelity implementation, such as employing the headlight or LED as an eye [39, 47] and using the display to depict a 2D eye animation [40]. The actual prototype created in 2022 [6, 21] was only tested in virtual reality and did not compare to other types of eHMI. The second interpretation is the evaluation method. Dey et al. [15] listed four categories of evaluation for 70 eHMI concepts: controlled outdoor [12, 22, 35], VR environment [5, 23, 29], video [4, 16, 20], and controlled indoor experiment [27, 32, 43]. Due to manufacturing limitations, the majority of comparative studies for multiple eHMI concepts, including the eye, are conducted using focus groups [10], video surveys [3], taxonomies [15], and literature

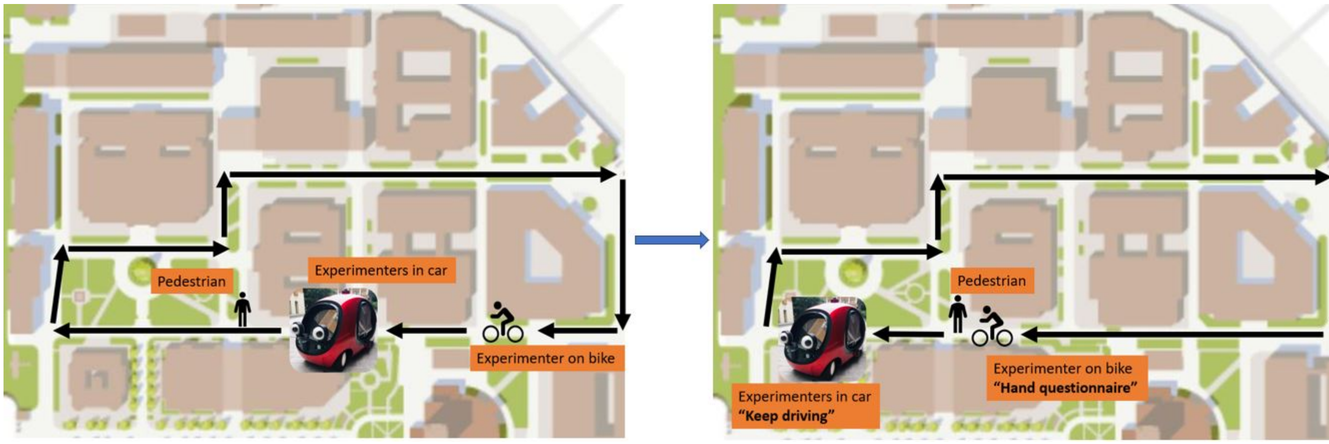

Figure 2: The study step. Two experimenters drove the car, controlled the eyes manually, and conducted the questionnaire of nearby pedestrians. As the car passed by, another onsite experimenter asked pedestrians to answer a questionnaire online.

reviews [24] rather than real-world evaluation with the physical eyes.

With this inspiration, we implemented a pair of physical eyes, attached them to a car, and conducted the real-world evaluation. Human eyes are so versatile in conveying multiple pieces of information that they may give pedestrians ambiguous cues [30]. Winter et al. [13] and Colley et al. [11] mentioned the lack of consensus and no common evaluation standard for the metric. According to the background, we planned to conduct a uncontrolled outdoor field study first. In this field study, we aimed to use inductive reasoning [44], starting with an uncontrolled outdoor evaluation to discover how pedestrians treat the eyes on a self-driving car, then coming to conclusions for further deductive research after thoroughly going over the collected data and looking for patterns.

3 THE APPARATUS

We obtained a self-driving car from a manufacturer Tier IV. The diameter of the eyes is 30 cm and the size is well matched to the car's size. To mimic the real eyes, the robotic eye is in a hemispheric shape with a black plastic pupil and a white ABS resin vitreous and is covered in transparent acrylic (Figure 1, left part). The eye movements are driven by two plane-rotated motors. The motion track resembles the movement of the human eye in a partial hemisphere. While computer vision has significantly improved, during our test, we found that the sunlight and the environment have a significant impact on the detecting of people automatically in real-time. As such, to precisely control eye movement, we decided to manually operate the eyes during the study based on pre-defined rules (described below <section 4.1>). We developed a touchscreen module (Figure 1, right part) that allows the eye-operator to control the motion of the eyes. We put a webcam between the two eyes so that the module shows a live view captured by the webcam for the operator to control the eyes in real-time. We calibrated the eye angle and the camera viewport so that the operator can simply touch the corresponding position to let the eyes look at pedestrians. The operator can drag on the interface to constantly update the eyes' looking direction. The eye movement appears smooth and continuous.

