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Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment

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ABSTRACT

The aim of this research was to identify potential external features on a fully autonomous vehicle (FAV) and investigate which features would help pedestrians to understand the intended behavior of a FAV at a crosswalk, improve their receptivity toward FAVs, and affect their crossing behavior. In the case of a FAV, technology may be primarily responsible for control of a vehicle, and therefore, interpersonal communication is not possible. The researchers wanted to identify potential interface/s on FAVs to make pedestrian-FAV interaction positive, in which pedestrians receive a clear message about the vehicle's intended action. In an experimental study, thirty participants walked across a virtual crosswalk in front of a FAV. Four visual and four audible features were tested. At the beginning of the study, the participants responded to a baseline receptivity survey, and at the end, they replied to a demographic questionnaire and a pedestrian behavior questionnaire, gave ratings for the features, and completed a personal innovativeness scale and an after-study receptivity survey. Crossing time and waiting time were collected from the simulator data. The results showed that pedestrians' receptivity toward FAVs significantly increased with the inclusion of external features. A walking silhouette or 'braking' in text were the most favored visual interfaces, while a verbal message was found to be the preferred audible feature. Females and people from 30+ age group reacted the most positively to the features. Those pedestrians who often commit errors or who show aggressive behaviors toward other road users rated the implementation of FAVs poorly, even with the external features. On the other hand, pedestrians who intentionally violate traffic rules and those who get distracted on the road were found to be more cautious in the presence of FAVs and appreciated the inclusion of the external features.

1. Introduction

Once road-users enter the road network, they start a constant exchange of information with the traffic environment and other road-users around them in order to be ready to respond immediately. Drivers use various formal and, in some cases, mandatory methods to communicate with other road users, for example, turn signals, brake lights, and emergency lights. Along with these formal methods, many informal methods are often used to communicate with other road users: eye contact, facial expression, and hand gestures (Charisi et al., 2017; Šucha, 2014).

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Table 1
SAE proposed levels for vehicle automation. Source: SAE International (2014).

SAE levels for vehicle automation		Description
SAE Level 0	No automation	Human driver performs driving task even when equipped with warning and/or intervention systems
SAE Level 1	Driver assistance	Human driver performs driving task with the help of one driver assistance system of either steering or acceleration/deceleration
SAE Level 2	Partial automation	Human driver performs driving task with the help of one or more driver assistance systems of both steering and acceleration/deceleration
SAE Level 3	Conditional automation	Automated driving system performs mode-specific driving; however, the human driver must be ready to take back control to a request to intervene
SAE Level 4	High automation	Automated driving system performs driving tasks, even if a human driver does not need to take back control to a request to intervene. However, the automated system can operate only in certain environments and under certain conditions
SAE Level 5	Full automation	Automated system performs all driving tasks, in any environment and under all conditions that can be conducted by a human driver

In this era of advanced automated technology, automated vehicles at different levels (See Table 1) are expected to dominate the future transportation system. A fully autonomous vehicle (FAV) is categorized as level 5 vehicle automation technology that operates independently by means of software and hardware instead of a human driver and executes all safety-critical driving tasks for an entire trip. With a FAV, other than providing navigation input, human operators and/or passengers are not expected to take control of the vehicle at any time during the trip. While on the road, these vehicles will communicate with road users through formal means only; interpersonal interaction will not be possible. Among road users, this change will be hardest for pedestrians who are among the most vulnerable and who often assure their safety by interacting with vehicle operators while crossing a road using informal modes of communication; for example, eye contact or hand gestures (Llorca et al., 2011; Mirnig et al., 2017). Interpersonal interaction can offer a sense of road safety that technology is not currently able to provide. At least in the initial stages of FAV's implementation, pedestrians' sense of comfort may be challenged because of trust issues with this new and unproven technology. A survey study revealed that inability to establish interpersonal communication is one of the major reasons for an increase in perceived risk for the vulnerable road-users (pedestrians and bicyclists) when interacting with autonomous vehicles (Bikeleauge, 2014). Therefore, it is necessary to find a way for pedestrians to interact with a FAV. Recent research in this area has introduced different modalities of communication: visual intent displays or projections (Deb, Warner, Poudel & Bhandarib, 2016; Clamann, Aubert, & Cummings, 2017; Fridman et al., 2017; Mahadevan et al., 2018), auditory signals (Deb et al., 2016; Mahadevan et al., 2018), and physical prototypes using a robotic hand (Mahadevan et al., 2018) or humanoid robot (Mirnig et al., 2017). Most of these studies used picture and/or video-based surveys (Deb et al., 2016; Fridman et al., 2017) or real-world experiments (Clamann et al, 2017; Mahadevan et al., 2018). However, participants' exposures in a traffic environment with the threat of being hit by a vehicle may change their perceptions to a great extent. A real-world controlled experiment or a picture or video-based survey cannot create that threat.

This study used virtual reality (VR) to perform an experiment in a simulated traffic environment in which participants interacted with a FAV, equipped with external features, at a virtual crosswalk. The study was designed to (i) identify potential interface designs for FAV-pedestrian interaction and (iii) investigate which designs would allow pedestrians to understand the intended behavior of these vehicles at a crosswalk, improve their receptivity toward FAVs, and influence their crossing behavior accordingly. Deb, Carruth, Sween, Strawderman, and Garrison (2017) validated the VR platform used in this study for pedestrian safety research. The validation confirmed that pedestrians responded similarly in the VR traffic environment, as they would do in a real traffic environment. In order to keep participants only focused on the interface designs, the researchers chose to use FAV in this study, which can be operated by without any human operator. There was no option for interpersonal interaction with the vehicle, as the vehicle did not have any human operator.

2. Literature review

2.1. Interfaces for human-computer communication

Communication between computers and humans occurs through an interface designed to transmit a message from a computer to a human (Kammersgaard, 1988; Lancaster & Warner, 1993). The human, based on his/her recognition and understanding of the content of the message, validates its authenticity and interprets it as information or a request to perform a simple action. In the past, computer-human interfaces were not required in traffic for vehicle-pedestrian communication due to the presence of a human driver. With the advent of autonomous vehicles, this necessary communication must occur through designed interfaces. For consistency in the traffic system, interface designs supporting pedestrian safety and comfort should incorporate existing and familiar traffic components (signs, signals) or communication methods (smiles,