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Safety Implications of Automated Vehicles Providing External Communication to Pedestrians

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Safety Implications of Automated Vehicle Providing External Communication to Pedestrians

A Research Report from the University of California Institute of Transportation Studies

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16. Abstract
Automated Driving Systems (ADSs) are developing at a rapid pace and even testing on public roads, but pedestrians' interaction with ADSs is not comprehensively understood and investigated to ensure safe operations of ADSs. The objective of this study is to investigate the effective interaction between ADSs and pedestrians. We developed prototype interfaces using different modalities, for example text vs. symbol and variety of symbols. These interfaces communicated three types of information: 1) intention of ADS; 2) instructing pedestrians what to do, and 3) ADS's awareness of pedestrians. We tested the interfaces through two field studies in three uncontrolled intersection with crosswalks. The Wizard of Oz method was used, in which an experimenter worked as a driver and was invisible by wearing an outfit to simulate an automated vehicle (AV). The interfaces were displayed on an LED panel mounted on the AV. Results showed external interface on the AV didn't change the decision time for pedestrians to cross. However, the vehicle movement patterns (e.g., slowing down the vehicle speed) continued to be a significant cue for pedestrian. All participants perceived the communication of the ADS's intent (e.g., "stopping" printed on the LED panel) and the advisory information from the ADS (e.g., an icon that indicated it was safe for pedestrians to cross); these were both more effective than trying to convey the awareness of the ADS (e.g., an icon with an open or closed eye). The subjective ratings showed positive effects of the interfaces that were easy to understand (e.g., text interface and symbol interface) as they did help pedestrians to feel safe and trustful when interacting with the ADS.

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Disclaimer

Safety Implications of Automated Vehicles Providing External Communication to Pedestrians

UNIVERSITY OF CALIFORNIA INSTITUTE OF TRANSPORTATION STUDIES

December 2019

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Executive Summary

In this project, we tested several different types of external communication interfaces mounted on highly-automated vehicles to evaluate their ability to provide useful information to pedestrians in urban driving environments. In the first phase of this project, we identified critical situations when vehicles and pedestrians interact with each other: one pedestrian interacts with one car, one pedestrian interacts with two cars, two or more pedestrians interact with one car, and multiple pedestrians interact with multiple cars from both directions. Identifying these critical scenarios helped with the selection of different types of signage and the design of several external communication interfaces to test in the second phase of the project.

In the second phase, we designed and developed prototype interfaces using different signage (e.g., text vs. symbol), which can be used so AVs can effectively communicate with pedestrians in their vicinity. There were three types of information that the interfaces communicated: 1) The AV's awareness of pedestrians or the surrounding traffic 2) the intention of the AV (e.g. to slow down, stop, etc.); and 3) telling pedestrians what to do (e.g. cross, don't cross). A LED panel was developed to display the external interfaces and mounted on the top of the test vehicle.

In the main data collection phase, we conducted experimental tests and compared the different prototype interfaces in order to investigate pedestrians' behavior while interacting with the AV, as well as their understanding of messages displayed by the vehicles. An experimenter wearing a black outfit, invisible to others outside the test vehicle, drove the test vehicle to simulate a full autonomous vehicle. A remote controller was used by a second experimenter to display different messages on the LED panel. The test vehicle looked to be operating autonomously to the participants who were asked to watch the approaching vehicle and decide whether or not it would be safe to cross an intersection. Participants were also asked to wear eye tracking glasses in order to obtain data on their eye movements and gaze behavior (how long they looked at a particular area of the vehicle before making their decision). Data were collected in a preliminary stage and then a main testing stage.

Results from the preliminary testing as well as the main data collection showed that the presence of an external communication interface on the AV didn't change the amount of time participants took to decide whether or not to cross the intersection. Vehicle movement patterns (e.g., slowing down the vehicle speed and showing an intention of stopping at a considerable distance away from the designated crosswalk) continued to be the most significant cues for deciding whether to cross, though the participants did pay attention to the messages being conveyed on the AV's display panel. On the other hand, the subjective ratings by the participants showed positive results for the interfaces: some were easy to understand (e.g., text interface and symbol interface) and they did help pedestrians to feel safe and trustful when interacting with AVs. Their eye movement patterns further showed more attention being paid to those easy-to-understand interfaces, suggesting that subjects well understood them

and used them to make their decision. Regarding the message conveyed by the external interfaces, all participants of the study perceived the communication of the AV's intent and the information from the AV about what the pedestrian ought to do were more effective than the mere fact that the AV was aware of the pedestrian's presence.

Introduction

Background and Motivation

The importance of interactions between automated vehicles (AVs) and vulnerable road users such as pedestrians and cyclists has been widely recognized (Kyriakidis et al., 2019; Rasouli, Kotseruba, & Tsotsos, 2018). Research of interactions between human-driven vehicles and pedestrians has shown that pedestrians rely on many nonverbal cues from the driver, such as eye contact and hand waving (Guéguen, Meineri, & Eyssartier, 2015; Sucha, Dostal, & Risser, 2017). Pedestrians also rely on the cues from the vehicles themselves, such as distance and velocity of the vehicle, number of pedestrians simultaneously crossing, as well as vehicle platoon size (Himanen & Kulmala, 1988; Schmidt & Färber, 2009). With partially automated vehicles, drivers' attention may shift away from the driving environment and other road users, which results in a lack of cues from drivers for pedestrians. Moreover, in fully automated vehicles drivers may be absent, which leaves pedestrians to infer awareness and intent from the vehicles alone.

As of May 2018, the California DMV has issued Autonomous Vehicle Testing Permits to 53 entities, with safety drivers inside of the vehicle.[1] In April 2018, the revised regulations governing the safe deployment of autonomous vehicles took effect, which opened the door to entities who wanted to test vehicles without safety drivers on California's public roads. It is foreseeable that vehicle-pedestrian interactions will be a big challenge. With the introduction of different levels of automation, pedestrians will be interacting with manually-driven vehicles, partially-automated vehicles, as well as fully-automated vehicles in the future.

Research into AV and pedestrian interactions so far has focused on the technological challenges, such as perception, localization, path planning and vehicle control (Koehler et al., 2013; Quintero, Almeida, Llorca, & Sotelo, 2014; Rasouli et al., 2018). A relatively less explored area is vehicle-pedestrian interaction from the pedestrians' perceptive. However, this research is critical for the safe deployment of AVs, as it provides information that will highlight (1) whether pedestrians will be able to understand the vehicle's driving mode (no automation, semi-automation, full automation) and vehicle's intentions when there are different levels of automation and (2) how pedestrians will interact with AVs with or without external communication. If the interaction between pedestrians and automated vehicles leads to miscommunication or confusion, it could also disrupt traffic operations. AVs will only be acceptable and deployable if they are proven to be communicative and safe for pedestrians and all other road users (Kyriakidis et al., 2019).

[1] https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/permit

Related Work

In the context of AV and pedestrian interactions, the communication of awareness is defined as the vehicle's ability to acknowledge the pedestrian's presence. The communication of intent is defined as the vehicle's ability to communicate its next action to the pedestrian (e.g., about to stop or not stop for the pedestrian) (Mahadevan, Somanath, & Sharlin, 2018).

Rothenbucher, Li, Sirkin, Mok, and Ju (2016) performed observational field experiments to investigate pedestrians' interactions with an AV, which was operated by a human driver hidden inside. No additional communication interface was used. Based on the analysis of the video recording data and post-study interview, the researchers concluded that most pedestrians behaved normally at crosswalks when encountering the AV. Only a small number (less than 20%) of pedestrians actively approached the car to look for a driver and were hesitant about crossing. Clamann, Aubert, and Cummings (2016) compared three visual interfaces which were displayed in the front of an autonomous van: (1) advice, indicating when it was safe or not safe to cross in front of the vehicle, via a Walk/Don't Walk symbol; (2) information, presenting speed of the vehicle; and (3) a blank screen with no information. Similarly, results of the experiment did not show any significant differences between the three displays, which implied that having no display at all was as effective as the advice and information displays. Only 12% of the participants reported that the interfaces influenced their decision whether to cross. Instead, distance from the vehicle was the main determinant.

In contrast, some experimental studies have had more positive conclusions about using external interfaces for communication between pedestrians and AVs. Lagström and Lundgren (2015) investigated whether it would useful to enhance vehicles' ability to communicate with pedestrians when introducing automated driving. Results indicated that pedestrians had a need to know when a vehicle was in automated driving mode. In the second phase of their study, the researchers developed a prototype, a LED strip lighting up in different sequences, in order to communicate that the vehicle "is in automated mode," "is about to yield," "is resting" and "is about to start." The evaluation results showed that pedestrians were able to understand the LED signals conveyed by the interface. They were also confident in their interpretation of the signals.

Chang, Toda, Sakamoto, and Igarashi (2016) added "eye icons" to a car's headlight area in order to establish visual communication between the pedestrian and AV. The effect of the interface was evaluated in a virtual-reality simulated environment. The authors found that this feature decreased the mean decision-making time from 2.32 to 2.03 seconds. Mahadevan et al. (2018) conducted a design study to explore interface designs for pedestrian and AV interactions. They implemented four prototypes and deployed them on a Segway[2] and a car. Two user studies were conducted to assess the effectiveness for communicating the awareness and intent of the AV. They found that all participants in the study perceived communicating awareness and

[2] http://www.segway.com/

intent cues to be important. Furthermore, communicating intent was more important than communicating awareness. The authors also proposed the use of different interfaces (e.g., interfaces on the vehicle, on street infrastructure, and on pedestrians' mobile phone) for communicating autonomous vehicle awareness and intent to pedestrians. They also found that participants preferred receiving cues from an interface and vehicle movement over communication from the vehicle alone. Also, vehicle movement patterns (e.g., slowing down the vehicle showing the intention to stop, stopping at a considerable distance away from the designated crosswalk) continued to be a significant cue for pedestrian and AV interaction, even when interfaces were provided. de Clercq, Dietrich, Núñez Velasco, de Winter, & Happee (2019) investigated the effects of four external interfaces (i.e., front brake lights, "Knightrider" scanning light, smiley face, text) on participants' crossing intentions using a virtual reality set-up. Participants felt safer to cross with all four interfaces in comparison to the baseline without any interface. The authors also investigated the effect of changing the timing when a warning was given: (1) early, 50 meters; (2) intermediate, 35 meters; and (3) late, 20 meters. The earlier the warning was given, the earlier participants felt safe to cross. Therefore, the results indicated that the external interface had the potential to enhance traffic efficiency.

