Driver behavior impact on pedestrians' crossing experience in the conditionally autonomous driving context

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Abstract

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ABSTRACT
Autonomous vehicles are developing at a rapid pace while pedestrians’ experience with autonomous vehicles is less researched. This paper reported an exploratory study where 40 participants encountered a conditionally autonomous vehicle with unusual driver behaviors at crossing by watching videos and photos. Questionnaires and semi-structured interviews were used to investigate pedestrians’ experience. The results showed distracted driver behaviors in the conditionally autonomous driving context had negative impact on pedestrians’ crossing experience. Black window on conditionally autonomous vehicles made pedestrians feel uncomfortable and worried.

KEYWORDS
Conditionally Autonomous Vehicles, Distracted Driver Behavior, Pedestrian-Vehicle Interaction, Pedestrians’ Experience, Human-Computer Interaction (HCI)

ACM Reference format:

1 INTRODUCTION
1.1 Autonomous vehicles
Autonomous vehicles are expected to reduce drivers’ workload and reduce the number of traffic accidents caused by human error [7]. Due to the potential benefits of autonomous vehicles, almost every automaker has entered the race of developing autonomous vehicles. Technology giants including Apple and Google, as well as big auto-parts suppliers such as Bosch and Delphi, are also actively preparing self-driving technology. Autonomous driving is defined by the Society of Automotive Engineers (SAE) as driving with one or more safety critical functions controlled by the vehicle [12]. There are six levels of automation, which differ based on the distribution of responsibilities between the driver and the system. Vehicles with level 0, 1 and 2 automation require the human driver to monitor the driving environment all the time, whereas that responsibility in level 3 to 5 gradually fall on the autonomous driving system. These levels are identified and briefed below (Table 1).

This paper focuses on Level 3 conditional automation, where the system is able to fully take control from the human driver under specific circumstances (e.g., mapped area, low speed, in traffic) while the driver is expected to respond appropriately when requested. Since conditional automation doesn’t require human driver intervention constantly, drivers are able to engage in secondary activities such as working, texting messages and making phone calls. These distracted driving behaviors [1] are likely to be seen frequently in level 3 conditionally autonomous driving.

1.2 Distracted driving
Distracted driving [1] is any activity that diverts attention from the task of safe driving, including talking or texting on the phone, eating and drinking, entertainment or navigation system. Studies showed that nowadays drivers frequently involved themselves in a variety of visual distracted activities, occurring when drivers look away from the roadway (e.g., to adjust a radio) and cognitive distracted activities, occurring when drivers think about something not directly related to the current vehicle control task (e.g., reading a message) [32] [1]. These driver distractions have increased the
risk of a crash [16]. According to National Highway Traffic Safety Administration (NHTSA), distracted driving is the leading factor in the most crashes and near-crashes in the United States of America, the number of fatalities resulting from distracted driving has increased by 8.8 % from 2014 to 2015 [1]. The frequency of driver distraction is likely to increase with an increase of automation of the vehicle, as the driver has fewer and fewer driving tasks to take part in. We may expect that distracted driving behaviors would show up more frequently in conditionally autonomous driving compared to in manually driving. The impact of driver distraction in conditionally autonomous driving to other road users, especially to the most vulnerable group of road users - pedestrians, hasn’t been researched.

1.3 Problem statement

Currently, pedestrians often rely on non-verbal communication with drivers [27] [15] [24]. For instance, pedestrians, intending to cross an unsignalised crossing (where there is no stop sign or traffic signal), often establish eye contact with the driver to ensure that the approaching car will stop for them. Other forms of non-verbal cues such as hand gestures or body postures are also used to resolve ambiguities in typical traffic situations. However, when communicating with the driver in conditionally autonomous driving vehicles, pedestrians could not highly rely on non-verbal cues. Because the driver may engage in other activities other than driving and could not give effective cues [25]. Furthermore, pedestrians could misunderstand a driver behavior when it doesn’t match their expectations of an usual driver image based on previous experience. For example, distracted driving behaviors are considered to be risky nowadays, which also break the law and violate social norms [6]. Problems and danger could arise at the moment pedestrians could not well understand the unusual driver behaviors in the context of conditionally driving.

Therefore, there is a need to investigate pedestrians’ perceptions, emotions and expectations when they encounter unusual driver behaviors in conditionally autonomous vehicles at urban unsignalised crossing, where the right of way is not clear. The following research questions were investigated in this paper:

- The main research question: How will various types of unusual driver behaviors in a conditionally autonomous vehicle impact pedestrians’ crossing experience?
- Two sub questions: What information is important for pedestrians during the communication with conditionally autonomous vehicles? Are explicit interfaces of the vehicle needed by pedestrians?

