Ghost Driver: A Field Study Investigating the Interaction Between Pedestrians and Driverless Vehicles

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Abstract— **How will pedestrians and bicyclists interact with autonomous vehicles when there is no human driver? In this paper, we outline a novel method for performing observational field experiments to investigate interactions with driverless cars. We provide a proof-of-concept study (N=67), conducted at a crosswalk and a traffic circle, which applies this method. In the study, participants encountered a vehicle that appeared to have no driver, but which in fact was driven by a human confederate hidden inside. We constructed a car seat costume to conceal the driver, who was specially trained to emulate an autonomous system. Data included video recordings and participant responses to post-interaction questionnaires. Pedestrians who encountered the car reported that they saw no driver, yet they managed interactions smoothly, except when the car misbehaved by moving into the crosswalk just as they were about to cross. This method is the first of its kind, and we believe that it contributes a valuable technique for safely acquiring empirical data and insights about driverless vehicle interactions. These insights can then be used to design vehicle behaviors well in advance of the broad deployment of autonomous technology.**

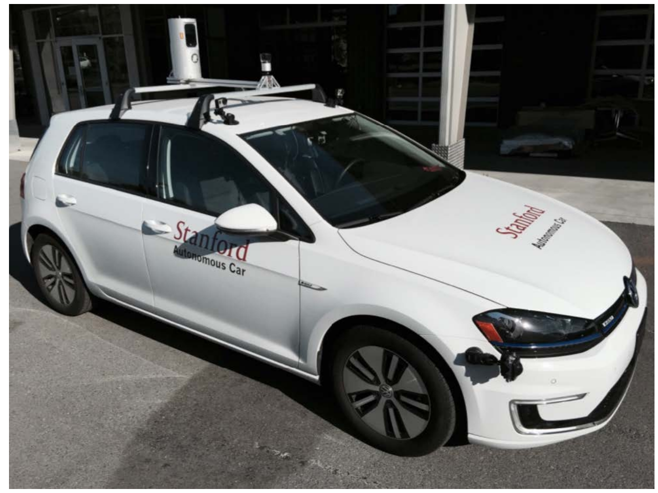

Fig. 1. GhostDriver features a hidden driver to simulate an autonomous vehicle in field experiments with pedestrians and cyclists.

I. INTRODUCTION

The advent of autonomous vehicle technology raises questions about how these novel vehicles should interact with the other cars, people and cyclists on the road. There are early indications that autonomous vehicles may cause minor accidents through their anomalous driving behavior, even if they are following the letter of the law and not at fault. Google's June 2015 accident report for its self-driving vehicle fleet, for example, indicates that they have suffered five minor accidents while driving 200,000 miles, nearly ten times what the National Highway Traffic Safety Administration reports as the national average for "property only" fender benders [12]. While it is certainly important that actual autonomous cars always use the safest known protocol for interacting with other entities, it is not always clear, given the contingent nature of interaction, what the safest behavior is. The differential power relationship between the vehicle and non-vehicular road users, like pedestrians and cyclists, makes the question even more pressing: How will pedestrians respond to autonomous cars in the wild? As of yet, little is known about this topic largely due to methodological challenges in obtaining empirical data about pedestrian interaction with autonomous vehicles.

In this paper, we outline a novel method for investigating interactive behavior patterns between pedestrians and driverless vehicles. We employ a Wizard-of-Oz study wherein the driver of a confederate vehicle is hidden from view, so as to create the impression of being a driverless vehicle, and deploy it within a field experiment setting to observe how pedestrians and cyclists will naturally respond. This method has been validated with an initial study (n = 67) that looks at how a vehicle without any special communicative displays or warning mechanisms is received by passersby. This method is the first of its kind, and we believe it contributes a valuable way to gain empirical insight about road user behavior and viable designs for driverless vehicles of the future.