There are also on-going activities by the industry to include interfaces for pedestrian and AV interaction either on demo vehicles or concept vehicles, as shown in Figure 1. Drive.ai, which started testing their self-driving vans in Texas, uses "Waiting for You" texts to tell pedestrians or cyclists it is OK to cross the street. [3] Nissan, in their IDS concept car, also used "After you" messages on the windshield and lighting surrounding the vehicle body, demonstrating that pedestrians and cyclists can safety interact with the AV.[4] Ford, together with the Virginia Tech Transportation Institute, tested a lighting method for self-driving vehicles to signal vehicles' intent to pedestrians, human drivers and cyclists, aiming to develop and promote a standard visual language that everyone can easily process and understand.[5]

1 2 3

Figure 1. Examples of Industrial Applications for Pedestrian and AV Interaction

[3] https://www.drive.ai/

[4] https://www.nissanusa.com/vehicles/future-concept/ids-self-driving-electric-car.html

[5] https://media.ford.com/content/fordmedia/fma/me/en/news/2017/09/14/ford--virginia-tech-go-undercover-to-develop-signals-that-enable.html

Objectives of This Project

In this project, we aimed to explore the effective interaction and appropriate interface between highly-automated vehicles and pedestrians in urban driving environments. The objectives of this project are summarized as follows:

(1) In order to understand the intended meaning of an interface, it is important to know the context within which the interface is displayed. Therefore, in the first phase of this project, the objective was to identify the safety-critical scenarios when vehicles and pedestrians interact with each other. This phase was conducted in conjunction with an existing Berkeley DeepDrive project.

(2) In the second phase of the project, the objective was to design and develop prototype interfaces using different modalities (e.g., text vs. symbol), with which AVs can effectively communicate with pedestrians in the vicinity.

(3) In the third phase of this project, we conducted experimental testing to compare different prototype interfaces in order to evaluate pedestrians' understanding of the awareness and intent of the vehicles. More specifically, the objectives of the third phase were to investigate:

   a. Is it essential to enhance AV's ability to communicate with pedestrians about vehicle driving mode and vehicle intention?

   b. What are the best design recommendations for a simple and effective interface?

   c. Additionally, in the experimental studies we used eye-tracking glasses to capture data on pedestrians' visual attention and used vehicle-mounted outward-facing cameras to record pedestrians' pose and movement, as a potential input for the AV's perception of the pedestrians' intentions in specific situations.

Anticipated Impact

The goal of this project was to investigate and make recommendations about the interaction between pedestrians and automated vehicles when different levels of automation are introduced and operated in urban environments.

(1) First, as California has issued regulations which allow entities to test their automated vehicles on public roads both with and without safety drivers, this project's findings provide information that highlights the safety concerns regarding pedestrians' interaction with those vehicles being tested. Based on the information, the relevant agencies could decide whether test vehicles should be equipped with external communication devices.

(2) Second, although the future role of interfaces for automated vehicle and pedestrian interaction needs further investigation, we hypothesized that some indication of

automation mode or external communication of vehicle awareness and intent would be essential when the autonomous vehicles are introduced especially with mixed levels of automation. If interfaces vary from one manufacturer to another it could be very confusing for pedestrians. Therefore, it may be essential to develop industry standards, or public regulations to guide their design and function.

(3) Third, a fundamental motivation for this project was to put pedestrians at the center of this research question and to capture their views and needs. For example, what can pedestrians easily identify with and what can they expect from the automated vehicles? Positive experiences when pedestrians encounter automated vehicles on the road is critical to their confidence, trust, and acceptance of the technology even if they don't own an AV or ride in one.

Pre-Experiment Studies

Safety Critical Scenarios for Vehicle and Pedestrian Interaction

In this phase of the study, the purpose was to understand the safety critical scenarios when pedestrians interact with vehicles. This phase of work was done through combined efforts with the Berkeley DeepDrive (BDD) project *Pedestrian-Vehicle Interaction – Data Sets and Analysis.*[6] The data was captured by video near the north gate of the UC Berkeley campus at unmarked mid-block pedestrian crossings, where students often spontaneously cross in order to go from building to building. Image processing techniques were used to segment each input video frame at the pixel level into three object classes, including (1) pedestrians; (2) background and foreground; and (3) vehicles. Both the pedestrian behavior and vehicle trajectory were captured. A unified time axis with a local geographic coordinate system was set up for each data set. All the data that belong to the same data set were mapped onto this time-geography space. Pedestrian behaviors were defined as a series of basic action elements, including walk forward, step back, stop, speed up, slow down, turn left, turn right, head turn left, head turn right, wave hand and so on. These pedestrian actions were recognized directly or deduced from trajectories. The above work was done by the BDD infrastructure project team.

Based on the image processing, the current project team were able to extract the video segments when pedestrians were in the vehicle's vicinity. After extracting those video segments, the research team manually went through each segment and annotated the video. For each video segment, the following items were generated on the recording sheet: video file name, timestamp of the interaction, crossing path of the pedestrian, number of pedestrians, and vehicle actions. After this, we identified the critical scenarios in which vehicles and pedestrians interacted with each other and classified them into different categories. Table 1 shows the four categories, including (1) one pedestrian interacts with one car, (2) one

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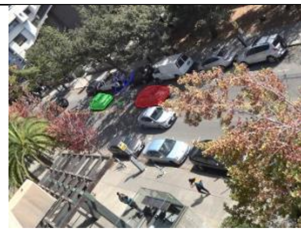
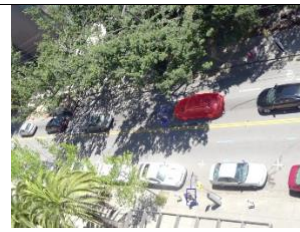
[6] https://deepdrive.berkeley.edu/project/pedestrian-vehicle-interaction-%E2%80%93-data-sets-and-analysis

pedestrian interacts with two cars, (3) two or more pedestrians interact with one car, and (4) multiple pedestrians interact with multiple cars from both directions. Identification of these critical scenarios helped with the selection of different modalities and designs for the external communication interfaces used in the 2nd phase of the project.

Table 1. Exemplar Critical Scenarios of Pedestrians and Vehicle Interaction

			
Scenario 1: One pedestrian interacts with one car	Scenario 2: One pedestrian interacts with two or more cars	Scenario 3: Two or more pedestrians interact with one car	Scenario 4: Multiple pedestrians interact with multiple cars from both directions

Design and Develop Prototype

Conception

In this phase of the project, we designed and developed prototypes for external communication displays and the information that should be conveyed to pedestrians. Based on a literature review, there are three types of information that the AVs communicate with pedestrians: 1) intention of the AV (Mahadevan et al., 2018) , 2) advice for pedestrians regarding what to do/ not to do (Clamann, Aubert, & Cummings, 2016), and 3) the AV's awareness of pedestrians (Chang et al., 2017). Ultimately, all three types of information were used to enable pedestrians to decide more quickly and safety whether to cross or not to cross the street.

Design of the Interfaces

We next developed four interface designs that could convey the three types of messages. The first two interfaces conveyed the intent of the AV. For instance, we proposed a text interface for advising pedestrians of the current or/and future state of the AV. In the first display, the current status of the AV was shown by using the words "Moving" or "Stopped" while in the next display the future status of the AV was indicated by the words "Stopping" or "Starting." The second proposed interface used colored displays conventionally used in transportation (i.e., yellow, red, and green). In the third interface, we used standard crosswalk symbols based on the Manual on Uniform Traffic Control Devices (MUTCD)[7] to advise pedestrians to cross or not

[7] https://mutcd.fhwa.dot.gov/

to cross. Finally, we used opened and closed animated eyes to replicate eye contact between drivers and pedestrians, to convey the AV's awareness of the pedestrian. Table 2 illustrates the four interfaces with their displays and their communicated information. After heuristic evaluation among our collaborators who have different backgrounds including engineering and psychology, we selected only three interfaces. The two interfaces which were intended to convey the status of the AV with colors were excluded due to potential confusion that might create for pedestrians.

Table 2. Interface Design Types and Their Communicated Information

Type of the Interface	Type of Communicated Information	Display	The Communicated Information
Text	Intent of the AV		The AV is moving.
			The AV is stopping.
			The AV is stopped.
			The AV is starting.
Colored Display	Intent of the AV		The AV is moving. The pedestrian should not work.
			The AV is slowing down.
			The AV is stopped. The pedestrian can walk.
			The AV is about to start [Blinking].
Symbol	Advisory information		Do not walk
			Do not walk if you have not started [Blinking].

Type of the Interface	Type of Communicated Information	Display	The Communicated Information
			Walk
Animated eye	Awareness of AV regarding pedestrian		The AV is not aware of the pedestrian.
			The AV is aware of the pedestrian.