4 FIELD STUDY

We run an in-the-wild study in an open space (university campus) in a Wizard-of-Oz style to answer our research question: what do pedestrians think about the eyes on the car in a real environment as a communication modality without any prior knowledge of experiment? The study was approved by the ethics committee of the authors' institution.

4.1 Condition and Participants

The experiment route illustrated in Figure 2. After assessing the pedestrian flow, we conducted our study in sunny or cloudy weather (no rainy day) between 11:30 a.m. to 12:30 p.m. for five consecutive working days. It is possible that the same people will interact with the robot on different days. However, based on the questionnaire feedback, we have not found such a case. The study was conducted collaboratively by three onsite experimenters (Figure 3). There were two experimenters in the car, the driver, and the eye operator. The third experimenter followed the car on a bicycle while keeping a certain distance and distributing the questionnaire access code. All onsite experimenters followed their rules accordingly. To pretend to be self-driving and secure the pedestrians' safety, the driver adhered to three rules: 1) ensure the pedestrian safety, 2) keep the same speed, and 3) always stop at crosswalks and wait for pedestrians to go first. The eye operator controlled the eyes to stare at each pedestrian one by one (approximated 3 seconds each) in ascending order of their distance from the car if there are several of them. When pedestrians walk in a group, the gaze will be drawn to the center of the group. Experimenters saw through one-way glass. Although previous research showed that such a design might affect pedestrians [9], we still chose this method to lessen the impact of the presence of researchers on the results. During the study, the two experimenters in the car did not engage with pedestrians. The bike riding experimenter kept a distance, so that the pedestrians were unaware of being observed. The onsite on-the-bicycle

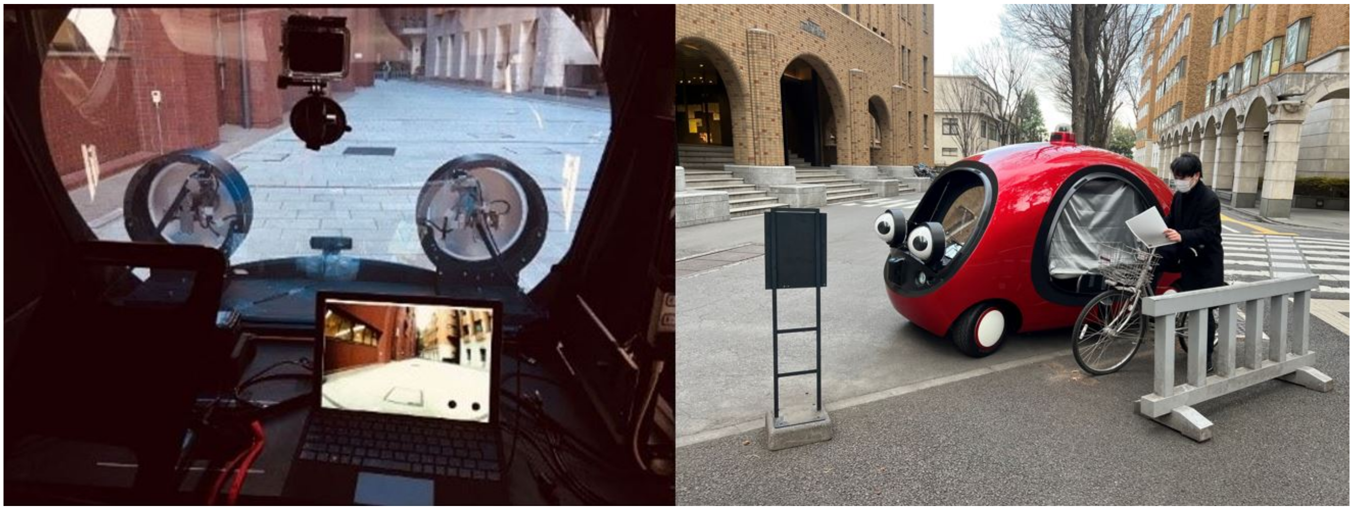

Figure 3: The study setup inside (left) and outside (right). Two experimenters in the car, driver and eye operator, and another onsite experimenter delivering the access to the questionnaire.

experimenter delivered a paper with a QR code to each pedestrian who interacted with or showed interests with the car. The paper contained a greeting message, a QR code for accessing the consent form and the questionnaire online, and a statement regarding the honorariums. We handed out 50 papers in total and received 39 complete responses.

