Pedestrians-Automated Vehicles Interaction: Toward a Specific Trust Model?

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Abstract. According to Hoff and Bashir (2015), who developed a theoretical model of trust in automation, this study deals with pedestrians' adoption of automated vehicles (AVs) and their trust in the AVs. External HMI (Human Machine Interface) integrated into AV is known to increased pedestrians' trust during road crossing. To empirically apply this model and evaluate the trust potential of eHMI's, we conducted a study with 49 participants in a virtual reality environment. The study manipulated two factors: vehicle type (conventional, automated, and automated with eHMI) and road infrastructure (unmarked, pedestrian crossing with and without traffic lights). Participants self-rated their trust in automation before and after the study. Trust and emotions were retrieved after each road crossing. Preliminary results indicated a positive impact of eHMI on pedestrian's behaviors, trust and emotional levels. Infrastructure was also enhancing positive emotions and trust. During an uncertain situation such as pedestrian crossing, pedestrians felt more control with a conventional vehicle than an automated vehicle. The theoretical application of Hoff and Bashir's model is discussed regarding the results. Further research is needed to clarify dynamic contexts' implications and eHMI efficiency on automation trust.

Keywords: Automated vehicles · Trust in automation · External communication display · Pedestrian-vehicle interaction · Emotion · User study

1 Introduction

This communication is part of prospective ergonomics research on the future interaction of trust between pedestrians and automated vehicles. From a theoretical point of view, this work applies the theoretical model of Hoff and Bashir (2015) on trust in automation. The aim is to empirically measure its relevance and adapt it to dynamic contexts of human-machine interaction. Concretely, this approach involves measuring the effectiveness of the human-machine interfaces of automated vehicles on the crossing activity, the emotional and trust feelings to guarantee pedestrians' safety in this interaction.

The integration of automated vehicles (AVs) aims to make roads safer, regulate traffic by clearing throat, and reduce accidents. To achieve these objectives, it must integrate

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into the urban environment and ensure secure interactions with vulnerable road users, in particular pedestrians. As such, there is growing interest in how VAs (Level 4/5, Society of Automobile Engineers) should communicate and interact with pedestrians in urban settings [2]. Indeed, road users' problems can arise when the different protagonists of a given situation act according to diverging formal or informal traffic rules. Since the machine cannot predict human intentions, it is essential to establish a dialogue and a relationship of trust to guarantee both the objectives and the safety of the protagonists. Communication of vehicle intentions can be done by explicit means (e.g., turn signals) or implicit means (e.g., deceleration). To meet this goal, automakers and researchers have explored traditional methods of explicit communication. They used various external human-machine interfaces (eHMI) to communicate with pedestrians, such as screens, a smile, a hand, or even an LED strip (see review of [3]). Current research has shown that these eHMIs integrated with AVs can help pedestrians make safer crossing decisions, while in contrast, others have not found conclusive behavioral improvements and claim that HMIs are unnecessary. Research shows that the information implicitly communicated by vehicle behavior, such as deceleration [2], and sometimes road infrastructure (e.g., pedestrian traffic lights), would be sufficient to communicate the intentions of the vehicle and allow a safe and appropriate interaction with pedestrians [4]. However, the fundamental problem in designing useful and acceptable systems is in the trust that humans place in robots. Beyond the lack of a user-centric approach to the design of these HMIs [5], few studies have assessed their potential gain in terms of trust in such interactions.

Thus, trust is an essential condition of the relationship between partners, human or with artificial. Trust in the machine influences an individual's decision to use it or not [6]. It is a dynamic process in which each actor "considers the other as a resource capable of preserving their interests in a given situation" [7]. Hoff and Bashir (2015) proposed a trust model specific to the relationship between humans and automation comprising four levels of trust: dispositional, situational, and learned trust - initial and dynamic -. **Dispositional trust** is the general tendency to trust automation, referring to variations in culture, age, gender, and personality traits. **Situational trust**, on the other hand, is specific to the "context of interaction". Indeed, if the environment exerts a strong influence on situational trust, the individual's mental state can affect this trust in the situation. Finally, the **initial learned trust** is based on the preliminary knowledge of the system, whether or not it has come from previous experiences (for example, the reputation of the system's brand). Then, new knowledge is continuously created during the first interaction and feeds the so-called "**dynamic learned**" trust in the system. Experience is at the center of many decision-making models, particularly in the three levels of Rasmussen's double scale [8]: the "Skill-based" level (Skill-based behavior), the "Rule-based" level (Rule-based behavior), and the "knowledge-based" level (knowledge-based behavior). Hence, situational trust and learned trust - initial and dynamic - are closely related. The distinction between these three levels of trust depends on the perceived relevance and perceived usefulness of certain information to the individual. In short, the four levels of trust; dispositional, situational and learned - initial and dynamic - are interdependent. They are influenced by the environment and the individual's subjective perception resulting from his knowledge and experiences with the automated system.