Development of the Prototype

We used a 144*32-pixel LED display for showing the selected interfaces. The pixel size is 0.315*0.315 inch. The LED panel, 10.08 inches high and 45.35 inches wide, was mounted on the top of the AV. The size of the panel was selected by considering the width of the AV and the position of other sensors (e.g. Lidar) on the vehicle. The LED was controlled by a remote controller which had 16 keys which allowed researchers to show 16 different displays. The LED was connected to a laptop and a software module which read and displayed the prototype .bmp files. We used Photoshop software to create the .bmp files for the prototypes. Table 3 illustrates the detailed information regarding the .bmp files of the prototypes.

Table 3. Detailed Information of the Interface Designs

Type of the Interface	Design Details
Text	Font: FHWA series C 2000
	Height (of X): 30 pix (9.45’’)
	Width (of X): 18 pix (5.67’’)
	Stroke: 5 pix (1.58’’)
	Spacing: 3 pix (0.95’’)
Symbol	Hand Height: 30 pix (9.45’’)
	Hand Width: 20 pix (6.3’’)
	Hand Color: Amber (f4901d)

Type of the Interface	Design Details
	Display Time (for Blinking display): 660ms
	Walking Sign Height: 30 pix (9.45’’)
	Walking Sign Width: 16 pix (5.04’’)
	Walking Sign Color: White (ffffff)
Animated Eye	Opened-eye Height:30 pix (9.45’’)
	Opened-eye Width: 112 pix (35.28’’)
	Opened-eye: Color white (ffffff)
	Closed-eye Height: 23 pix (7.25’’)
	Closed-eye Width: 112 pix (35.28’’)
	Closed-eye Color: White (ffffff)

Preliminary Data Collection

Participants

Six participants (3 males and 3 females) with a mean age of 27.17 years (SD=5.42) were recruited from the University of California, Berkeley community. The goal was to select a sample group of people who were representative of pedestrians in an urban traffic environment, such as on or near the UC campus. According to the preliminary screening survey, all participants grew up in the U.S. and had 20/20 or corrected to normal vision with no mobility impairments. Since none of them had experience interacting with AVs, they were considered naive users. Furthermore, they were never involved in pedestrian-related motor vehicle collision as a pedestrian.

Apparatus

Two vehicles were used in this study. One was a conventional vehicle with a human driver controlling the throttle, brake and steering. The other one was an AV, which could be controlled automatically. However, as mandated by law, the AV was manned by a dedicated driver wearing an outfit in the shape of the original seat and covered with a regular seat cover designed to hide the driver. The area around the eyes was covered with only a black see-through fabric to give the driver peripheral vision. The AV was a Ford MKZ and was equipped with one Lidar, two cameras, GPS module, Radar, and drive-by-wire sub-system (see Figure 2).

Figure 2. The AV with LED Display and the Outfit

As shown in Error! Reference source not found., the display interface was mounted on the top of the vehicle. During the experiment, a researcher used the remote controller to display different messages based on a predetermined sequence during each trial.

Participants were equipped with a keypad and an eye tracker. Pupil Labs' eye tracker[8] was used to record where the participant was looking during the experiment. The device captures video and audio streams, detects pupils, tracks gaze, tracks markers in the environment, and records the data in an open format. The eye-tracker has three cameras, two eye cameras run at 200hz and one world camera that records subjects' field of view and runs at 120hz. The eye-tracker uses a dark pupil detection algorithm, which assumes that the dark area of the eye image corresponds to the pupil, and the clearer area to the iris. Participants were assisted with putting on the eye-tracker prior to the experiments.

Participants also used a keypad to record the time that they started looking at the vehicle and the time that they would like to cross, and to rate the safety of each display. Figure 3 shows both the keypad and the eye-tracker.

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[8] https://pupil-labs.com/pupil/

(A)

(B)

Figure 3. (A) Eye Tracker and (B) Keypad

Interface Design

As described in the previous section, we designed three interface types for the AVs including text, symbol, and animated-eye to communicate with participants (see Figure 4-A). Using the mounted panel these messages were displayed to participants from varying distances (see Figure 4-B) as follows:

- Start point: The point at which pedestrians start looking at the vehicle and perceive the first message display. According to the American Association of State Highway and Transportation Officials' (AASHTO) standards, their perception reaction time (PRT) is 2.5 seconds (Scott, Atkins, Bentzen, & Barlow, 2012). Considering 7 seconds for slowing-down time, 2.5 seconds for the perception reaction time, and the speed of the vehicle (15mph), the participants should start seeing the vehicles around 209 feet away from the crosswalk.

- Slowing-down point: The point at which the vehicles need to start slowing down. Considering the critical gap for pedestrians which is around 7 seconds (Capacity Manual, 2000)[9] and the speed of the vehicles which is 15mph maximum, the pedestrian needs 154 feet of space to react (cross or not cross). Hence, the point at 154 feet away from the crosswalk is the slowing-down point.

- Stop point: The point at which the vehicles need to come to a full stop. According to Department of Motor Vehicles' manual, it is important to stop the vehicle within 5 feet of the crosswalk. [10] Therefore, 5 feet away from the participants was considered as the stop point.

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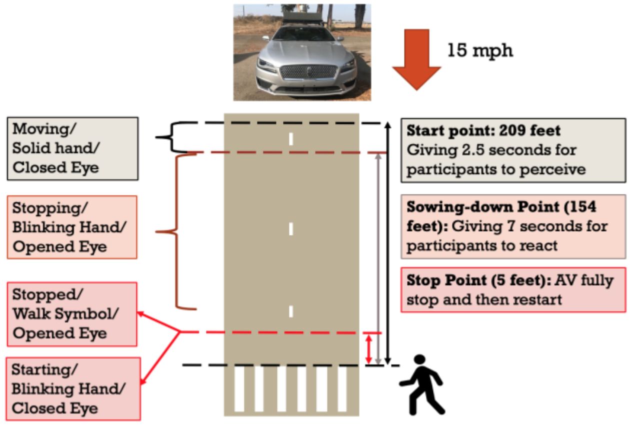
[9] Capacity Manual, Transportation research Board of the National Academies (2000), pp. 60.
[10] https://www.dmv.ca.gov/portal/dmv/detail/pubs/hdbk/right_of_way

Interface Type	Interface Display	Communicated Information
Text	MOVING	The vehicle is moving forward.
	STOPPING	The vehicle is stopping.
	STOPPED	The vehicle is stopped.
	STARTING	The vehicle is about to start.
Symbol		The pedestrian should not walk.
		The pedestrian should walk.
		The pedestrian should be cautious.
Animated Eye		The vehicle is not aware of the pedestrian.
		The vehicle is aware of the pedestrian.
Manual Car	Driver's eye contact	The drive is aware of the pedestrian

(A)



(B)

Figure 4. (A) Interface Design Types and the Communicated Information (B) The LED Strip Mounted on Instrumented AV and Distance for Displays

Procedure

Experimental trials included pedestrian crossing scenarios in which participants showed their intention to cross in front of the AV or the conventional vehicle at three similar crosswalks. Participants were asked to briefly observe the approaching vehicle and indicate when it was safe to cross. After arriving at our experimental site in Richmond Field Station (a university facility), participants were led to a conference room, asked to complete a Background Information Form and sign the Consent Form. Then participants were given a safety orientation and asked to not to cross the crosswalks and only to show their intention to cross by pressing buttons on the keypad.

In order to have participants become familiar with the procedure, one practice session was arranged before proceeding to the actual experiments. They were helped to put on the eye-tracker. A researcher calibrated the eye-tracker at the beginning of each trial. The eye-tracker calibration process worked as follows. First, subjects were asked to stand at approximately one meter from the researcher. Subjects were asked to look at the center of a bullseye-like target (see Figure 5) that the researcher was holding at a height of 100 cm. Then, the experimenter moved the target to each of nine positions on an imaginary 3 × 3 matrix. Subjects were asked to keep their eyes at the center of the target with their head fixed. To validate that the calibration was correctly performed, the same procedure was repeated twice before starting the experiment. To increase the precision and accuracy of the eye-tracker, the same calibration procedure was repeated after each trial.

Figure 5. Target Used for Eye-Tracker Calibration

The procedure for the practice session was as follows:

- A researcher asked the participants to imagine that they wanted to cross the crosswalk.
- When the AV arrived at the start point, the researcher would point at the AV and say, “the car is coming.” After this, participants turned around, started looking at the AV, and pressed a specific key (e.g. Enter) on the keypad. At the same time, the AV kept moving towards the participants at the maximum speed of 15 mph. The LED displayed a red cross mark.
- When the AV was 154 feet away from the participant (the slowing down point), the LED displayed a green arrow pointed to the other side of the street. In the meantime, the participants observed the approaching vehicle, and decided whether to push a specific key (e.g. 0) indicating their intention to cross the crosswalk.
- The AV started decelerating from 73 feet away from the crosswalk. The vehicle would smoothly come to a stop 5 feet away from the crosswalk (the stopping point).
- The task was considered completed once the participants successfully crossed the crosswalk or the participants didn’t cross the crosswalk and the AV passed the intersection. After the task was completed, participants were asked questions about their reasons for deciding to crossing or not cross and their understanding of the external interfaces.

For the actual experiment, the same procedure was used. Each pedestrian interacted three times (at three crosswalks) with all three different external interfaces, and three times with the conventional vehicle. Furthermore, in three additional trials, the AV did not show an intention to stop and did not stop for the pedestrian. Therefore, each pedestrian went through a total of 15 trials, as shown in Table 4. All the trials were randomly ordered and implemented.