4.2 Thematic (inductive) analysis for questionnaire

The questions were designed to collect information related to the most important issues in the car-to-pedestrian interaction, including the sense of safety, trust, and the communication effectiveness. The Q1 to Q5 are 5-scale Likert questions, are followed by the 'why' question. We highlighted that the 'why' is important and asked the participant to write their thoughts as much as possible. We received the Likert scale answers with the reasons (why questions). One researcher went through all the responses and concluded the themes. The second researcher joined afterward to conduct the theme, review and summarize the key findings of pedestrians' thoughts towards the self-driving cars with eyes. The questions are:
Q1: Can the eyes tell you if the car is self-driving? Why?
Q2: Can the eyes help you understand the car's driving intentions? Why?
Q3: Can the eyes make you trust the car more? Why?
Q4: Can the eyes make you feel the car is noticing you? Why?
Q5: Can the eyes help you enhance your sense of safety? Why?
Q6: Please use one word to describe your feeling when the eyes look at you?
Asking leading questions might bias the results. We continued to ask the questions in this way to emphasize to them that they should answer them only based on their feelings toward the eyes.

5 RESULT

5.1 Questionnaire

Overall, most respondents agree with Q1, Q4 and Q5, while splitting on Q2, and Q3 (Figure 4).

The result showed that the eyes on the car could help increase people's sense of safety when they notice the car's gaze. However, they thought the eyes were not useful for them to enhance their trust or understand the car's intention.

5.2 key findings from "why" questions

Key Finding 1: Eyes are considered to play an important role in indicating that the car is self-driving.

According to the feedback for the "why" question (Q1), almost all participants (30 out of 39) agree with it. First, the eyes can make the car outstanding and differentiate it from other cars in advance: *"From a distance, it's hard to tell if someone is driving in the driver's seat, but it's easy to see that the car has eyes."* Secondly, the eyes have a sense of livelihood that makes the car look self-conscious. It gives the cue that the car is operating by itself rather than being driven by a driver: *"The eyes give the car personality and character, making it have its own identity. The eyes are moving, it shows that the car is awake and operating."* However, some participants (3 out of 39) disagree with it, stating that we cannot associate the eyeball with living things or self-driving. The recognition depends on pedestrians' personal experience. *"If it were widely understood that cars with eyes = self-driving cars, I think it would be true, but I don't think that's the case in today's society."*

Key Finding 2: When compared to the car's implicit movement (e.g., speed) and built-in signaling mechanisms (e.g., blinkers), the eyes by themselves are considered to be relatively ineffective at showing its intentions.

There are nearly half of the participants that did not choose "agree" in the "car's intention understanding" (Q2) questions. Their reasons are concluded into two themes. First, participants viewed