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II. BACKGROUND

A. Pedestrian Safety and Autonomous Vehicles

Pedestrian and cyclist safety is particularly important in traffic situations. In 2012, 4,743 pedestrians were killed in the US in motor vehicle traffic crashes, representing 14 percent of all traffic fatalities, while 726 cyclists were killed [23]. These road users are especially vulnerable to injury compared to individuals in vehicles.

Autonomous vehicles can safeguard pedestrian safety in several ways. Autonomous pedestrian collision avoidance [18] can overrule a driver's action or inaction by steering away from pedestrians at critical times. Pedestrian protection systems detect when a collision is unavoidable and deploys active braking, pedestrian airbags or other methods to reduce harm [19]. A preventative strategy to protect pedestrian safety *before* a safety-critical situation occurs is to facilitate coordinated action between pedestrians and autonomous vehicles. Here we explore how pedestrians respond at an intersection where the pedestrian cannot communicate with a car driver, since communication with autonomous vehicles could be an area of confusion for pedestrians.

B. Responses to Autonomous Vehicles

Although still in an experimental phase we can assume that commercial autonomous vehicles will be on our roads within the next few years [16]. As soon as cars become autonomous, drivers become mere passengers. Established practices like making eye contact or giving hand signs will no longer be reliable means of communication. With fully autonomous, driverless cars, road users cannot observe any head movements indicating that they have been noticed. Besides questions around safety there also might be an issue of how comfortable people feel walking in front of self-driving vehicles if they do not get any acknowledgment. How will pedestrians and cyclists respond to autonomous cars that do not have a visible human driver? Might their behavior change when traveling through a crosswalk in front of an autonomous car compared to a normal car?

With the rapid advancement of car automation technology in recent years, questions about human interaction with autonomous vehicles becomes pressing. This research focuses mainly on the interaction between the autonomous vehicle and the person in the car [4][17][24]. As far as we know there is no research yet that looks at the interaction between an autonomous vehicle and pedestrians, cyclists, or other human drivers at a real-world crosswalk.

C. Implicit Interaction at the Crosswalk

Interaction between car drivers and other road users is important for road safety, but little is known about the nature of this interaction. Implicit Interactions Theory [14] provides a framework for thinking about the interaction users have with novel technologies. It suggests that a preliminary step in addressing our research topic is to derive specific step-by-step hypotheses about the expected pedestrian interaction with a normal car and where this interaction may break down with an autonomous car. The step-by-step pattern that we anticipated with a normal car was the following: a) pedestrian approaches intersection, b) car approaches intersection, c) person makes eye contact, d) driver makes eye contact, e) driver indicates not giving way, f) pedestrian waits, g) driver moves through crosswalk, h) pedestrian crosses or e′) driver indicates giving way, f′) driver stops and waits, g′) pedestrian crosses, h′) driver moves through crosswalk.

An autonomous car may cause a breakdown in the pattern where eye contact is typically made (steps c and d)— a critical point in which intent is communicated. This breakdown—a lack of nonverbal communication from a driver as well as the complete lack of the presence of a driver—is atypical and represents a breach of the established reality of car operation, making the car appear more autonomous. This in turn may lead to attempts to "repair" or compensate for the interaction through methods of iteration (searching for a driver, staring at the location where a driver would be, trying to talk to a driver, asking others about a driver).

D. Studies of Pedestrian-Driver Interaction

Previous field research that has explored pedestrian-automobile interaction has mainly employed confederates who take on the role of pedestrians at crosswalks and intersections. For example, a quasi-experiment conducted by [10] had confederate pedestrians stare or not stare at drivers who approached an intersection, finding that pedestrians who stared elicited greater stopping. Similarly, Piff et al. [25] had confederate pedestrians enter crosswalks at strategic times when an automobile was approaching to test whether higher versus lower class vehicles would violate traffic laws more frequently. Although less common, some field studies have employed confederate vehicles to gather behavioral data about pedestrians (as is done in this study). In particular, [20] had drivers record pedestrian walking direction while driving on specific road sections and demonstrated that three-quarters of pedestrians walked facing rather than with traffic; this behavior correlated with lower fatality risk in historic data. Another observational field study [38] showed that over half of pedestrians do not look for vehicles after arriving at a curb but that all of them looked at oncoming vehicles during crossing. Other researchers have used simulation-based experiments, such as [31], in which stationary children presented with a bike at different speeds judged whether they could cross the road; both distance and speed of the approaching bike were used by participants to make such judgments. In addition, researchers such as [30] used video-taped footage of crosswalks to investigate the relationship between car speed and pedestrian behavior, finding that high speed was used as a signal by drivers to communicate to pedestrians that they did not intend to give way.