Table 4. Experimental Design and Trials in Preliminary Study

Location	Trial Type	Trial Type	Trial Type	Trial Type	Trial Type	Total Trial
Intersection 1	Text	Symbol	Animated Eye	Conventional Vehicle	None stop	5
Intersection 2	Text	Symbol	Animated Eye	Conventional Vehicle	None stop	5
Intersection 3	Text	Symbol	Animated Eye	Conventional Vehicle	None stop	5

Measures

The independent variable was the three types of interfaces together with interaction of participants with the conventional vehicle and with the AV considering the three interfaces. The dependent variables included decision time, number of eye fixations in each area of interest (AOIs), and subjective ratings. The decision time was measured by the participants' input with the keypad.

We defined three AOIs to analyze the gaze data: the AV interface, the car's windshield and the car's bumper (see Figure 6). Subjects carried a camera on top of their heads, attached to the eye-tracker, that filmed their point of view. This way, we could record each subject's individual perspective of the approaching car in each trial. To categorize the eye fixations that fell in each of these three AOIs, we ran each subject's video through an object detection algorithm (a revised version of *Tensorflow*) that could first detect the car in each frame and then sectioned this box into the named three parts (i.e., bumper, windshield, AV interface).

Figure 6. Three AOIs

We focused our analysis on the length of time the participants focused their eyes on each of the three AOIs. For all data analysis, we used the Pupil Labs software (Pupil Player), that included a dispersion-based fixation detection algorithm set to 3 degrees of visual angle. Fixations shorter than 50 milliseconds (ms) and longer than 900 ms were excluded. Analysis was carried out with the PyGaze package in Python 3.1.

Regarding the participants subjective experiences, participants were interviewed at the end of each trial. They were asked about (1) the information that helped them to make the decision to cross safely in front of the AV, (2) their ability to understand the information that each display communicated to them, (3) their rating about the effectiveness, usefulness, ease of use of the different interfaces, and (4) their rating of trust and perceived safety about the AV.

Results

Decision Time

Figure 7 illustrates the average decision times for participants for each condition: (1) text interface, (2) symbol interface, (3) animated-eye interface, and (4) conventional vehicle. Decision time represented the time between the point the participant started to look at the vehicle and the point they indicated their intention to cross. Figure 7 shows the lowest average decision time was 9.16 for the conventional vehicle and the highest average decision time was 11.12 for the animated eye interface. Although the participants seemed to take longer to decide when interacting with the vehicles with display interfaces, the analysis of variance (ANOVA) [11]reveals no significant difference among decision time in these four situations (F-values= 0.43, p-value= 0.74).

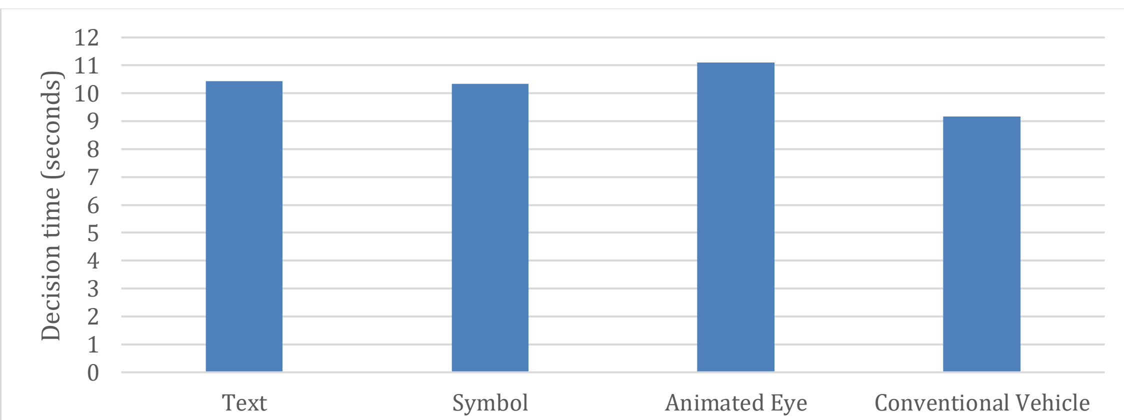


Figure 7. Average of Decision Times for the Four Conditions

[11] Analysis of variance (ANOVA) is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among group means in a sample.

Subjective Comprehension and Ratings

After each trial, participants were asked about the information that helped them to make a decision. As shown in Figure 8, for the text and symbol interfaces, most participants responded that both vehicle speed and the external interface were the critical information sources. The next most common response was that only the car's speed was important for decision making.

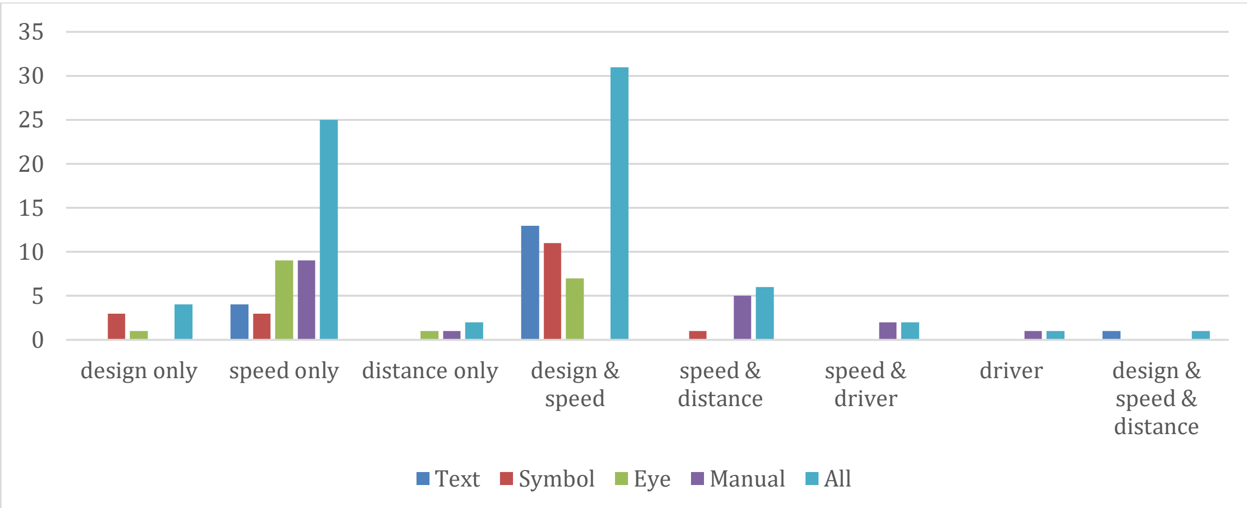


Figure 8. Subjective Reasoning for Crossing Street

Participants were also asked about their understanding of the information that each display communicated to them. In 100% of the time, they understood the information that the text interface conveyed. The symbol interface and animated eye were understood more than 70% of the time. The blinking and closed-eye displays confused the participants most, with understanding at only 30% and 17% of the time respectively.

After each trial, participants rated statements regarding how effective, easy, useful, safe and trustworthy the interfaces were. The rating scale was between 1 (extremely disagree), and 7 (extremely agree). Figure 9 shows the average rating for each interface.

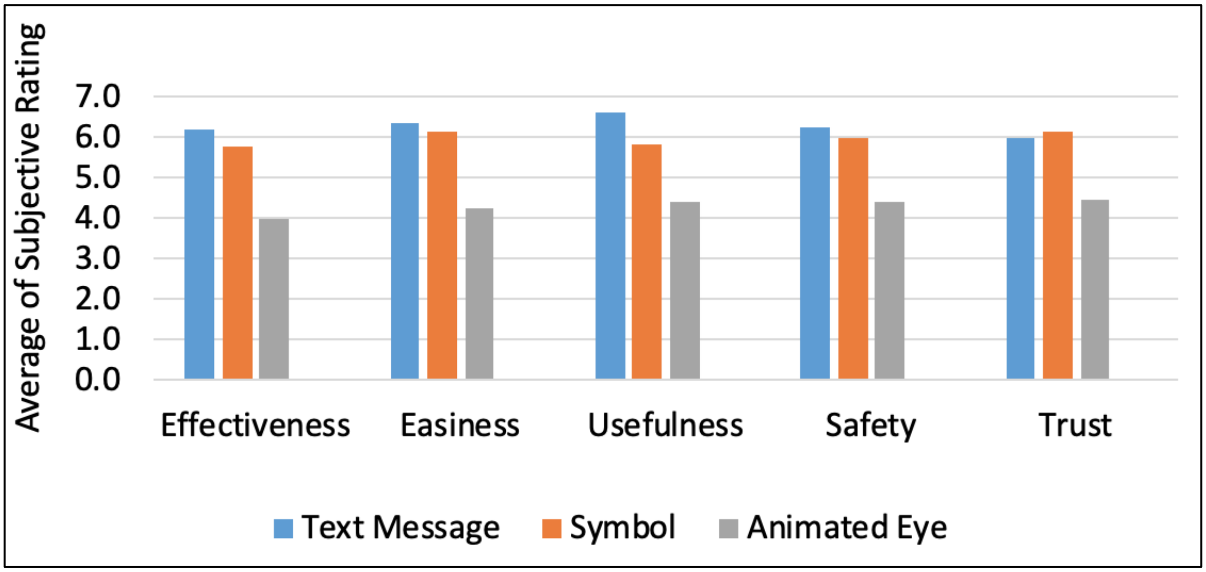


Figure 9. Average of Subjective Ratings

The ANOVA reveals that subjective ratings were significantly different among all interfaces (p-values <0.05). According to Tukey's test results at level of 0.05 significance, both text and symbol interface were effective, easy to understand, perceived to be safe and trustworthy. However, in terms of usefulness, the text interface was the most useful interface (Mean= 6.6) and the animated eye was the most confusing interface (Mean=4.4). Participants rated the animated-eye significantly lower than the other two interfaces for all the five questions.