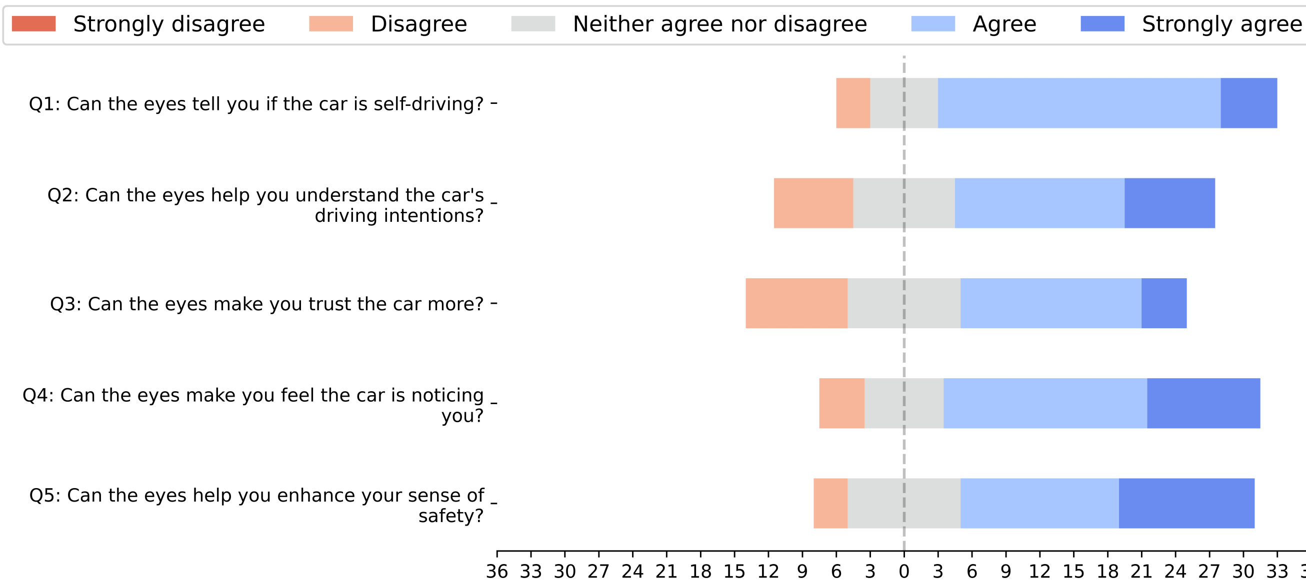

Figure 4: Likert scale answers to the questions asking the scene of trust, safety and understanding toward the eyes on the car.

that even in the traditional pedestrian and driver interactions, they seldom understood drivers' intentions based on the eye contact: *"My judgment is based on whether the driver nods and the eye contact is not used."* They pointed out that they rely more on observing the direction of wheels, activation of blinkers, the car's changing speed and the distance between them. Their experience taught them to interact with the car based on the traffic rules and the car's implicit properties (e.g., slow down, speed up), which would not change whether they could read the car's intention from their eyes. Secondly, there is no clear relationship between a car's intention and eye movement. They agree that we (people) have common sense and the underlying usage of eye movement in non-verbal communication. However, the information conveyed in traffic scenarios should be systematic and rigorous because the misbehavior leads to accidents and unaffordable risks: *"It would be useful if the passerby understood what the eye movement meant, which at this time they don't, so I don't think it would be useful."*

Key Finding 3: Eyes are considered to be a useful tool to enhance the sense of safety by showing the car's perception to pedestrians.

Some pedestrians might know that a self-driving car is equipped with a powerful detection system: *"People should know that it is LiDAR and cameras that are detecting them."* They pointed out the importance of appealing the car's ability: *"I would rather feel relieved if cars are fully equipped with high-tech sensors, even just decoration of them."* In addition, participants confirmed the need to have sensor feedback visible to pedestrians. That is, using some methods to help people picture the presence of the car's sensors and enhance their sense of safety: *"I may indulge in the illusion that since this car has eyes, it looks alive and conscious and will make sound decisions."* People (22 out of 39) described our car with eyes as 'cute,' 'pretty,' and 'interesting' to describe their feeling in Q6. In addition, the eyes were considered to be a friendly and warm approach: *"Compared to camera, which has a cold, surveillance-like image of my surroundings, I feel cute and warm with eyes."* This shows the eyes are one of the useful tools to show a car's perception to pedestrians and enhance the sense of safety while adding friendliness toward the car. On the other hand, some (8 out of 39) described the eyes as 'creepy' and 'uncomfortable'. It shows that there is a certain variety in impressions.

Key Finding 4: Eyes was not considered as a major factor affecting their trust in interactions with cars.

Among Q2-Q5, the trust question (Q3) received some opposite results. Some participants disagreed with the sense of trust, even though they agreed on the eyes helping them understand the car's information, and increasing their sense of safety. Many participants pointed out that the source of trust is rooted in their experience. Pedestrians have the tacit assumption of a human driver, who may not do anything reckless. Another source of trust is interaction experience with machines. Participants said that even if the eyes give off friendly vibes, they are clear that the eyes are operated by a computer. *"Although eyes may provide a sense of personification, a car is still a machine and does not have emotions or judgement."* and *"I think that the presence of eyes gives more character, but whether that leads to trust is another issue. I think the best way to gain trust is to show data."*

Key Finding 5: Eyes, as they can express emotions, are considered to be a promising substitute for the driver together with other communication channels.