Eye contact is particularly important in pedestrian-driver interaction. In its safety reminders for pedestrians the U.S. Department of Transportation recommends people "to make eye contact with drivers as they approach you to make sure you are seen" [6]. Pedestrians can increase their own safety by interacting with car drivers through signals and gaze [15]. Drivers also tend to make decisions about the intention of a bicyclist by looking at the bicyclist's face [32]. A driver's gaze goes first onto the face of a bicyclist and remains there for longer periods than gaze toward a bicyclist's hand signs [33]. Eye contact between drivers and other road users not only confirms that road users are noticed, but it also increases compliance with instructions and rules [11][15]. [10] compared the compliance of drivers who stop at a crosswalk with and without eye contact. Drivers who make eye contact with a pedestrian were more likely to stop at a crosswalk and let the pedestrian pass.

These works suggest several important points. Driver-pedestrian interactions are a valuable area of study because of safety concerns. The majority of past research related to pedestrian traffic treats the crosswalk (or intersection) as the focal point of interaction and participants' crossing behavior as a main assessment indicator [29]. At crosswalks, visual eye contact is a particularly common form of human-pedestrian interaction that is unavailable with a driverless car. Based on the importance of eye contact, we would expect that alternate visual cues from a vehicle could be used to coordinate communication during person-vehicle interactions, even if nonverbal cues from a driver may be absent. Gathering information about pedestrian behavior using a confederate car, as is done in this work, is a relatively novel methodology. Finally, it is currently unclear how a car that is perceived as autonomous would influence pedestrian behavior.

III. MATERIALS AND METHODS

A. Field Study Design: A Breaching Experiment

To observe how people interact with self-driving cars, we developed a "breaching" experiment [9][34]. A breaching experiment is an experiment in which the experimenter behaves in a way that does not match with the established norms of reality for the situation at hand. The experimenter then observes how people who are naive to the experiment respond to the situation. In general, people respond to breaching experiments that violate established realities of interpersonal interaction by searching for nonverbal acknowledgment from other people that the experimenter is being "weird", by attempting to repair the situation with the experimenter (for example, through humour) or by expressing emotions such as embarrassment, nervousness or anger [9].

In the breaching experiment described in this work, a "mock" version of an autonomous car without a human driver was placed in a real-world road setting. In reality, modern cars require a human driver to be present in the car. Even self-driving car prototypes have this as a legal requirement. Thus, we expect that the established reality that people have about both normal and self-driving cars is that a person will be behind the wheel. In our experiment, however, this expectation was breached. The car driver appeared to be absent from the car. This methodology allowed rapid ethnographic research "to observe and understand interesting patterns or exceptional behavior and then to make practical use of that understanding" [2].

B. Apparatus: Creation of a Ghost Driver

a) Motivation for hiding the driver: The main challenges of putting an autonomous vehicle in the wild are regulatory and safety related issues. We were therefore interested in observing how pedestrians would respond to an autonomous vehicle in the wild. However, we selected to use a faux driverless vehicle rather than one that could actually navigate by itself. Besides the technical challenges of implementing a fully autonomous car, Californian law does not allow completely self-driving (i.e., driverless) cars on public streets yet. While the California Department of Motor Vehicles (DMV) issues licenses for testing autonomous technology, regulations require that a human operator sits in the driver seat at all times to take over in an emergency or when the autonomous technology is turned off [27]. This means that any present-day self-driving car with functional autonomous technology must have a human operator in the driver seat. Our goal was to evoke the impression that a confederate car is driving autonomously and deprive pedestrians and cyclists of any chance to interact with a human in the car. Therefore, we decided to create the illusion of a fully autonomous vehicle by hiding the human driver from view.