2 BACKGROUND

2.1 When are autonomous vehicles coming?

Currently, all the autonomous vehicles available in the market are level 2 autonomous capabilities with features including acceleration, braking and steering assistance. level 5 fully autonomous vehicles aren’t ready yet, but there is wide consensus that level 3-4 autonomous vehicles will be commercially available to some customers within five years [13]. They may be operating on the road if appropriate laws and regulations are in place. We can see some examples:

- Audi planned to introduce level 3 automation to the road with its next generation A8 full-size sedan by 2018. The car will include a camera-based driver awareness system that can see whether the driver is awake.
- Ford announced they would skip level 3 and set the goal of having level 4 capable autonomous driving taxis by 2021. The vehicles will not have steering wheel and pedals, for use in commercial mobility services such as ride-sharing and ride-hailing within mapped areas.
- Baidu, the Chinese equivalent of Google, announced its autonomous vehicles with level 3 automation will enter road tests by the end of 2017. Baidu also disclosed the expectation to have level 4 autonomous vehicles for commercial applications in China by 2019 and for a mass production by 2021.

Even though autonomous systems are developing at a fast pace, there are still many challenges like technical obstacles, legal questions and ethical problems to be overcome in the industry. Most analysts believe it will take many more years, even decades, before fully autonomous vehicles replace conventional vehicles in significant numbers. A long transition period is to be expected in which conventional vehicles and different levels of autonomous vehicles share the road. Pedestrians could get confused about what capabilities the vehicle has, and what behaviour is therefore to be expected in the transition period [30]. This paper aims to study on pedestrians’ experience with level 3 conditionally autonomous driving that is less researched than conventional vehicles and fully autonomous driving.

2.2 The issue of ‘Transfer of control’ in conditional automation

The ‘Transfer of control’ issue existing in conditional automation could potentially influence road safety [30]. Autonomous driving system can ask the driver to take over the driving task, e.g., when the vehicle enters an unmapped area or in case of system malfunctions. Resuming the driving tasks after a period of autonomous driving makes high demands on the driver and this may result in making errors. A study from National Highway Traffic Safety Administration showed it took drivers of conditionally autonomous cars an average of 17 seconds and even longer to respond to transfer requests [2]. In addition, Zeeb et al. [33] found driver take-over quality degrades when performing secondary tasks, especially for tasks with increased level of distraction.

This issue is very relevant to pedestrian, because if the driver wastes too long time to take over the control properly in an emergency situation with pedestrians, accidents may already happen to pedestrians. It would be interesting to know whether pedestrians have up-to-date knowledge and prevention measures about this potential risk existing in conditional automation.
2.3 Pedestrian-vehicle communication strategies

2.3.1 Formal rules. Lurie [20] was one of the first to claim that there are two kinds of rules in traffic — formal and informal. Formal rules are traffic regulations and laws that regulate road user behavior and prescribe proper ways to behave. However, traffic regulations vary from country to country. In terms of right of way, compared to the western understanding which refers to the legal right for pedestrians to proceed first at zebra crossing, in China the person who comes to the way first has the right of way. In practice, this translates into motorists and cyclists don’t need to yield to pedestrians and pedestrians have to take the responsibility of avoiding the collision. This difference brings challenges to apply same autonomous driving systems under different regulations and norms.

2.3.2 Informal rules. Theoretically, pedestrians’ decision-making of crossing the road is based on formal regulations. Sometimes, however, they also use informal rules such as eye contact, nodding and hand gestures to communicate with the driver [27][15]. Non-verbal communication is essential in driver-pedestrian interactions because they well predict intention and awareness of each other. Several studies investigated the effects of different communication cues on the interaction between pedestrians and drivers. Gueguen et al. [10] studied the effect of smile given by a crossing pedestrian to a driver. They indicated that drivers tended to yield when they saw the smile. In another study, Ren et al. [23] found that eye contact increased the time to collision, implying that car drivers decelerated more smoothly and earlier, which greatly improved pedestrians’ safety.

However, in conditionally autonomous vehicles, informal communication will make less sense both for pedestrians and the driver. Pedestrians can’t rely much on informal communication because the effect of making eye contact to a driver is not the same if this driver is not actually monitoring the car, and may even be involved completely in other tasks, such as reading the newspaper or typing a text message. It will also be hard for conditionally autonomous vehicles to detect and predict behaviors of pedestrians sufficiently. With current technology, vehicle sensors have difficulties to detect such subtle and ambiguous informal communication cues given by pedestrians [18][30].