All in all, the trust would be a dynamic process explicitly linked to the context, which is marked by the characteristics of the automated system, by the characteristics and knowledge - prior and learned - of the individual. However, this model is based on fixed human-machine interactions (e.g., computer), and since its creation, it has not been empirically proven in a dynamic interaction situation such as in the road environment [9].

1.1 Research Objectives

Establishing a situation of trust with pedestrians is crucial for the integration of automated vehicles into traffic. Little studied, this trust is identified as a critical factor influencing the use of an automated vehicle [10] and especially uncertain situations [11] such as crossing a street. To satisfy this, explicit communication by external HMI integrated into AVs has been one of the avenues most explored by the automotive industry. However, additional new empirical evidence is needed to clarify their impacts on pedestrian safety. The objective of our work is thus twofold.

On a practical level, this involves measuring the effectiveness of the eHMI integrated into the automated vehicle on pedestrian crossing activity, with a double vision both on the crossing behaviour and the levels of emotions and trust of pedestrians. We hypothesize that AVs' eHMI communication affects the behavior and emotions of pedestrians as they cross.

On a theoretical level, it contributes to the validation and adaptation of Hoff and Bashir's theoretical model for dynamic man-machine interaction contexts, with a particular focus on the situational and dynamic trust learned. We hypothesize that applying the theoretical model in a dynamic context will allow the model to evolve towards a more realistic representation of dynamic human-machine interaction contexts.

To achieve these goals, pedestrians were confronted with conventional vehicles (CVs), AVs and AVs equipped with eHMI (eHMI-AV) with three different crossing configurations (i.e., without pedestrian crossing, with pedestrian crossing with or without infrastructure). After each crossing, the pedestrians self-assessed their level of trust and their emotions.

2 Method

Participation in the study was open only to people with valid driving licenses and had normal vision. A set of data collected from 49 participants (24 females and two age range; 20–35 years and 45–60 years) were analyzed (M = 41.02, SD = 12.3; age range = 20–60 years).

The participant was seated in front of a computer placed 2.5 times the 'screen's size and moved around the virtual environment using an Xbox controller joystick. The virtual city was modeled in 3D via *Unity* with conventionals or automated vehicles. It consisted of four intersections and five buildings of interest, which he could enter to answer questionnaires projected on one of the entrance hall walls.

Counterbalanced, each participant crossed in front of 5 different vehicles: a conventional vehicle (CV; with a driver's avatar looking at the front), an automated vehicle without eHMI (without-eHMI-AV), and three automated vehicles with an eHMI (eHMI-AV) by LED strips, pictograms, or diffused LED net. These three communication systems result from a preliminary study that combined approaches through interviews, focus groups, questionnaires, benchmarks, and co-design. All vehicles were programmed to slow down as soon as the pedestrian reached the sidewalk (4 s of time gap) and stopped in the same way. The eHMIs displays four messages “I m starting”, “I am driving”, “I slow down to stop,” and “I am stopped and patent” and, depending on the road configuration (presence or absence of pedestrian) and road regulations (e.g., red light). The participant will be confronted with different signaling levels to cross: pedestrian crossing with lights (PCL), pedestrian crossing without lights (PC), and no infrastructure (n).

Participants answered several questionnaires throughout the study and end with an individual interview. In the first phase, participants filled socio-demographic information. Initial and learned trust in automation was also measured using the same questionnaire before and three weeks after the study (*Trust in Automation Scale*; [12]). Trust in drivers was also measured before the study with an adapted version.