Fig. 2. The seat cover costume was sheer so that the driver could see through, and had arm outlets so that the driver could steer the car.

b) Car seat costume: To accomplish this, we developed a Wizard-of-Oz experiment [5]. In a rapid prototyping session [28], we designed a seat costume worn by the driver to make him or her invisible (Figure 2). This was inspired by an invisible driver prank published on YouTube [26]. The basic shape of the original seat was formed in wire mash, stabilized with paper-mâché, and covered with a regular seat cover. To give the driver peripheral vision we covered the wire mash around the head only with a black see-through fabric. The driver was dressed in black attire and black gloves. The driver could maneuver the car using the bottom section of the steering wheel without being seen.

c) Automobile: We used a Volkswagon eGolf with props added on to emphasize that the car was an autonomous vehicle. These included a LIDAR on the roof, radars on the front, cameras on its roof and vinyl stickers on the hood and the doors that read "Stanford Autonomous Car".

C. Location

Two locations were used for the experiment. The first location (shown in Figure 3) was a parking lot on the Stanford campus. A setting in an urban area was selected as most pedestrian accidents occur in urban areas, while a crosswalk was selected because crossing the road is the most frequent event in pedestrian accidents [7]. The exit of the parking lot crosses a sidewalk leading onto a street. Pedestrians have the right of way and exiting cars have to stop. The main walking directions are from west to east and from east to west. This street is highly frequented by pedestrians, especially in-between lectures and during lunch.

The second location was a traffic circle on Stanford's campus with a high frequency of cyclists especially between lectures. The main cycling directions are from west to east

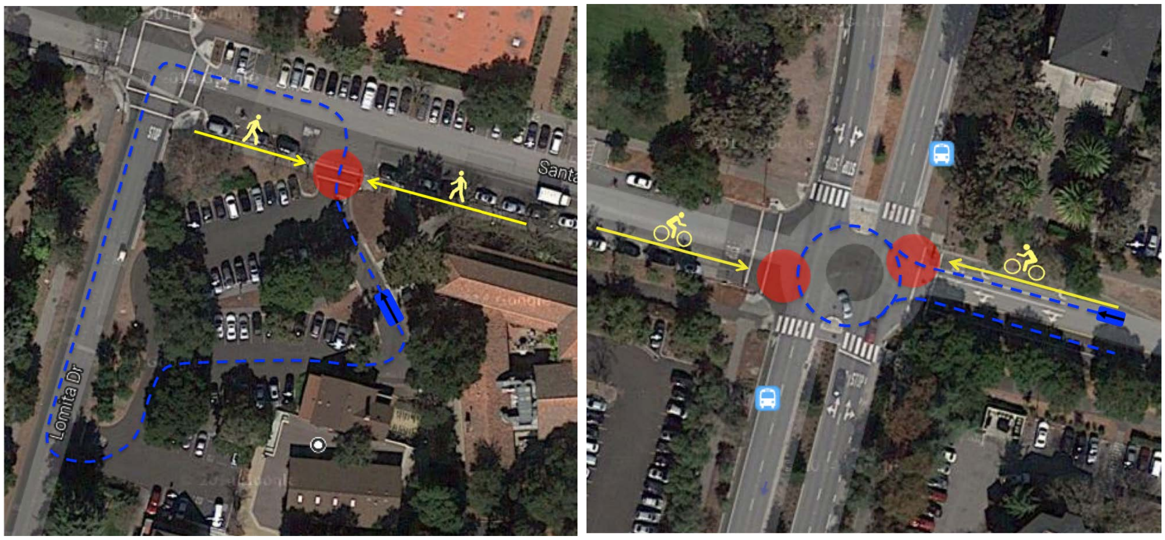

Fig. 3. Locations used in experiment. First location at a parking lot (left). Second location at a traffic circle (right).

and from east to west. Cyclists have to slow down and pay attention to the traffic going through the circle. Most car traffic travels from south to north in the traffic circle. The car entered the traffic circle from the east and did a few circles before exiting again. During the time in the circle cyclists interacted with the car. Our focus at this location was on video observation of cyclists since their speed was too high to stop them safely for questioning.