Eye Movement

Because of the impact of overexposure and brightness on the infrared eye cameras, five subjects' data had to be excluded. We discuss these limitations in the Discussion section. The data presented here shows results for the one subject's gaze data that remained valid. Although not statistically significant, the results presented here reveal the potential of adding an eye-tracking measure to understand pedestrians' behavior.

First, the eye-tracker was able to demonstrate that the subjects were indeed doing the task at hand. Throughout the trial, subjects looked at different parts of the vehicle to make the decision of whether to cross or not. Figure 10 shows a heatmap of the densities of number of eye fixations for one subject in one trial, as an example of the distribution of fixations. The red areas indicate more fixations and the blue areas fewer ones.

Figure 10. Heatmap for Number of Fixations

Second, Figure 11 shows the number of fixations in the three AOIs for each interface type. Note that the trials for manual driving and text conditions were so short that no fixations were recorded, and hence are not shown here. From this one subject, we can see that the symbol-interface had a larger number of fixations in general, all of them on the AV interface. For the animated-eyes interface, the subject in general had a smaller number of fixations, more than half of them to the AV interface but also spread around the rest of the car (windshield and bumper). Although as mentioned, this result should not be generalized since it is only for one subject, it suggests that difficulty understanding the eye-interface led to fewer fixations on the AV interface. As a result, the subject relied on the windshield and bumper to estimate the speed of the car and used that information to make a decision of whether to cross or not.

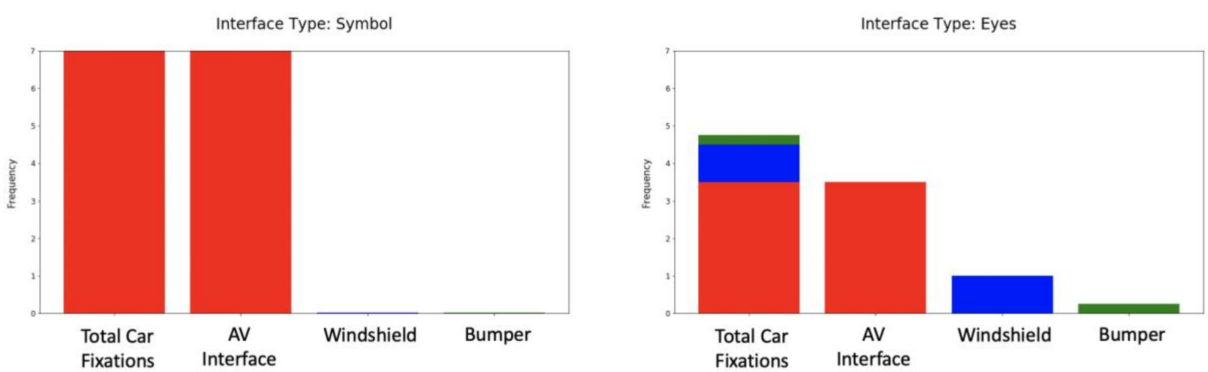


Figure 11. Number of Fixations on the Three AOIs

Main Data Collection

Participants

The same recruitment process was used for the main data collection. Ten individuals (4 males and 6 females) with a mean age of 26.36 years (SD=4.06) participated in this phase of testing. As in the preliminary study, all participants grew up in the U.S., had normal vision and no mobility impairments. They were considered naive users of automated vehicles. Furthermore, none of them had been involved in pedestrian-related motor vehicle collisions as a pedestrian.

Interface Design

The interfaces used were the same as the preliminary testing (shown in Figure 4-A). Using the same mounted LED, the interface designs were displayed to participants from the same distances as the preliminary testing (see Figure 4-B). In this phase, to compare the results to an AV without any external interfaces, we included one scenario in which the AV had a blank LED screen.

Procedure

In this phase of the study, the experiment set-up, instrumentation and procedure were the same as the preliminary study. Therefore, the independent variable is the five types of trials, which included interaction with a conventional vehicle, interaction with the AV displaying the three different interfaces, and interaction with the AV without any interface. At each intersection, there was also one trial where the AV didn't stop for the pedestrian. In this phase of the study, each participant went through 18 trials in total, as shown in Table 5.

Table 5. Experimental Design and Trials in the Main Data Collection

Location	Trial Type	Trial Type	Trial Type	Trial Type	Trial Type	Trial Type	Total Trial
Intersection 1	Text	Symbol	Animated Eye	Conventional Vehicle	Automated Vehicle	None stop	6
Intersection 2	Text	Symbol	Animated Eye	Conventional Vehicle	Automated Vehicle	None stop	6
Intersection 3	Text	Symbol	Animated Eye	Conventional Vehicle	Automated Vehicle	None stop	6

Also the same as in the preliminary data collection, after the complementation of the task, participants were asked questions about their reasons for crossing or not crossing the crosswalk and their comprehension of the external interfaces. Besides the questions used in the preliminary testing, during the main data collection we also added a further question to see which display from each interface design helped participants make their decision the most.

Measure

As in the preliminary testing, the dependent variables included decision time, number of eye fixations and subjective ratings. To improve data accuracy from the eye-tracker, we included one more protocol in the calibration procedure. In this part, subjects were asked to keep their eyes at the center of the bullseye-like target and move their heads vertically (up and down) and horizontally (left and right) for five seconds, respectively. This procedure allowed us to calibrate for pupil positions on the corner of the eye. Additionally, we asked participants to rate the safety of crossing when each interface display was shown on the LED.

Results

Decision Time

Error! Reference source not found. Figure 12 illustrates the average decision times for each condition: (1) text interface, (2) symbol interface, (3) animated-eye interface, (4) AV without interface, and (5) conventional vehicle. Decision time represented the time between the point the participant started to look at the vehicle and the point they indicated their intention to cross. Similar to the primarily results, the lowest average decision time was for the conventional vehicle (mean=9.06) and the highest average decision time was for animated-eye interface (mean =11.16). ANOVA reveals no significant difference among decision times in these situations (f-values= 0.683, p-value= 0.41).

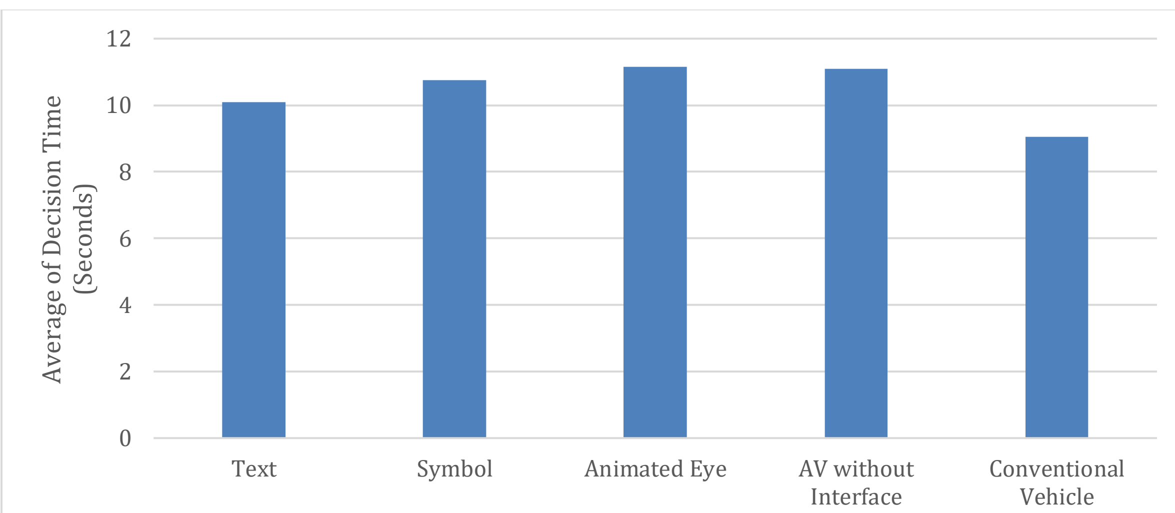


Figure 12. Decision Time of All Five Conditions

Subjective Comprehension and Ratings

Regarding the information that helped participants to make a decision, for the text and symbol interface conditions, both vehicle speed and the interface were critical information sources. For the text design, speed and interface were selected 60% of the time. For the symbol design, speed and interface were selected 53.3% of time. For the animated eye, speed and interface were selected just 40% of the time. Speed of the vehicle was the most important information that helped participants to make their decision (see Figure 13).