2.3.3 External interface. When vehicles become autonomous, new ways that involve in external interfaces have been considered and developed by automotive companies and researchers, to build intent communication between pedestrians and vehicles. For example, Google applied for a patent (Figure 1, [22]) in 2012, which describes a system in which self-driving cars would be able to present messages (images or text) to pedestrians as well as broadcast audible alerts to communicate to pedestrians. Semcon proposed a concept where self-driving cars interact with pedestrians by smiling (Figure 1, [26]). When the car detects a pedestrian at crossing, a smile sign in front of the car will be lighted up and confirm that the car will stop. Mercedes’s F 015 Luxury in Motion (Figure 1, Mercedes-Benz [21]) communicates with pedestrians using messages projected on the road. When F 015 notices a pedestrian waiting to cross, it will stop and beam a laser crosswalk onto road in front of the pedestrian. A concept developed at ISIA Roma Design Institute called AutonoMI (Figure 1, Graziano [9]) uses lights on the vehicle body to point towards pedestrians and follow their movement of crossing the road, indicating the car has detected the pedestrians. Some other concepts include Nissan IDS concept with light messages on the bottom of the windshield, and AVIP concept developed by Swedish Victoria ICT with a strip of LEDs on the top of the windshield.

However, there is not a standard for pedestrians and autonomous vehicles communication until now. It’s not clear to what extent these novel ways of communication have been tested in practice, and to what extent pedestrians would trust them. On the other hand, Clamann et al. [5] studied on effectiveness of new methods of vehicle-pedestrian communication and concluded that pedestrians are more likely to rely on existing crossing strategies (e.g., vehicle approaching speed) than displays installed on the front of the vehicle.

2.4 Pedestrians’ reaction to autonomous vehicles

In 2015, Lagstrom and Lundgren [17] investigated the pedestrian’s experience with changing driver behaviors by a Wizard-of-Oz field experiment in which driver was differently distracted. In this study, a questionnaire was administrated to measure pedestrians’ emotional state when encountering a vehicle where the driver was engaged in various tasks. The results revealed pedestrians had more stress and less willingness to cross the road when the driver were more distracted in driving. However, the participants were not told the study was related to autonomous vehicles, we assumed their
awareness and knowledge of autonomous vehicles were deficient compared to now. Some other researches have positive results on pedestrians attitude of interacting with autonomous vehicles. For example, Rodríguez [24] used interviews and surveys to investigate pedestrians’ perceived safety of WEpods (the first experimental self-driving pod tested on Dutch roads). The results indicated that pedestrians felt safer when sharing the road with the WEpods compared to conventional vehicles. Besides, they perceived the same level of safety when encountering WEpods and conventional vehicles at an unsignalised crossing. The positive result was also found by Rothenbücher et al. [25]. They conducted a Wizard-of-Oz field study to investigate pedestrians’ reaction to an approaching self-driving car, which is actually driven by an invisible driver wearing custom-made black suits. The results showed the crossing behavior of participants appeared normal as judged by the paths they walked. Besides, participants also have positive comments on driving-style of the self-driving car they encountered in the experiment.

3 METHODS

This study uses a mixed method that combines both quantitative and qualitative approaches. In the experiment, participants were exposed to videos showing the scenario and photos of various human driver behaviors in a car at unsignalised zebra crossing. A survey, which included a Self-Assessment Manikin (SAM) questionnaire measuring pedestrians’ emotional state (Figure 5, [4]), and a semi-structured interview with predefined questions about pedestrians’
crossing experience, was conducted after the participant viewed each photo.

3.1 Participants

40 Participants between the ages of 20 and 58 (M=28, median = 24), including 24 male and 16 female, were randomly selected from company offices, KTH campus and metro station Universitet in Stockholm. All the participants have normal vision and can speak and read English. They are used to walk in an urban environment so they can easily identify themselves as pedestrians. Participants read and signed the informed consents before participating.

3.2 Procedure

Before the experiment started, participants were informed that the purpose of the study is to determine pedestrians’ opinions and experience about conditionally autonomous vehicles where the system is able to fully take control from the human driver under specific circumstances (e.g., mapped area, low speed, in traffic). Participants were introduced that the whole process was audio recorded for data analysis and the recording would be used only for the purpose of the study. They were also asked to provide demographic information including age, gender, nationality. The experiment was conducted in three phases:

(1) First, the test leader showed the video and read aloud the following scenario description:

Suppose it’s in the future and about 5 years from now, there are conventional cars and conditionally autonomous cars sharing the road. You are walking through a city center and are just about to cross an unsignalised zebra crossing. You look to your right and see a car was approaching to you and just stopped at the crossing. Then you look into the car and see what is shown in the photo (Figure 2 or Figure 3). How do you feel about crossing the road?