The pedestrians argued that the eyes cannot fully substitute absent drivers. Drivers can communicate with pedestrians by using gestures or nodding their heads, in addition to eye contact: *"It seems like a signal that says, 'I am aware of your presence.' But it* *still feels different from communicating with drivers."* Further, eye-communicating is time-consuming, which is not effective when pedestrians must make a quick decision. A participant indicated that eye communication may only be efficient in a simple communication case: *"the eyes could be used as a substitute for signaling with pedestrians in a stationary environment."* Alternatively, the eyes can be useful as a supplementary or in combination with other interfaces in a mixed eHMI design: *"I think eye is a clear way to indicate which way the car wants to go or show that pedestrians are detected. But if the car is trying to show more complicate information, we need another means of communication."*

6 DISCUSSION

In terms of the validity of the pedestrian's feeling to the car (Q6), our results turned out to be positive (key finding 3). Previous studies, however, point out two opposing human reactions to odd objects. They first catch people's attention, but afterwards, people tend to be avoided [37]. Most pedestrians in our study only have brief interactions with the car; their actual acceptance of physical eyes may decline as they interact with the car longer. In the following discussion, we compared our findings to previous studies through the literature review. We discovered that actual eyes sometimes produce distinct findings than prior research.

Compare to past results 1: Which information shall be displayed?

Prior studies examined status, perception, and intention, as well as their combinations. Their findings confirmed the importance of intention conveyed [15, 30] and pointed that perception is a gimmick [18]. Their findings conflict with ours that understanding the car's perception is significant (key finding 3) and the futility of intentions conveyed (key finding 2). A possible interpretation is that the type of eHMI matters. If the eHMI type is an textual LED display, showing the car's intention would be straightforward. However, the movement of the eyes provides the impression of scanning and searching, giving a pedestrian an idea of what the car has seen. As a result, we hypothesized that different types of eHMIs have strengths in convey different types of information based on their features.

Compare to past results 2: The awareness of self-driving car

One potential benefit of using 3D physical eyes rather than 2D display eyes is the possibility for pedestrians to recognize the type of car in advance. For pedestrians, the eyes tell them the car is unusual from a distance (Key finding 1) rather than waiting for the car to get closer to find whether there is a driver, as in a survey for "ghost driver research" [38]. If pedestrians could recognize self-driving cars from mixed-traffic road ahead of time, they could plan their encounter ahead of time, which would make them feel safer.

Compare to past results 3: The shortcoming of "eyes on car"

As mentioned in the related work, the wide usage of eye contact in daily life makes it seem promising. However, numerous comparison studies that looked into various communication modes and found that eye-eHMI is ineffective [7, 15, 17, 45]. Our results confirmed those opinions with following explanations: First, since traditional eye movements have diverse meanings, it is challenging to translate them into robotic motions because it is unclear how these eye behaviors may be mapped in various traffic contexts (key finding 2). It might be the reason that eye is not predominant to other modalities in mass comparative investigation, but received better results when only examining one type of message [6, 21]. Second, while eye contact plays a large part in interpersonal communication, most of it is done with the other precise methods (body language or verbal). Eye contact becomes even more of a complimentary technique because it can express emotion (key finding 5), acting as a supplementary hint. This ability could be helpful in resolving the issue posed by a paper [42] that transmits a message to a different extent (advisory or commanding).

7 CONCLUSIONS AND FUTURE WORK

To discover how the pedestrians think about the car's eyes in a real situation, we mounted a set of robotic eyes on a self-driving car and carried out a field study. From the thematic analysis of the questionnaire data, we obtained five key findings about the benefits and drawbacks of using the eyes in car-to-pedestrian interaction. We found that the "physical" and the "real world evaluation" might give different results despite sharing the same "eye" concepts.