Prior to running the study, a “waiting area” was scouted for each location. This was a location with low car traffic that had a large area for the car to park while waiting for participants. The waiting area we used for the first location was a wide one-way road that served as the exit path to a parking lot. The waiting area we used for the second location was the curb of a two-way road beside the traffic circle.

D. Driver Training and Logistic Considerations

Special logistic considerations are required for a field study in which a person is hidden while driving a car.

a) Driver habituation to the course: Driver habituation of the course includes all activities conducted to help the driver navigate safely and comfortably while wearing the faux seat cover. During training, the driver was given a map of each course. He then did three sets of training activities in sequence. First, he drove the course without the seat cover on his body. Second, he placed the suit on his body and got accustomed to the suit by driving in the waiting area (this was done for location 1 only). Third, he drove each course with the seat cover on his body when no pedestrians were present. The driver repeated each activity until he was comfortable with it before moving to the next activity.

b) Modification of driver behavior: The modification of driver behavior is a second logistic consideration that occurs after driver habituation to the course. Ideally, a driver could be trained to drive as an autonomous car would drive to increase the validity of the simulation. In practice, information about the driving patterns of autonomous cars are anecdotal (such as that the cars drive slowly) and we know of no industry standard for their driving behavior. Therefore, our method suggests modification of driver behavior to specifically suit the needs of the researcher. For example, a researcher interested in testing the perception of two different autonomous vehicle driving behaviors could train a driver to steer and accelerate in accordance with each of those behaviors. As another example, the primary purpose of this study was to test the feasibility of the hidden driver method, so we wanted pedestrians to take note of the car. We therefore trained the driver to accelerate in a safe way that would attract attention to it.

c) Communication with driver: Communication between the research team and the driver is a third logistic consideration that occurred after training the driver. It turned out that getting the timing of the car’s approach to match the approach of the pedestrian was quite challenging. To mitigate this, one researcher served as a coordinator during study trials. He notified the driver of the approximate time it would take each pedestrian to arrive at the intersection. In a pre-test of this signaling, a researcher acted as a sample participant and approached the crosswalk while the coordinator signaled to the driver as they would with a real participant.

An alternate form of driver habituation and signaling is to train the driver to take a set amount of time to travel from the waiting spot to the crosswalk. The spotters can then mark a location on the sidewalk that represents the same set amount of time for a pedestrian to travel from the marked location on the sidewalk to the crosswalk (based on average human walking speeds). The spotters signal to the driver for him to begin driving to the crosswalk once any pedestrian crosses the marked location on the sidewalk.

Because the general method suggested here is new, it has some inherent variability. One major source of variability in the current study was in the moment at which people looked at the approaching car. Some participants looked at the car prior to its arrival at the sidewalk, while others did not look at it because they were focused on their mobile device. This played a critical role in participants' deliberation times. We embraced these variations for our exploratory study to evaluate a broad, rather than specific, set of responses.

E. Protocol

We ran a proof-of-concept experiment in daylight from 11am to 2pm for three days over a span of 19 days in Winter 2015. We worked with a team of five people: A driver of the confederate car, a coordinator giving instructions to the driver and three interviewers. All team members were provided with hand-held, two-way radios. At the start of the experiment, the car was parked at the waiting location. Once the coordinator saw pedestrians walking towards the crosswalk, he told the driver their walking direction (from the east or west), approximate walking speed, approximate distance and if it was a single person or a group. The invisible driver then accelerated to be at the intersection right at the moment when the pedestrian was about to cross. We varied the driving style from conservative on the first day to a bit more aggressive and ambiguous on the second day. On the second day, the car approached the pedestrian with a higher speed and stopped later. The car also briefly started after it came to a full stop as the pedestrian was about to cross. This condition was selected to simulate variability in the performance of an autonomous car's pedestrian detection system. Participants were then approached by an interviewer who informed them of the study purpose, obtained consent and asked survey questions, if they agreed to the interview.