(2) Next, the participant was exposed to one of five photos in random order. After viewing the photo carefully, the participant was required to complete SAM questionnaire (Figure 5) and had a semi-structured interview with the test leader. In the semi-structured interview, the participant was asked the following questions and related improvised questions:

1) “Can you describe what you encountered at the crossing?”
2) “Would you cross immediately? Why?”
3) “How sure do you think that you are safe to cross, tell in percent (0-100%)?”

(3) The phases in (2) repeated five times until the participant have viewed all five photos and answered related questions. At the end, the test leader asked overview questions like:

1) “In which meeting did you feel comfortable or uncomfortable?”
2) “Which driver behavior is acceptable or not acceptable in a conditionally autonomous car?”
3) “Which photos do you think are conditionally autonomous cars?”
4) “How would you communicate if you don’t want to cross the road?”

3.3 Factors

Two factors were defined in the experiment: one within-subject factor with five levels of human driver behaviors and one between-subject factor with two groups of cars. The 40 participants were randomly divided into two groups (group A and group B). Group A was tested with five levels of human driver behaviors in a normal car, while Group B was tested with same five human driver behaviors but in a car with a display mounted on the roof displaying “Safe to cross”.

3.3.1 Five driver behaviors. The five driver behaviors shown in the above photos were: making eye contact, talking on phone, sleeping, gesturing “Don’t cross” and a black window where the driver is not seen. Making eye contact was chosen as it gave the pedestrian a clear indication that the driver had seen them. The talking on phone behavior showed some distraction of the driver, while the sleeping behavior was totally distracted and it was used to help participants understand the car was driven by robot rather than human. The choice of a driver gesturing “Don’t cross” aimed to show a situation that human had different suggestion to pedestrians with that of robot. Since the human drivers will gradually become passengers in the future, they may want more privacy inside the car and don’t want to be seen from outside. So we chose the black window to show the absence of human driver, and pedestrians could not get any information from this behavior. When choosing the behaviors, considerations were also made towards how visible behaviors would be for the tested subjects.

3.3.2 Two groups. Two groups of cars were: the normal car and the car with the display mounted on the roof displaying the English text “Safe to cross”. The text was displayed in green — an universal standard color in traffic that means “cross”. The only difference between two groups of cars was with or without the display. Since conditional automation is still with human intervention with steering and braking, the look of the car with conditional automation will not be exceptionally different, hence we kept the look as a typical car today. But there would be certain ways to distinguish conditionally autonomous cars from conventional cars, and the cue we gave to participants is the display with informative messages. Participants were not directly informed that the car they saw in the photos was equipped with conditional automation or not, and participants were left to decide on their own. The purpose of two groups was to know if the display can help pedestrians distinguish conditionally autonomous vehicles from conventional vehicles and if the display is helpful for pedestrians to make crossing decision.

3.4 Materials

3.4.1 Ten Photos . This experiment used 10 photos (5x2) to illustrate 5 different driver behaviors in 2 groups of cars stopped at an unsignalised urban crossing (Figure 2, 3).

3.4.2 Two Videos. Two videos were used to help participants understand the scenario, giving the idea like what the unsignalised urban crossing looked like, which car was approaching. The videos are silent since the sounds are not taken into account in this experiments. One video is for group A and one is for group B. Two videos are same except that in group B the car has mounted display changing from no text to text “Safe to cross”.

"In which meeting did you feel comfortable or uncomfortable?"
"Which driver behavior is acceptable or not acceptable in a conditionally autonomous car?"
"Which photos do you think are conditionally autonomous cars?"
"How would you communicate if you don’t want to cross the road?"
3.4.3 Self-Assessment Manikin (SAM) questionnaire. The Self-Assessment Manikin (SAM) scale is used to directly measure the pleasure, arousal, and dominance related to personal affection in response to various experience and situations, including reactions to pictures [4]. Figure 5 shows the SAM figure with pleasure, arousal, and dominance scales on the top, middle, and bottom rows, respectively. SAM was chosen because this thesis focuses on the pedestrians’ emotional experience of a crossing encounter with conditionally autonomous car. SAM was a fast and easy tool to quantify an experience, and the pictorial approach makes it ideal to be used in a cross-cultural environment (subjects were from 6 different countries) compared to other verbal and literal questionnaires. In addition, it can also easily be distributed as printed material to be filled up by hand. In the SAM questionnaire, subjects were asked to answer the question “How do you feel about crossing the road?” by choosing from number 1-9 provided below each of the emotion figure.

![Figure 5: SAM questionnaire](image)

Other materials: a smart phone for audio recording, pens and the notebook.