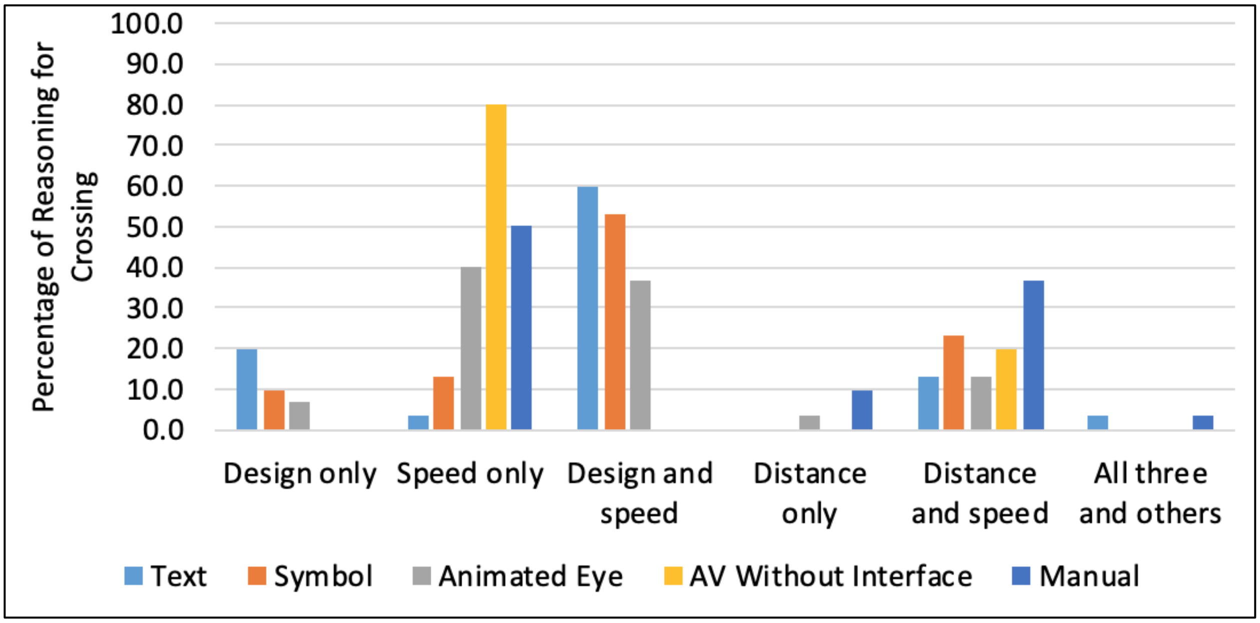


Figure 13. Subjective Reasoning for Crossing

All displays for the text interface were understood by participants except the stopping display which was not understood 6.7% of the time. With the symbol interface, the solid hand display was not understood 10% of times. The most confusing display was the blinking hand; participants did not understand the meaning of the display 33.3% of the time. The walking display was understood 100% of the time. For the animated-eye interface, the closed-eye display was not understood 26.7% of the time while the opened-eye display was not understood 10% of the time. Table 6 shows the detailed understandability results.

Table 6. Understandability Results

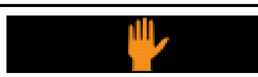
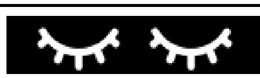
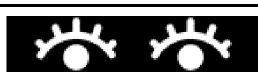
Interface Type	Interface Display	Understandability		
		Understand	Not Understand	Not See or Not looking
Text	MOVING	100%	0%	0%
	STOPPING	90.0%	3.3%	6.7%
	STARTING	46.7%	0.0%	53.3%
	STOPPED	0.0%	0.0%	100%
Symbol	 (solid hand)	73.3%	10.0%	16.7%
		60.0%	33.3%	6.7%
	 (blinking hand)	40.0%	0.0%	60.0%
Animated Eye		73.3%	26.7%	0.0%
		90.00%	10.0%	0.0%

Figure 14 illustrates the helpfulness of the interfaces. More than half of the times participants found the text interface helpful. In the symbol interface case, the walking sign display was the most helpful display (30% of times) while 43.3% of the time participants stated that none of the displays were helpful. For the animated-eye, in majority of times (60%) participants found none of the displays helpful.

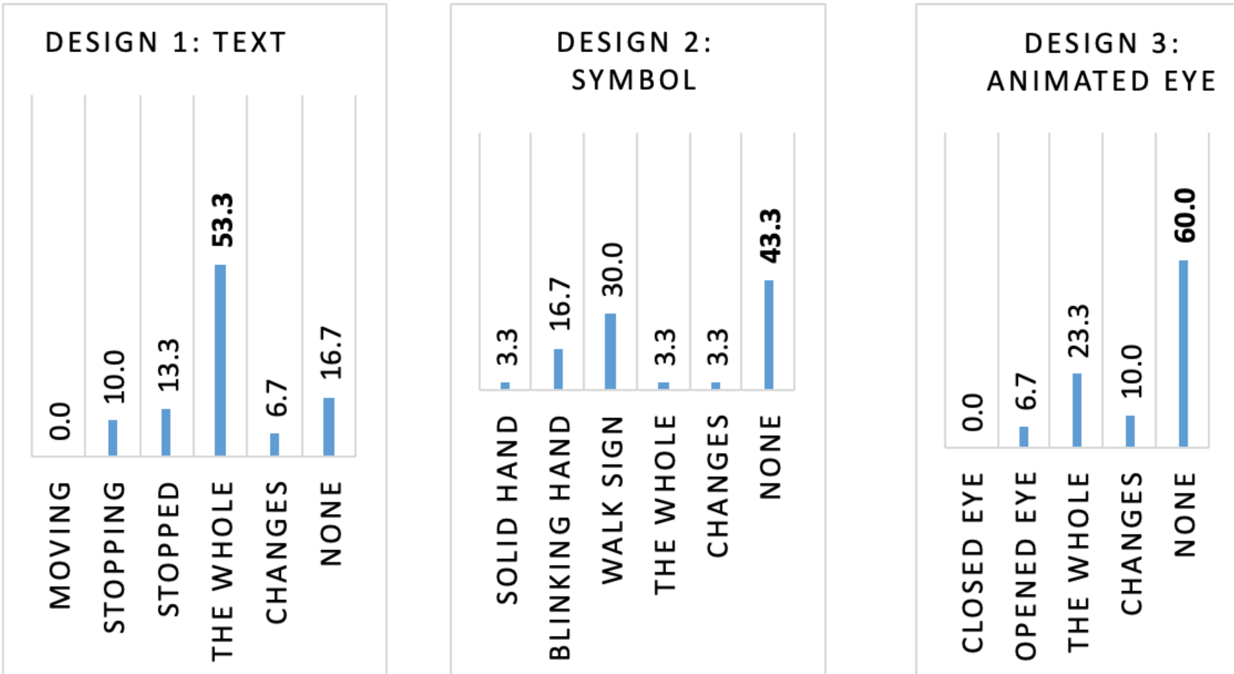


Figure 14. Helpfulness of Each Display of Interface

Regarding how effective, easy, useful, safe and trustworthy the interfaces were, Figure 15 shows the average ratings for each interface. The ANOVA results showed the subjective ratings were significantly different among all interfaces (p-values <0.05). According to Tukey's test results, both text and symbol interface were effective, easy to understand, and useful. The text interface was considered the safest (mean=5.4) and most trustworthy interface (mean=5.3). Overall, participants rated the animated-eye significantly lower than the other two interfaces.

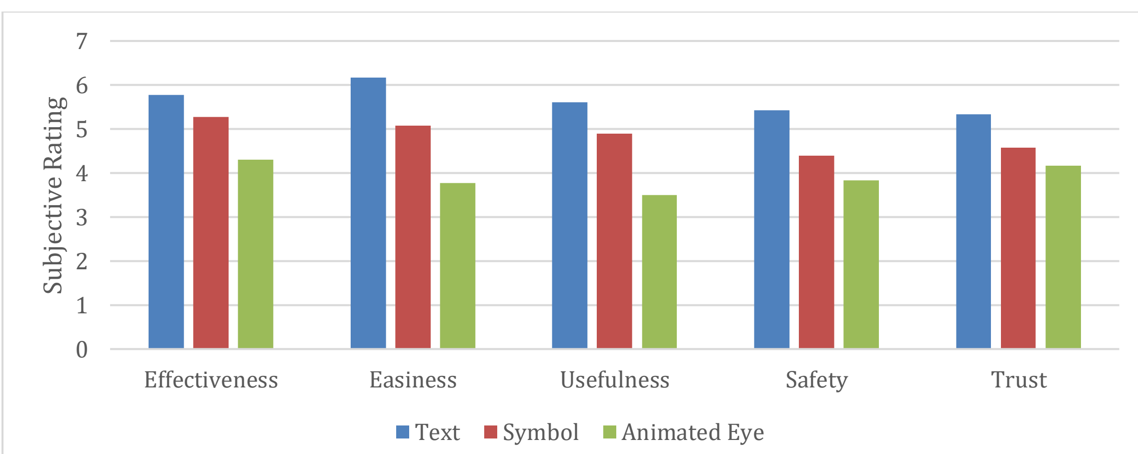


Figure 15. Average of Subjective Ratings

In this phase, we asked participants to rate the safety of crossing while each interface display was shown (from 1=extremely not safe to 7=extremely safe). Table 7 represents ANOVA results. There were no significant differences among ratings for the different designs in group 1 and group 2. However, in group 3, the “stopped” display is significantly different (F-value= 18.71 and P-value= 0.001).

Table 7. Comparing Safety Rating of Displays

Group	Text	Symbol	Animated Eye	F-Value	P-value	Best Interface
1				0.04	0.843	N/A
2				2.478	0.119	N/A
3				18.71	<0.001*	Text

Eye Movement

As in the preliminary testing, we had to exclude the data from eight subjects for the analysis of gaze data (see Discussion section for details). For the purpose of showing the potential of adding an objective gaze measure to evaluate the understandability and usability of the AV interfaces, we show the data for two subjects below. Figure 16 shows number of eyefixations in each of the AOIs (AV interface, windshield, and bumper). The text interface type shows more fixations on the interface, suggesting that subjects could understand it and use it to make their decision. In contrast, the eyes and symbol interface types had in general fewer eye fixations and these were more distributed between the three AOIs. When there was no display on the AV, or the car was manually driven, subjects had to rely on looking at the bumper to estimate speed and time to impact to make a decision whether to cross the intersection or not.