F. Consent

The study procedures and materials were approved by the Stanford Research Compliance Office. The study employed deception at its onset. Participants were not made aware that the car had no driver because we wanted to assess their responses to a driverless car. Participants were not aware that they were being filmed because it was a publicly-accessible area on Stanford property. Participants were informed about the purpose of the study after the car intervention if they agreed to stop and talk with the interviewer (some participants rushed to their destination and did not stop). All video segments were analyzed. Videos and video stills were included in research meetings and publications only if the participant gave video consent.

G. Measures

a) Video recordings: We used video recordings to capture people's responses [13][21]. Detailed video footage was gathered using four HD cameras set up to record different perspectives. One was installed in the car next to the rear-view mirror to get the driver's perspective. A second camera was on the top of the car pointing forward. A third was a 360° camera also on the roof. A fourth camera was installed on the opposite street providing a distance shot of the scene. Similar field research techniques have been used to investigate behavior of other autonomously moving objects such as robotic trash cans [8][36] and robotic furniture [28].

b) Survey questions: Open-ended survey questions were asked after the interaction to see if people believed that the car was driving autonomously and to assess their impressions of the car. The interview guide was formulated to be broad at first and then more specific in order to avoid leading questions. The sequence was the following: 1)"Can you please describe the experience you had at the crosswalk with the car?"; 2) "What did you observe about the car? Please feel free to mention everything that you noticed."; 3) "Was there anything special about the car that you observed?"; 4) "How did you think that the car was moving?"; 5) "Did you think the car was moving on its own?"; 6) "Could you tell that there was no driver in the car?". Three additional questions were asked to assess participants' self-responses about their behavior and expectations of the car: 7) "Did the fact that the car was autonomous influence your behavior? If so, how?"; 8) "How did you decide whether to continue to cross the intersection or not?"; 9) "Did the car do what you expected it to? Please explain."

H. Participants

We captured 67 people interacting with the car on video (49 at location 1 and 18 at location 2). 30 participants (12 female) were interviewed after their interaction with the car.

I. Analysis

For the video analysis, seven researchers jointly watched the video footage to look for behavioral patterns and responses. For the open-ended survey questions, one researcher reviewed all responses, identified themes and coded whether the participant believed the car to be driving autonomously or not. The results that follow are based on the video coding session and self-reported responses to survey questions.

IV. RESULTS

A. Methodological Validation

One prerequisite for the experiment was that people noticed there was no driver in the car and were convinced that the car was driving autonomously. As a manipulation check, the first part of the questionnaire was designed to validate this by asking open questions about their experience ("What did you think about your experience at the intersection?"). Of 30 interviewees, most people who interacted with the car believed that it was driving on its own (87%) and noticed the missing driver (80%) (Table I). Two people were not sure how the car was moving, while two people indicated they thought the car might be remote controlled.

The video footage confirms the persuasiveness of our manipulation. We saw a lot of people who were excited to see the car because they assumed it was self-driving. Some people took photos or videos of the car, talked about it with friends or posted about it on social media. These observations and the self-report questionnaire showed that our Wizard-of-Oz approach worked well and achieved its purpose.

TABLE I
DID PEOPLE NOTICE THAT THERE WAS NO DRIVER? AND DID THEY THINK THE CAR WAS SELF-DRIVING?