3.5 Data analysis

The impact of driver behavior was studied by means of a within-group comparison within one group (Group A normal car or Group B car with mounted display). And the expectation of conditionally autonomous cars was studied by a between-group comparison. Specifically,

1) The SAM data were color-coded by driver behavior and plotted with the valence on the horizontal axis and activity on the vertical. In the meanwhile, control data were represented as the size of the bubbles. The average of each parameter on driver behavior was compared.

2) The quantitative data collected from semi-structured interview and overall questions were analysed by different statistic ways:

   1) The percentage of perceived safety to cross from question “How sure you think you are safe to cross the road in percent?” was considered as interval data and analyzed with bar chart and mixed Anova test (which is a statistic test used to analyze the variation among group means [8]) by average value of all the responds of in term of each factor, in order to see if there were any indications of how the perceived safety related to driver behavior and car type. 2) The number of participants that not accepted a certain behavior was counted and is illustrated in Figure 7.

3) The qualitative recorded interviews were coded by the interviewer. A content analysis [11] was carried out to identify common themes among the participants.
4 RESULTS

4.1 Pedestrians’ emotional reaction

The emotional reaction of the participants towards the five driver behaviors in two groups of cars are shown in Figure 4. The results showed driver behaviors had impact on pedestrians’ emotion state.

Eye contact: As can be seen from the biggest blue bubbles in the bottom right corner, pedestrians generally thought that seeing a human driver alert and looking into their direction gave them good experience with lots of pleasure, much calmness and full of control.

Gesturing “Don’t cross”: The driver who was gesturing “Don’t cross” gave pedestrians the most negative feeling among all five behaviors. The participants described this behavior as “strange”, “confused”, “crazy” in the interview. Especially seeing the driver showing “Don’t cross” while the car displaying “Safe to cross”, they felt almost no control of the situation, accordingly the grey gridding bubble was the smallest compared to all others.

The other three behaviors were closed in the center of pleasure-calmness plate but still had difference.

Sleeping: Pedestrians felt sleeping behavior very unhappy and surprised. They commented it as “very dangerous” “not alert” “can’t deal with emergency well”. In both two groups of cars, most participants recognized the car was driving on its own because the driver was sleeping with an eye-patch. They felt more pleasant with the car having extra information on the display. The control and the calmness were no significant effect between the normal car and car with display.

Phone call: Talking on phone in normal car made pedestrians feel some unpleasant but they still stayed calm and had control, as this behavior was quite often seen nowadays, pedestrians were not surprised about that. They also commented “The car finally stopped at the crossing so the driver should see me even he is talking on phone”. Talking on phone in a car with mounted display made them have a neutral feeling of calmness and happiness but they had the same control of situation with that in a normal car.

Black window: The black window gave pedestrians calm and pleasant experience in a normal car. They explained that nowadays some people did the same thing on their windows. However, it moved a bit to unpleasant and excited feeling when they encountered it in a car with mounted display. Participants had comments “Maybe the driver behind black window was sleeping”, “Can’t see any information inside the car made me scary” when they can only see “Safe to cross” display.

Comparing the results from two participant groups, the car with mounted display made participants feel either more excited or more happy or both except for black window. As you can see in the Figure 4, the striped bubbles (except the green one) appear upper or righter or both compared to the filled bubbles. But in terms of control, participants didn’t feel more control with the group of the car with mounted display.

4.2 Pedestrians’ perceived safety

Mixed-design Anova test with one within-subject factor (human driver behavior) and one between-subject factor (type of the car) is used to analyze the data of perceived safety of pedestrians. The effect significance in Anova test was summarized in Table 2. The mean value of all response towards each behavior in each group is presented in Figure 6.

<table>
<thead>
<tr>
<th>Measure: Perceived Safety</th>
<th>Significant level at P=0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>df</td>
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<tr>
<td>Condition</td>
<td>1</td>
</tr>
<tr>
<td>Behavior</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 6: Mean perceived safety of participants

Comparing between two groups, their effects on pedestrians’ perceived safety were not significant different (P=0.316), because the P value was bigger than significant level of 0.05. Therefore, from statistical perspective, pedestrians’ perceived safety of the normal car and that of the car amounted display didn’t significantly differ.

However, we can still find small difference from the bar chart (Figure 6). The orange bar is always lower than the blue bar, illustrating a tendency that pedestrians were less sure about their safety when crossing in front of the car amounted display than crossing in front of the normal car. As we can see, perceived safety of eye contact and that of black window between two car groups had a bigger reduction than that of other behaviors. The reason could be that pedestrians felt safe when seeing that the driver behaved normally and the car looked normal. When pedestrians saw the car with mounted display, they realized it was autonomous car and started to worry about their safety. There is little reduction in sleeping because participants already had idea that the car was conditionally autonomous in both groups so they perceived similar safety.