To measure the effect of physical eyes quantitatively and prove those hypotheses we summarized in the field study, we plan to run a follow-up field study. We plan to conduct a comparison-controlled outdoor evaluation with the three types of eyes shown in current "eye" research: the physical eyes, the eyes on display, and the eyes represented by the modified headlights. Furthermore, we intend to attach a camera to the car for video recording in order to conduct the behavior analysis. We bought two GoPros (Hero10, 4K fidelity) and attached them to the sides of the car. We are investigating the quantitative metrics (e.g., road crossing willingness, engagement ratio toward the car's eyes, head pose when the car approaches) as well as the analysis method (e.g., manually video coding, Yolo-based video processing). The follow-up study is planned to start one year later, as there will be a group of incoming freshmen on campus.

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REFERENCES

[1] Henny Admoni and Brian Scassellati. 2017. Social eye gaze in human-robot interaction: a review. *Journal of Human-Robot Interaction* 6, 1 (2017), 25–63.
[2] Narges Ashtari, Andrea Bunt, Joanna McGrenere, Michael Nebeling, and Parmit K Chilana. 2020. Creating augmented and virtual reality applications: Current practices, challenges, and opportunities. In *Proceedings of the 2020 CHI conference on human factors in computing systems*. 1–13.
[3] Pavlo Bazilinskyy, Dimitra Dodou, and Joost De Winter. 2019. Survey on eHMI concepts: The effect of text, color, and perspective. *Transportation research part F: traffic psychology and behaviour* 67 (2019), 175–194.
[4] Pavlo Bazilinskyy, Dimitra Dodou, and Joost De Winter. 2020. External Human-Machine Interfaces: Which of 729 colors is best for signaling 'Please (do not) cross'?. In *2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. IEEE, 3721–3728.
[5] Marc-Philipp Böckle, Anna Pernestål Brenden, Maria Klingegård, Azra Habibovic, and Martijn Bout. 2017. SAV2P: Exploring the impact of an interface for shared automated vehicles on pedestrians' experience. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. 136–140.
[6] Chia-Ming Chang, Koki Toda, Xinyue Gui, Stela H. Seo, and Takeo Igarashi. 2022. Can Eyes on a Car Reduce Traffic Accidents?. In *Proceedings of the 14th*

international conference on automotive user interfaces and interactive vehicular applications.

[7] Chia-Ming Chang, Koki Toda, Takeo Igarashi, Masahiro Miyata, and Yasuhiro Kobayashi. 2018. A video-based study comparing communication modalities between an autonomous car and a pedestrian. In *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 104–109.

[8] Chia-Ming Chang, Koki Toda, Daisuke Sakamoto, and Takeo Igarashi. 2017. Eyes on a Car: an Interface Design for Communication between an Autonomous Car and a Pedestrian. In *Proceedings of the 9th international conference on automotive user interfaces and interactive vehicular applications*. 65–73.

[9] Mark Colley, Christian Hummler, and Enrico Rukzio. 2022. Effects of mode distinction, user visibility, and vehicle appearance on mode confusion when interacting with highly automated vehicles. *Transportation research part F: traffic psychology and behaviour* 89 (2022), 303–316.

[10] Mark Colley and Enrico Rukzio. 2020. A design space for external communication of autonomous vehicles. In *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 212–222.

[11] Mark Colley, Marcel Walch, and Enrico Rukzio. 2020. Unveiling the lack of scalability in research on external communication of autonomous vehicles. In *Extended abstracts of the 2020 chi conference on human factors in computing systems*. 1–9.

[12] Rebecca Currano, So Yeon Park, Lawrence Domingo, Jesus Garcia-Mancilla, Pedro C Santana-Mancilla, Victor M Gonzalez, and Wendy Ju. 2018. ¡ Vamos! Observations of pedestrian interactions with driverless cars in Mexico. In *Proceedings of the 10th international conference on automotive user interfaces and interactive vehicular applications*. 210–220.

[13] Joost de Winter and Dimitra Dodou. 2022. External Human-Machine Interfaces: Gimmick or Necessity. *Delft University of Technology, Delft, The Netherlands* (2022).

[14] Frédéric Dehais, Mickaël Causse, François Vachon, and Sébastien Tremblay. 2012. Cognitive conflict in human–automation interactions: a psychophysiological study. *Applied ergonomics* 43, 3 (2012), 588–595.