	Yes	Not Sure	No
Participant recognized that there was no driver in the car	24 80%	4 13%	2 7%
Participant thought that the car was self-driving	26 87%	2 7%	2 7%

B. Preliminary Findings on Pedestrian Behavior

a) Initial observation of car: Based on the experiment setup, people could detect through their peripheral vision that the car was approaching. The props and decals drew attention to the car so that most of the participants eventually noticed the car as it moved toward the crosswalk. Participants indicated their attention was focused on the car in part through turning their head and looking for the driver, which explains why so many people saw that there was none.

b) Participant crossing behavior: We saw from the videos that people did not seem shy to walk in front of the car. The crossing behavior of participants appeared normal as judged by the paths the participants walked. Of 67 observed interactions only two people clearly tried to avoid getting in front of the car by walking around it. This was on the second day when the car was driving a bit jerky (re-starting after it had come to a full stop). These two people looked for a driver to communicate with him or her and resolve confusion about the car's behavior.

c) Increased uncertainty about car behavior influenced movement speed: In post-interaction interviews, some participants mentioned increased uncertainty about the car's behavior. One participant said: "I waited for a while to see what it's going to do, then tried to cross. But then, while I was trying to cross it intended to start, so I stopped and waited." We saw moments of hesitation like a short stop or a slow down of the speed of walking in these cases. When the car restarted its movement after making a full stop, it looked like the established procedure broke down and caused attempts to repair this breakdown [14] by slowing down, repeatedly searching for a driver and using other cues such as movement to judge the car's intentions.

d) Response to aggressive behavior: Although the car sometimes misbehaved, nearly all people seemed to be very tolerant and forgiving. We saw just one person on the second day who seemed to be upset by the car creeping into the sidewalk. That person said of their interaction with the car: "I guess, if it were a person I'd have a really negative reaction towards them but then, the autonomous car is a really interesting concept. So it was less negatively impacted." Overall people seem to grant that the car was still learning.

e) Expectations of and trust in the car: Participants generally had *lower* expectations of autonomous cars compared to human drivers in that they were more forgiving of misbehavior, but *higher* expectations based on the fact that it is meant to eliminate human error. One participant walking in front of the car said: "The risk I took by crossing the intersection was higher than I realized because nobody is behind the wheel of the car. At the same time, there are no human errors, there are just car sensors." Pedestrians and cyclists appear to lack trust because there is no human driver, yet recognize the potential for greater trust because of the use of an algorithm instead of a human driver. What sounds contradictory might just be a dualistic concept of trust. Trust can be based on in-the-moment information, such as seeing a lack of a human driver in a car. Trust can also be based on conceptual understanding of autonomous vehicles, such as their ability to avoid human error. Therefore, it might not be too surprising that although people liked and trusted the car, some of them mentioned unease or distrust. They remarked that they "didn't feel very comfortable," "wanted to make sure that it wasn't going to hit me," or "kept an eye out while crossing."

f) Positive responses to breaching: Participants had a generally positive response to the car. They seemed interested, curious and excited about it. In survey responses, 12 of the 13 interviewees who characterized the driving-style of the car described it positively using words like 'safe', 'smooth', 'deliberate', and 'conservative'. We also asked participants if the car did what they expected it to do (e.g. stop at a stop sign). Of the 22 people who answered this question just one person said no, describing that it behaved like an 'insecure driver'. Nineteen people said that it did what they expected from it and two people did not have any expectations.

Breaching the established reality of having a human driver in a car by making the driver appear absent resulted in a general positive effect. This is in contrast to the negative effects reported by some experiments in which the established reality of social relationships is breached [9].

V. DISCUSSION

A. Reflections on Methodology

First, the primary purpose of this work is in elucidating a new method for conducting research in autonomous vehicle interactions. The Wizard-of-Oz approach taken here probes how people will react to driverless cars using a faux driverless car as an intervention in a real-world setting. Based on a proof-of-concept observational study, it appeared to work well and can be a valuable approach for similar research involving pedestrians and other road users. Compared to the use of car simulators that have the participant sit in a model car and view a digitally-rendered environment, this method has the advantage of being able to assess the behavior of pedestrians. Compared to virtual reality (VR) methods that have a participant view a digitally-rendered environment through a head-mounted display, this method has the advantage of allowing for *in situ* observation of behavior in a natural environment, rather than a lab.