When analyzed within-subject data, we removed data generated by gesturing behavior as the gesturing behavior is obviously different from other behaviors and can cause bias of effect significance. So the Anova test was run to see if other four behaviors have significant difference.
As can be seen in Table 2, driver behavior effect was significant (P<0.001) so there was a significant difference in pedestrians’ perceived safety among driver behaviors. In other words, driver behaviors have significant impact on pedestrians’ perceived safety. Specifically, the pair comparison results (Table 3) showed there was a significant difference between the pair (phone, eye contact) (P<0.001), the pair (phone, sleeping) (P=0.001), the pair (eye contact, sleeping) (P=0.01), the pair (black window, sleeping) (P=0.01). While there was no significant difference between the pair (black window, phone) because the value P is more than 0.05. The average perceived safety value reduced largely by 20.2 between eye contact and black window, and then reduced slightly by an additional 3.9 between black window and phone, and vastly had a great reduce of an additional 12.7 between phone and sleeping.

As can be concluded from above results, having eye contact with drivers made pedestrians believe the driver was actively in control and this well increased their perceived safety of crossing the road. Pedestrians’ perceived safety was seriously reduced depending on the distraction level of the driver (eye contact > phone call ≈ black window ≈ sleeping). In the case when the driver gestured “Don’t cross” while the car displayed “Safe to cross”, their perceived safety percentage reduced to around 5 (out of 100). None of participants decided to cross the road. They commented that “The driver looks upset”, “I definitely won’t cross because the car looks like having some technical problems and the driver could not manage it.”

### 4.3 Pedestrians’ Concerns

From the results of interviews, pedestrians were more concerned about questions: “When is the driver driving and when is the car in control?”, “What is the indicator of the the level of control from the driver? ”

In group A encounter with a normal car, most participants didn’t express the eye contact, phone call, black window behavior were related to autonomous driving. Some participants were not sure about gesturing behavior and sleeping. A majority of participants believed the sleeping behavior was in autonomous driving and this may suggest the fact that people tended to judge the question textit “who is controlling the car the human or the robot?” by drivers’ behavior. Many participants mentioned they wanted to have more information about the level of control from human and the state of the car like ‘stop’, ‘will drive’, ‘speed up’ or ‘slow down’.

In the group B encounter with a car with mounted display, participants could believe the car was equipped with conditionally automation but still couldn’t fully trust the information on the display due to lack of experience and knowledge of autonomous driving. They got confused about who is in control when they encountered the phone call driver who was a lot distracted and didn’t look at them at all. They were worried about the sleeping driver and thought the car may not have enough capability to handle the driving in all conditions.

Another concern emerging from semi-structured interviews is that Participants cared much about whether the human driver was attentive.

![Figure 7: Pedestrians’ acceptance towards three driver behaviors in conditionally autonomous vehicles](image)

As we can see from Figure 7, the sleeping driver was not acceptable by 32 (out of 40) participants investigated, while only 9 (out of 40) and 24 (out of 40) participants didn’t accept the talking on phone behavior and the black window respectively. We could conclude that keeping human driver attentive inside the conditionally autonomous car is important to pedestrians because the human can deal with emergencies when malfunction arises in autonomous system.

Participants commented the reason why sleeping was not allowed: “If the human driver was sleeping, and a malfunction or an emergency occurred, the driver couldn’t become alert immediately and handle the problem properly. This is very dangerous.” The phone call behavior was considered better because the human was still awake. “It seems take less time for driver to know what is going around when he is still awake”, a participant commented.

There were different opinions on whether the black window was acceptable in conditionally autonomous car. 16 (out of 40) participants claimed the black window was acceptable because they assumed there was an alert driver inside the car when they could not see things behind the black window. The other 24 participants felt uncomfortable seeing a black window and felt anxious if they can’t know what the situation was inside the car. Some even commented...
“I prefer seeing a sleeping driver than a totally black window which makes me so uncomfortable.” One participant said “I didn’t know I was afraid of the black window until you asked me, I want to see the driver because I will be more careful when crossing the road if I know the driver is sleeping or doing something else.”

The ‘Transfer of control’ issue mentioned early in the paper was not directly spoke by participants, but some participants had similar anxiety. However, most pedestrians hadn’t been aware of the ‘Transfer of control’ issue yet since they had no experience interacting with real conditionally autonomous vehicles. The effect of this issue on pedestrians remains to be studied.