[15] Debargha Dey, Azra Habibovic, Andreas Löcken, Philipp Wintersberger, Bastian Pfleging, Andreas Riener, Marieke Martens, and Jacques Terken. 2020. Taming the eHMI jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces. *Transportation Research Interdisciplinary Perspectives* 7 (2020), 100174.

[16] Debargha Dey, Azra Habibovic, Bastian Pfleging, Marieke Martens, and Jacques Terken. 2020. Color and animation preferences for a light band eHMI in interactions between automated vehicles and pedestrians. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[17] Debargha Dey and Jacques Terken. 2017. Pedestrian interaction with vehicles: roles of explicit and implicit communication. In *Proceedings of the 9th international conference on automotive user interfaces and interactive vehicular applications*. 109–113.

[18] Stefanie M Faas, Lesley-Ann Mathis, and Martin Baumann. 2020. External HMI for self-driving vehicles: which information shall be displayed? *Transportation research part F: traffic psychology and behaviour* 68 (2020), 171–186.

[19] Stephen M Fiore, Travis J Wiltshire, Emilio JC Lobato, Florian G Jentsch, Wesley H Huang, and Benjamin Axelrod. 2013. Toward understanding social cues and signals in human–robot interaction: effects of robot gaze and proxemic behavior. *Frontiers in psychology* 4 (2013), 859.

[20] Lex Fridman, Bruce Mehler, Lei Xia, Yangyang Yang, Laura Yvonne Facusse, and Bryan Reimer. 2017. To walk or not to walk: Crowdsourced assessment of external vehicle-to-pedestrian displays. *arXiv preprint arXiv:1707.02698* (2017).

[21] Xinyue Gui, Koki Toda, Stela H. Seo, Chia-Ming Chang, and Takeo Igarashi. 2022. "I am going this way": Gazing Eyes on Self-Driving Car Show Multiple Driving Directions. In *Proceedings of the 14th international conference on automotive user interfaces and interactive vehicular applications*.

[22] Azra Habibovic, Jonas Andersson, Maria Nilsson, V Malmsten Lundgren, and J Nilsson. 2016. Evaluating interactions with non-existing automated vehicles: three Wizard of Oz approaches. In *2016 IEEE intelligent vehicles symposium (IV)*. IEEE, 32–37.

[23] Marius Hoggenmüller, Martin Tomitsch, Luke Hespanhol, Tram Thi Minh Tran, Stewart Worrall, and Eduardo Nebot. 2021. Context-Based Interface Prototyping: Understanding the Effect of Prototype Representation on User Feedback. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 370, 14 pages.

[24] Qianni JIANG, Xiangling ZHUANG, and Guojie MA. 2021. Evaluation of external HMI in autonomous vehicles based on pedestrian road crossing decision-making model. *Advances in Psychological Science* 29, 11 (2021), 1979.

[25] Omae Laboratory. 2011. *Research on information transmission to the exterior in self-driving self-driving cars using eyeball devices.* Retrieved December 8, 2022 from http://web.sfc.keio.ac.jp/~omae/poster/omaelab.pdf

[26] Jae-Gil Lee, Ki Joon Kim, Sangwon Lee, and Dong-Hee Shin. 2015. Can autonomous vehicles be safe and trustworthy? Effects of appearance and autonomy of unmanned driving systems. *International Journal of Human-Computer Interaction* 31, 10 (2015), 682–691.

[27] Jamy Li, Rebecca Currano, David Sirkin, David Goedicke, Hamish Tennent, Aaron Levine, Vanessa Evers, and Wendy Ju. 2020. On-road and online studies to investigate beliefs and behaviors of Netherlands, US and Mexico pedestrians encountering hidden-driver vehicles. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*. 141–149.

[28] Ritch Macefield. 2007. Usability Studies and the Hawthorne Effect. *J. Usability Studies* 2, 3 (may 2007), 145–154.

[29] Karthik Mahadevan, Elaheh Sanoubari, Sowmya Somanath, James E Young, and Ehud Sharlin. 2019. AV-Pedestrian interaction design using a pedestrian mixed traffic simulator. In *Proceedings of the 2019 on designing interactive systems conference*. 475–486.

[30] Karthik Mahadevan, Sowmya Somanath, and Ehud Sharlin. 2018. Communicating awareness and intent in autonomous vehicle-pedestrian interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.