B. Insights on Pedestrian Behavior

This exploratory work was meant to raise new questions rather than answer existing ones. What should a signaling system for pedestrians and cyclists look like? How and what content should be communicated? Do we need directional

Fig. 4. Participants walking in front of the Wizard-of-Oz self-driving car looking for a driver.

signals to point to and interact with individuals? One main insight of this paper is that overlooking the effect of novelty, people generally adhered to existing interaction patterns with cars unless there was a breakdown in expectations. We found that while erratic behavior on the part of the car was mentioned as a reason for hesitancy, the decision to cross was still made by most participants.

Two goals of communication between road users and car drivers are to evoke compliance by connecting with the driver and to get acknowledgment that one was noticed. The first goal becomes irrelevant as soon as the driver becomes a robot. We can be sure that robots follow set algorithms. While reliability of these algorithms can vary and their parameters are not always known, there is no moodiness or impulsive brashness as is possible with human drivers. Consequently, we cannot regulate an autonomous vehicle's compliance with the rules of the road through assertive nonverbal behavior as we may be able to do with human drivers. We do not need to give robots "the look."

Acknowledgment remains more relevant. Pedestrians about to cross in front of a car like to get a sign that they have been seen. With no human driver in the car, it might be assumed that people would like to get acknowledgment from the car itself. However, we found that people were surprisingly capable of managing this breach of normality without any communication cues. We assume that this is because pedestrians and cyclists have extensive experience in maneuvering without such signals—at nighttime and in other situations when the driver can't be seen.

C. Implications for Design

The main implication for designers is that they can expect most pedestrians to behave normally at crosswalks when encountering an autonomous car without a driver. A small minority were hesitant about crossing and actively approached the car looking for a driver. Thus, designers should design autonomous cars to account for both the majority response as well as the minority response. Designing for the majority may mean that designers can avoid adding special signaling cues, such as a robotic face inside the car or special lights, to replace a person's gaze in a driverless car. Designing for the minority response may mean implementing visible and/or audible warnings if people approach too closely while the car is at an intersection.

D. Limitations

Several limitations of this study are noted here. First, the study was conducted at a university campus location in Silicon Valley, which may consist of individuals who are particularly aware of automation or curious about technology. This limitation could be addressed by replicating the study in a non-university setting. Second, due to the *in situ* nature of the work, the sample of participants who agreed to participate in the survey portion of the study may have been subject to selection bias toward those who had a positive experience with the car or who had more interest in the car. This was partially addressed by videotaping road users, which was not subject to selection bias. Third, this study looked into autonomous vehicles without drivers; interactions between pedestrians and autonomous cars in which a person is in the car may be viewed differently than when there is no visible driver. This limitation could be addressed in future work.

E. Future Work

Future research could employ a similar method to the one described here to investigate other types of breaches with an autonomous vehicle apart from the complete absence of the car driver. For example, the circumstances of the breaching experiment could be modified to investigate how pedestrians behave when encountering an autonomous car in which the only visible person in the car displays behavior incongruent with typical behavior inside a car; the person could be eating, reading or applying makeup in the autonomous vehicle instead of driving. This would involve employing a hidden confederate driver as described in this work, but in a right-hand-drive vehicle as described in [1], with a confederate passenger sitting in the left seat of the vehicle who appears as the car's driver to other road users. It would be of interest how pedestrians respond to the person in the car and whether they would attempt to communicate with him or her. Although a person in an actual autonomous vehicle might not be driving at the particular moment of an interaction with a pedestrian (and therefore be justified in performing non-driving activities), pedestrians could wrongly interpret a person's presence in the driver's seat of an autonomous car as operating the vehicle. It might therefore be a cause for concern when the person is doing an unrelated task. This example demonstrates the flexibility and synergistic potential of the methodology proposed in this work.

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