4.4 Pedestrians’ intended interaction

The interaction pedestrians would use to communicate with autonomous vehicles in specific situations was investigated in the semi-structured interview. Towards the question “If you actually don’t want to cross the road, how would you communicate with the vehicle in the photo (with sleeping driver) that has stopped to let you cross?”, answers are classified as below: 30 (out of 40) participants would step back or turn around to let the car go. They commented “I just turn around and go back few steps, the car may see me leaving and it will go”, “I try to avoid looking at the car, like what I did in nowadays. The car may understand that I don’t want to cross.” 8 participants would try to communicate with the car actively like doing gesture or talking. They commented they would show a “please go” gesture which is used very often by waiters in restaurant to welcome customers. Only 2 participants would stand still and pay no attention, they commented like “I don’t care about the car, and it’s none of my business”.

These results help better understand pedestrians’ expected interaction with autonomous vehicles. If pedestrians don’t want to cross, they would be aware of moving out of the detected range of the autonomous vehicle, or remove their eyesight from the autonomous vehicle. But most people tend to avoid the explicit interaction like gestures and speech, as they said “I don’t like to pay a lot effort every time when I am at crossing”.

5 DISCUSSION

5.1 The impact of driver behavior

Having eye-contact with the driver makes pedestrians have more positive emotion and feel safer to cross. Keeping driver alert about driving environment is also what car-makers are trying to do to improve the driver’s take-over performance. Solutions that have been considered involve installing cameras and sensors to monitor aspects like head position and gaze direction of the driver, providing visual, aural, and haptic alerts to get the driver’s attention quickly when the driver intervention is required [28]. However, there is a trade-off between making the driver attentive and let him enjoy the time when the car drives autonomously. Frequently getting the driver’s attention by sensors and alerts would be annoying.

Distracted driver behaviors in the context of conditionally autonomous driving have negative impact on pedestrians’ experience. Pedestrians feel unhappy and not calm about crossing the road. They tend not to cross the road instantly and have safety concerns about crossing the road. The negative impact is increased obviously from phone call behavior to sleeping behavior. We might infer that the level of driver distraction is a crucial factor for pedestrians’ crossing experience from the perspective of pedestrians’ emotional state and perceived safety. Since the level of distraction is more complex, there isn’t a consistent definition or classification for each level of distraction [32]. We could not simply summarize the relationship between distracted driver behavior and its impact on pedestrians’ experience. Generally, we say the more distracted driver behavior, the more negative impact it has on pedestrians’ experience.

The gesturing “Don’t cross” behavior has significant negative impact on pedestrians’ experience. They commented “I have no idea of what is going on with the car and driver”. “The driver looks upset and it makes me frustrated”. When the driver and the automation system give opposite indications about crossing the road to participants, they all follow the suggestion from drivers. This result reflects the fact that people trust the human driver more than a robotic system or machine essentially. We could guess that the driver can still communicate with pedestrians actively and get positive response in conditionally autonomous driving.

The black window has the various impact on pedestrians from person to person. Since the distracted driver behavior has negative impact on pedestrians, some people may think installing black window in autonomous vehicles can hide unusual driver behaviors and eliminate the negative impact. However, it was tested to be a bad solution. Because results showed in average participants didn’t feel safer to cross the road when seeing a black window compared to seeing a distracted phone caller. More than half participants won’t accept a black window hide driver because it makes them uncomfortable and worried. Besides, it was quite interesting that using black window in normal car has more positive impact on participants’ experience compared to using it in display mounted car. The reason could be explained by that pedestrians had seen normal cars with black window quite often in present days, so they didn’t even think the car would be equipped with certain level of automation and had no concern. When they encountered mounted display car with an informative message, they guessed it was a kind of autonomous car, so they paid more attention to the driver inside and started to worry about the unusual driver behavior.

5.2 Human trust on autonomous driving

Experiment results showed that the car with a mounted display displaying “Safe to cross” didn’t have a significant effect on participants’ perceived safety compared to the car without display. This could suggest a lack of trust on the autonomous driving technology and on the new way of communication from pedestrians’ side. The comments from participants also gave explanation about their distrust. For example, one girl said “I don’t know the display signal was saying to me or some other people”, another participant doubted “I am not sure the ‘Safe to cross’ signal is working or just randomly displaying because the self-driving technology isn’t mature yet”.

Moreover, the distrust on autonomous driving system of drivers is also revealed seriously. A survey conducted in the United States by Kelly Blue Book showed the public has doubted whether autonomous vehicles would improve safety [3]. In the survey, about two-third of the respondents said they didn’t have enough confidence on autonomous driving system and wouldn’t be comfortable
riding in an autonomous car. One of the reasons given to the public distrust towards the autonomous technology is because most people had not seen the technology working on the road yet. Building the human trust on driving automation is an important issue. Increasing the reliability of self-driving technology continually in practice is the key point, at the same time, designers could help from the aspect of building solid interaction.