[31] Takafumi Matsumaru, Kazuya Iwase, Kyouhei Akiyama, Takashi Kusada, and Tomotaka Ito. 2005. Mobile robot with eyeball expression as the preliminary-announcement and display of the robot's following motion. *Autonomous Robots* 18, 2 (2005), 231–246.

[32] Milecia Matthews, Girish Chowdhary, and Emily Kieson. 2017. Intent communication between autonomous vehicles and pedestrians. *arXiv preprint arXiv:1708.07123* (2017).

[33] Yoichi Ochiai and Keisuke Toyoshima. 2011. Homunculus: the vehicle as augmented clothes. In *Proceedings of the 2nd Augmented Human International Conference*. 1–4.

[34] Oskar Palinko, Francesco Rea, Giulio Sandini, and Alessandra Sciutti. 2016. Robot reading human gaze: Why eye tracking is better than head tracking for human-robot collaboration. In *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 5048–5054.

[35] Ana Rodríguez Palmeiro, Sander van der Kint, Luuk Vissers, Haneen Farah, Joost CF de Winter, and Marjan Hagenzieker. 2018. Interaction between pedestrians and automated vehicles: A Wizard of Oz experiment. *Transportation research part F: traffic psychology and behaviour* 58 (2018), 1005–1020.

[36] Nicholas Pennycooke. 2012. *AEVITA: Designing biomimetic vehicle-to-pedestrian communication protocols for autonomously operating & parking on-road electric vehicles*. Ph. D. Dissertation. Massachusetts Institute of Technology.

[37] Christian Purucker, David E Sprott, and Andreas Herrmann. 2014. Consumer response to car fronts: eliciting biological preparedness with product design. *Review of Managerial Science* 8, 4 (2014), 523–540.

[38] Dirk Rothenbücher, Jamy Li, David Sirkin, Brian Mok, and Wendy Ju. 2016. Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles. In *2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN)*. IEEE, 795–802.

[39] Alexandros Rouchitsas and Håkan Alm. 2019. External human–machine interfaces for autonomous vehicle-to-pedestrian communication: A review of empirical work. *Frontiers in psychology* 10 (2019), 2757.

[40] Alexandros Rouchitsas and Håkan Alm. 2022. Ghost on the Windshield: Employing a Virtual Human Character to Communicate Pedestrian Acknowledgement and Vehicle Intention. *Information* 13, 9 (2022), 420.

[41] Jaguar Land Rover. 2018. *THE VIRTUAL EYES HAVE IT*. Retrieved Sept 12, 2022 from https://www.jaguarlandrover.com/2018/virtual-eyes-have-it

[42] Jinjuan She, Jack Neuhoff, and Qingcong Yuan. 2021. Shaping pedestrians' trust in autonomous vehicles: an effect of communication style, speed information, and adaptive strategy. *Journal of Mechanical Design* 143, 9 (2021).

[43] David Sirkin, Sonia Baltodano, Brian Mok, Dirk Rothenbücher, Nikhil Gowda, Jamy Li, Nikolas Martelaro, David Miller, Srinath Sibi, and Wendy Ju. 2016. Embodied design improvisation for autonomous vehicles. In *Design Thinking Research*. Springer, 125–143.

[44] Raimo Streefkerk. 2022. *Inductive vs. Deductive Research Approach.* Retrieved Sept 12, 2022 from hhttps://www.scribbr.com/methodology/inductive-deductive-reasoning/

[45] Elena Torta, Jim van Heumen, Raymond H Cuijpers, and James F Juola. 2012. How can a robot attract the attention of its human partner? a comparative study over different modalities for attracting attention. In *International Conference on Social Robotics*. Springer, 288–297.

[46] Akira Utsumi, Masahiro Tada, Naoki Yamamoto, Noriyoshi Matsuo, Takeshi Torii, and Kazunori Shidoji. 2013. Active safety with enhanced communication among traffic participants. In *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*. IEEE, 1167–1172.

[47] Sonja Windhager, Florian Hutzler, Claus-Christian Carbon, Elisabeth Oberzaucher, Katrin Schaefer, Truls Thorstensen, Helmut Leder, and Karl Grammer. 2010. Laying eyes on headlights: Eye movements suggest facial features in cars. *Collegium antropologicum* 34, 3 (2010), 1075–1080.