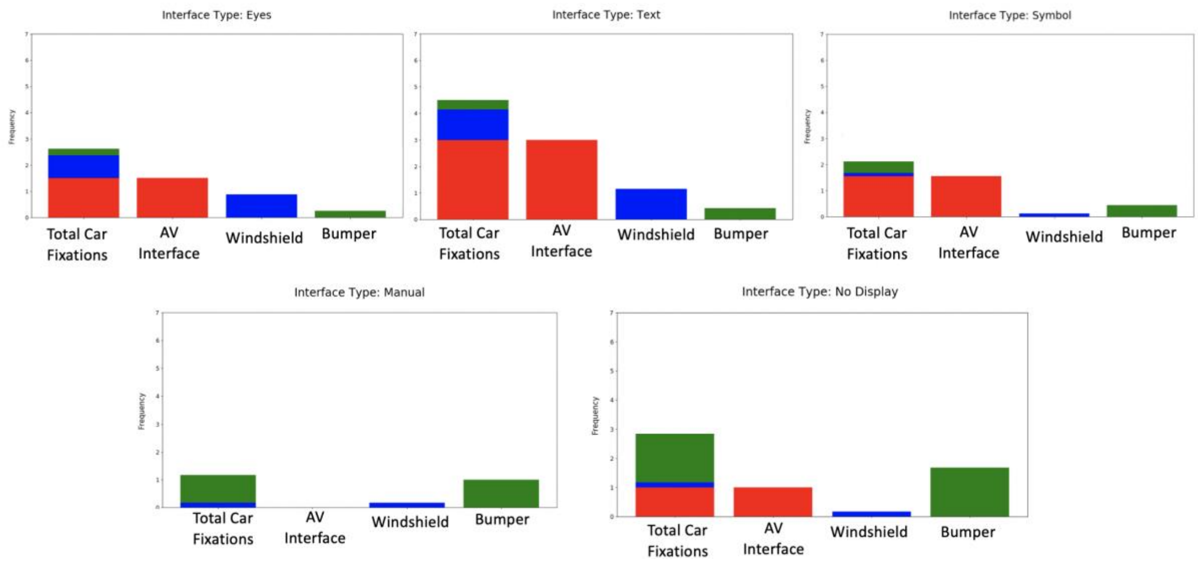


Figure 16. Number of Fixations on the Three AOIs (AV interface in red; Windshield in blue; and Bumper in green)

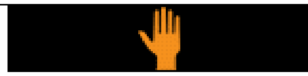
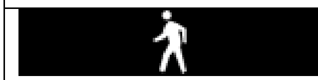
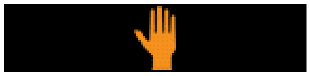
Further Interface Revision and Evaluation

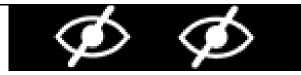
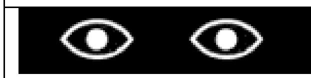
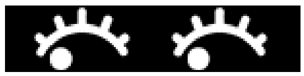
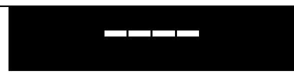
After completing the preliminary testing and the main study, the interfaces were redesigned. We also added new interfaces. The redesigned and new interfaces were evaluated through a survey. The goal was to assess their helpfulness and understandability. Table 8 illustrates the proposed interfaces. The text interface remained similar to that used in the previous phases because it was well understood by participants. We improved the symbol interface by deleting the blinking hand (while the car is in the process of stopping) since it was confusing to participants based on results from both the preliminary and main data collection. We added two animated-eye interfaces to make the closed-eye (not aware of you) more explicit. We also added a bar concept designed by the Ford company,[12] a speed interface which shows speed of the AV, and a mixed interface which combined the text, symbol and speed interfaces.

Table 8. Interfaces Tested in Survey

Interface Type	Display of Interface	Communicated Information
Text	MOVING	The vehicle is moving
	STOPPING	The vehicle is stopping

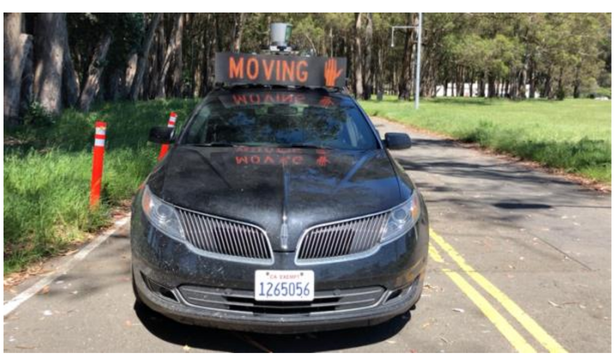
[12] https://media.ford.com/content/fordmedia/fma/me/en/news/2017/09/14/ford--virginia-tech-go-undercover-to-develop-signals-that-enable.html

Interface Type	Display of Interface	Communicated Information
		The vehicle is stopped
		The vehicle is starting
Symbol		Do not cross
		Cross
		Do not cross if you have not started [Blinking hand]
Speed		The speed of vehicle is 15 MPH
		The speed of vehicle is 10 MPH
		The speed of vehicle is 5 MPH
		The speed of vehicle is 0 MPH
Mixed		The vehicle is moving, so do not cross
		The vehicle is stopping, and the speed is 15 MPH
		The vehicle is stopping, and the speed is 10 MPH
		The vehicle is stopping, and the speed is 5 MPH
		The vehicle is stopped, so you can cross
		The vehicle is starting, so do not cross if you have not started [blinking]

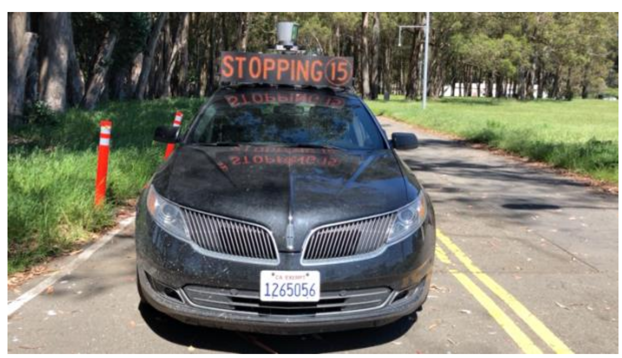
Interface Type	Display of Interface	Communicated Information
Animated eye: crossed eye		The vehicle is not aware of you
		The vehicle is aware of you
Animated eye: moving eyeball		The vehicle is not aware of pedestrian
		The vehicle is aware of pedestrian [the eyeballs are moving side to side]
Bar concept		The vehicle is moving in automated mode
		The vehicle is stopping [bar is moving from side to center]
		The vehicle is starting [flashing bar]

Survey Method

Seven short videos were recorded displaying the redesigned interfaces. Figure 17 shows selected frames from the mixed interface video. During the survey, each video was played for the participants and then they were asked questions regarding the helpfulness and the understandability of the redesigned interfaces. Ten individuals from the UC Berkeley community participated in this survey.



1



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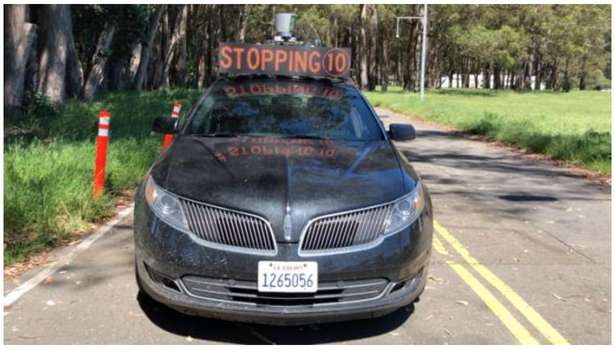
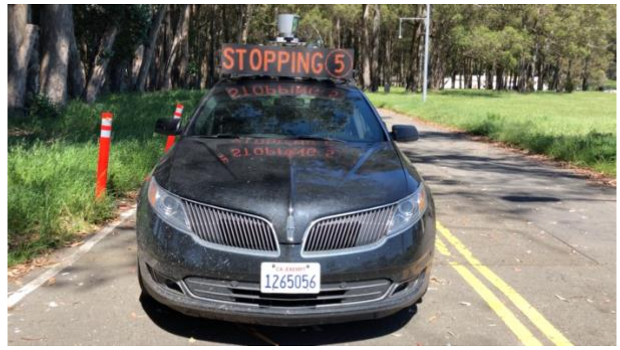
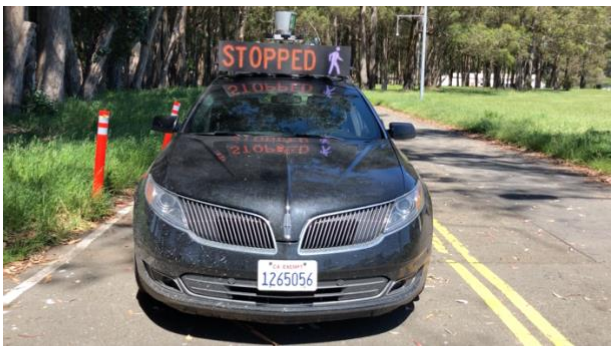
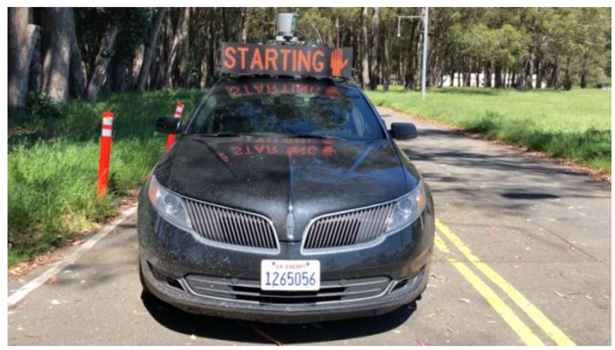




3 **4**





5 **6**

Figure 17. The Mixed Interface Design

Survey Results

We asked participants whether they found the interfaces helpful or not. As shown in Figure 18, the text, symbol, speed and mixed interfaces were the most helpful interfaces. Participants were also asked about the understandability of each display. Mostly, they were not sure about the bar concept and the two animated-eye interfaces. The stopping display for the mixed interface was confusing for participants. They were not sure what the number referred to (speed or count down). The rest of displays were well understood.