5.3 Implication for design

Firstly, what information is important for pedestrians during the communication with conditionally autonomous vehicles?

Results showed knowing the driving mode of the vehicle — autonomous driving or human driving is important for pedestrians. If there isn’t a clear signal indicating the driving mode, pedestrians may misunderstand the capability of the car and the role of the driver. It should be noted that the status when autonomous driving is transferred to human driving, which could last for 17 seconds or even longer depending on driver performance [2], need to be clearly informed to pedestrians too. Since there may be a potential danger for pedestrians in this status, pedestrians need to be informed and be prepared of prevention measures. Another item essential to pedestrians is understanding how capable the autonomous system is, in which situations autonomous system could handle properly? This was also concluded by Vissers et al. [30] in the research on safe interaction between pedestrians and autonomous vehicles. In the long transition period with conventional vehicles and different levels of autonomous vehicles, how much capabilities each system is equipped with is important to know by pedestrians for keeping safe interaction. Furthermore, the status of vehicle like ‘slow down to yield’, ‘drive away’, ‘rest’, ‘turn’ need to be informed to pedestrians. When autonomous system has a breakdown, a warning signal should also be sent immediately.

Secondly, are explicit interfaces needed by pedestrians?

In the early stages of pedestrians and autonomous vehicles interaction, explicit interfaces are welcomed by pedestrians. As experimental results showed in this paper, participants were happy and excited to have a display mounted on the car indicating vehicle intentions. Lundgren et al. [19] also recommended that providing pedestrians with corresponding information by means of an external vehicle interface is beneficial. Specifically, an electric display mounted on the top of car seems not to be a good idea since there was not a significant difference of pedestrians’ perceived safety towards with and without a display in experiment results. The similar finding was illustrated in Wizard of Oz experiments [5] that having a display was as effective as not having display for pedestrians to make the crossing decision. Therefore, the question what’s the best explicit interface of pedestrian-autonomous vehicle communication has not been answered yet. Researchers are still working on it. A common opinion is that multiple modalities should be used combining visual, audio, and even haptic feedback [14] [17].

In the further stage of pedestrian-autonomous vehicle communication, information can be overwhelming since the autonomous vehicles are everywhere and sending messages all the time. Too much information around pedestrians can be annoying and distracting, especially the audio signals will make lots of noise. When users have enough experience with a system, information becomes less relevant to maintain trust and acceptance and could be experienced as annoying [29]. So in the future when autonomous driving becomes common, pedestrians are familiar with autonomous driving behaviors and will be able to predict vehicle intentions, information is less needed and could be greatly simplified.

5.4 Limitations

Due to the short time frame and limited resources, there are several limitations. Firstly, photos and videos used in this experiment were taken with the real people and the car. The mounted display was edited to the photo after by using Photoshop. Participants might find the display not realistic and had bias. This could be addressed by making real display prototype and mounting it on the car to take original photos and videos. Secondly, most participants were employees in the automotive industry and the university students, they might have higher awareness of self-driving technology than average. This could be addressed by replicating the experiments with participants from diverse backgrounds. Thirdly, the color of the car in the photos is red. Red is usually associated with “exciting” which implies high arousal [31]. So participants’ emotional state may be slightly effected by the color. This could be addressed by using neutral colors like gray for the car.

5.5 Future Prospects

The relationship between distracted driver behavior and its impact on pedestrians could be further studied. According to Wierwille et al. [32], the driver distraction status can be divided in two main types: visual and cognitive. In the future, we could set up more distracted driving scenarios based on two types of driver distraction and study on their impact on pedestrians’ experience.

As autonomous driving systems become more and more advanced, they could make smarter decisions than human drivers. The conflict between driver and vehicle may happen quite often in the conditionally and highly autonomous driving context. We wonder how will pedestrians react in different kinds of driver-vehicle conflict scenarios. For example, if the vehicle displays “Don’t cross”, and the driver suggests pedestrians to cross, how will pedestrians react? If pedestrians always listen to driver, there would be a potential risk for them because sometimes the driver could be wrong. Therefore, more realistic conflict scenarios could be found and studied in the future.

Complicating things even more, social expectations on how drivers should behave will be dramatically different from place to place, culture to culture. Pedestrians’ experience regarding to same driver behavior will differ in different culture context. So the future study could involve more culture-based investigation, and enable to answer questions like “What are the similarities and difference of pedestrians’ experience towards certain driver behavior within different culture?”, “If there are conventionalized gestures for interaction of pedestrians with autonomous vehicles?”

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REFERENCES

[31] Louis B Weexner. 1954. The degree to which colors (hues) are associated with mood-tones. Journal of applied psychology 38, 6 (1954), 432.