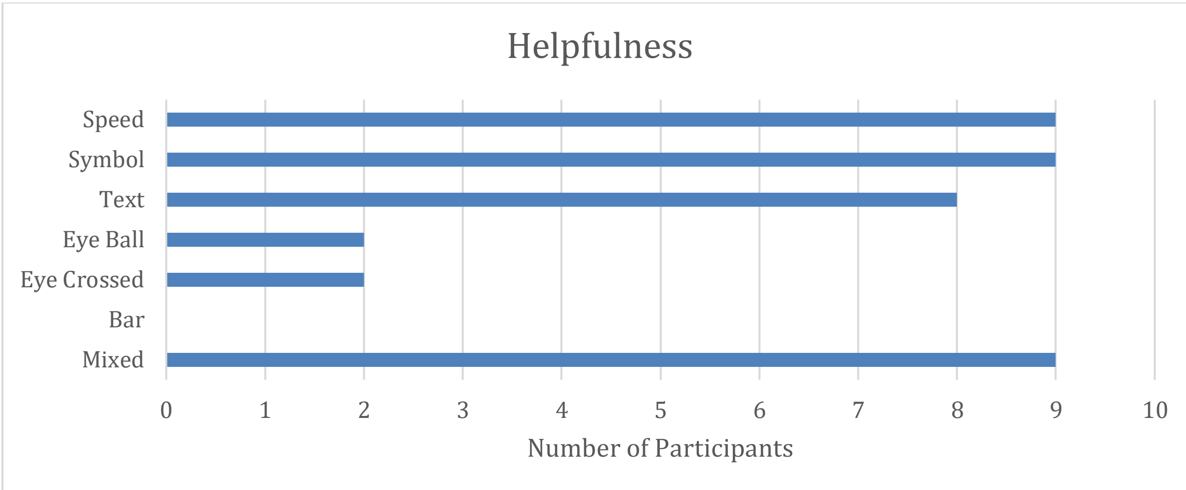


Figure 18. Helpfulness of the Seven Interfaces

Discussion

Results from the preliminary testing showed that it took a similar amount of time for pedestrians to perceive the vehicle and make a decision to cross the crosswalk when interacting with the AV with external communication displays in comparison with the conventional vehicle. Similar results were obtained in the later phase of main data collection. The decision time was also not significantly different between an AV with an external communication display and without. This suggests that when interacting with an AV, pedestrians do not need significantly less or more time to cross the crosswalk in comparison with the time needed when interacting with conventional human-driven vehicles.

These results are consistent with some previous studies. According to Clamann et al. (2016), pedestrians have previous experience crossing streets, and have developed some strategies for crossing which likely played a stronger role in their decision-making than the novel external interfaces mounted on experimental vehicles. Similarly, as observed by Rothenbucher et al. (2016), most participants still made the decision to cross although the erratic behavior of the car was mentioned as a reason for hesitancy. The authors concluded that people generally overlook the effect of novelty and adhere to existing interaction patterns with the vehicles. The same reason could explain in this study why the decision time for interacting with the AV and decision time for interacting with the conventional vehicle was not significantly different.

When further asked about their information sources for making the decision to cross, most participants responded that speed of the vehicle was the critical information in all scenarios for both the preliminary testing and the later phase of main data collection. While implementing the experiment, the speed of the AV and the speed of the conventional vehicle were the same. This could potentially further explain why there was no significant difference in the decision time between the AV and the conventional vehicle. This finding coincides with some existing research (e.g., de Clercq et al., 2019; Rothenbucher et al., 2016).

Although there was no significant difference in decision time between any scenarios, the subjective feedback, including easiness to understand, effectiveness, usefulness, safety and trust, were significantly different for the three external interfaces. In the preliminary testing, the text as well as the symbol interfaces were perceived to be easy to understand, useful and effective for making the decision to cross, with increased trust and perceived safety while interacting with the AV. The animated-eye interface had significantly lower ratings for all categories of subjective feedback than the other two interfaces. In the main data collection phase, participants provided similar subjective feedback regarding the three external interfaces.

We looked further into the effect of different external communication interfaces. The interfaces provided value to participants for making the decision to cross only with the text and symbol designs but not the animated-eye design. On one hand, participants thought that the text and symbol external interfaces provided certain useful information. On the other hand, the animated- eye interfaces didn't. There are two potential reasons. One is that the animated eye was not well understood by the participants. As mentioned above, the animated-eye interface was confusing for many participants. About 27% of the participants didn't understand the display with the closed-eye, and another 10% of the participants didn't understand the display with the opened-eye. The other reason is that the information to be conveyed by the animated-eye (i.e., awareness of the AV) is not helpful or useful enough for facilitating pedestrians' decision making, as suggested by comments like: *"[I am] confused, [I am not] used to this communication. What am I supposed to do? You see me, so what?"* Although the purpose of the animated-eye interface was to convey the vehicle's awareness of the pedestrian, it may be even if this information was understood, it was less useful than conveying the intent of the AV or telling the pedestrians what to do when interacting with the AV.

This project aimed to add a state-of-the-art mobile eye-tracker to validate the results obtained from subjective reports. Most research uses eye-tracking systems that require subjects to maintain their heads fixed on a chin-rest, which limits the validity of the results. Over the last few years, there have been improvements to head-mounted eye-trackers that allow subjects to move their heads and bodies around a scene while recording their eye movements. Most of these experiments still limit the research scenarios to indoors environments though. This project aimed to take this a step forward, to record outdoors. Unfortunately, we encountered two main challenges in the gaze data analysis as the outdoor environment forced us to exclude a major part of the data collected. First, the pupil detection algorithms available today assume a constant pupil size throughout a trial. This is fine in in-lab controlled environments where subjects stare at a screen in a dark room. However, in an outdoor environment, where the brightness changes constantly, subjects' pupil size will inevitably fluctuate. Second, the two eye cameras included in this Pupil Labs eye-tracker are infrared cameras. This type of device is extremely sensitive to sunlight and works the best in the dark. Again, because of the uncontrollable outdoor brightness, in many of the trials the image of the eye was overexposed and therefore unusable for analysis. In the future, we plan to develop an add-on filter sheet to place onto the head-mounted eye-tracker to filter the light that gets to the eye and eye cameras. This will ensure that the eye cameras are not overexposed, and the image is clear enough to be analyzed, as well as maintaining a stable level of brightness to maintain pupil size.

Despite these limitations, the eye-tracking measures suggest that there are differences in the area of the car that pedestrians fix on to retrieve the information necessary to make a decision whether crossing an intersection is safe or not. When facing a manual car, pedestrians can get information from the 1) driver's awareness and intention from the driver's face, through the windshield and 2) speed and time to impact from the bumper of the car. However, in an AV, the information from the windshield may not be there or may be uninformative if the driver is not in control of the vehicle. Moreover, if the vehicle has an AV interface, the question arises as to whether pedestrian will look at it and use it to potentially compensate for the lack of information from the driver's face. Although our gaze data is limited due to technical problems, we can use the number of fixations in each of the areas of the car (AV interface, windshield and bumper), to investigate the understandability and usability of each type of information. From our preliminary data we found that text and symbols generated the most eye fixations while for the rest of interfaces the fixations were more widely distributed across the car.

Due to project constraints, there were several limitations to this study. First, the objective of this study was to understand whether external communication displays are essential for the safe interaction between pedestrians and AVs. The study only considered the simplest scenario where one pedestrian interacts with one vehicle. The maximum speed was 15mph, which might not be realistic. However, future research should be expanded to include more complicated driving scenarios, such as multiple pedestrians interacting with multiple vehicles, which could better represent the busy urban driving environment. Second, there was also a limitation regarding the participants. Only student-participants who grew up in the US and had no prior experience with automated vehicles were recruited. According to some existing studies (e.g., Clamann et al., 2016; Rothenbucher et al., 2016), participants' experience with AVs and participants' demographic characteristics, such as age, may also have an influence on their behavior when interacting with AVs. Third, we only studied one vehicle with an LED display installed on the roof. Other factors, such as vehicle size, location of the display (e.g., windshield, roof, vehicle body), as well as the size of the display (i.e. LED screen) may also influence pedestrians' perception and interaction with the AVs (de Clercq et al., 2019).

Conclusion

The presence of external communication interfaces on the test AV did not change the decision time for pedestrians to cross the intersection. This study confirmed other research findings that vehicle movement patterns (e.g., slowing down the vehicle speed and showing an intent to stop at a considerable distance away from the designated crosswalk) continue to be a significant cue for pedestrians in AV interactions, even when interfaces are provided. However, the participants' subjective ratings showed positive effects indicating that some of the interfaces were easy to understand (e.g., text interface and symbol interface) and they did help pedestrians to feel safe and trustworthy when interacting with AVs. Participants' eye movement patterns further showed more attention paid to those easy-to-understand interfaces, suggesting that subjects well understood them and used them to make their decisions. Regarding the message conveyed by the external interfaces, it was found that all participants of the study perceived the communicating of AV intent and information from the AV about what pedestrians ought to do were more effective than merely conveying the vehicle's awareness of the pedestrian. Overall, we conclude that there is a need to enhance automated vehicles' ability to communicate their intent or tell pedestrians what to do when automated systems are in operation. This will help assure pedestrian's safety as well as earn their trust of the AV technology, when automated vehicles are introduced in the market.

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