On the day of the study, participants read and accept the free and informed consent form. They are then invited to participate in a familiarization phase with the equipment of about ten minutes (i.e., controllers). The participant performed three virtual reality immersion sessions of approximately 25 min. Each session aims to test an eHMI (LED strip, pictograms, LED net) whose meaning has been learned beforehand. A session is made up of 5 crossings. Participants are invited to go to 5 buildings to act to verify a fire extinguisher’s presence. The path they take requires them to cross the road between each building once. As soon as they enter a building located immediately after crossing, the participants responded orally to a questionnaire on their perception of the vehicle encountered before the crossing (e.g., identifying the type of vehicle, understanding the messages if applicable; Fig. 1). In terms of trust, emotions according to the three valence/activation/control scales from the Self-Assessment Manikin [13]. The questions about trust and emotional feelings were visual analog scales answered by line bisection on paper.

Question 9

De manière générale, je me suis senti(e)...

Fig. 1. On the left an example of an encounter’ scene between the pedestrian and an AV without HMI at a pedestrian crossing. On the right an example of the general trust measurement.

Crossing behavior in front of or behind the vehicle was counted to assess the importance of avoidance, reflecting suspicious behavior depending on each vehicle. The semi-guided interview was composed of open questions to collect participants’ opinions on their experiences with automation, eHMIs, their crossing strategies, and their immersion levels. The study lasted on average of 2 h and 30 min.

3 Preliminary Results

In overall analyzes, there are no significant differences between age or gender. Initially, participants felt less trust in drivers than for AVs ($M_{\text{drivers}} = 2.68$; $M_{\text{AVs}} = 4.08$ out of 7; $t(49) = -10.38$, $p < .001$). Participants had a high trust level (i.e., initial) in automation that did not increase significantly after the study ($M = 4.49$ out of 7; i.e., learned).

From a frequency table of crossing's behavior, the behavior of skirting the vehicle from the rear appeared significantly more frequently when pedestrians encountered vehicles without an eHMI (i.e., without-HMI-AV and the CV) than when it was equipped with eHMI ($N = 721$; $\chi^2 = 12.959$, $p < .001$).

During the crossings, the participants had dynamic trust levels modulated by road infrastructure ($N = 49$; $\chi^2 = 50.0$, $p < .001$). The more guided infrastructure, the more the trust increased ($p < .001$ for all comparisons).

The pedestrians' trust in our sample was influenced by the type of vehicle encountered ($N = 49$; $\chi^2 = 41.3$, $p < .001$). Pedestrians were significantly more trustful when encountered an eHMI-AV than a CV, and even less without an eHMI on the automated vehicle ($p < .05$ for all comparisons). Participants' emotions were also influenced by the type of vehicle (respectively; $N = 735$; $\chi^2 = 38.5$, $p < .001$; $N = 735$; $\chi^2 = 34.9$, $p < .001$; $N = 735$; $\chi^2 = 13.7$, $p < .001$). Without HMI, the AV induced a greater intensity, more negative emotions, and a lower emotion of control than the CV or the eHMI-AV ($p < .001$ for both comparisons). Pedestrians felt similar emotional levels when confronted with eHMI-AV and CV ($p = $ ns).

The crossing analysis with infrastructure's level showed a difference in pedestrian's emotions between AVs and CV ($N = 49$; $\chi^2 = 13.7$, $p < .001$). At the pedestrian crossing without lights, participants had a better sense of situational control confronting a conventional vehicle than an AV (i.e., with and without eHMI; respectively, $p < .05$ and $p < .001$).

4 Discussion

The present study is based on Hoff & Bashir's (2015) model in evaluating the effectiveness of automated vehicles equipped with eHMI on the crossing activity and the feelings - emotional and trust - of pedestrians. These first results underline the need for clear communication from AVs to improve pedestrians' feelings of trust and safety in their future crossings. They also indicate behavioral modifications of pedestrians.

Consistent with Hoff and Bashir's model, dynamic trust was influenced by system characteristics, infrastructure, and prior knowledge (e.g., verbatim: "I was suspicious of the driver, I know they drive like crazy."). During the interaction, trust level has mainly been modulated by an HMI's addition to the system to achieve a similar level to that obtained with vehicles with a driver. These results are consistent with current research, which shows an increase in trust when AVs are equipped with a communication HMI [14].

Likewise, confrontation with an automated vehicle, whether or not equipped with an HMI, changed pedestrians' behavior during their crossings. Without HMI, AV caused more avoidance behavior in the pedestrians of ours sample. With the HMI, this behavior was significantly less than those seen with a conventional vehicle. In line with previous results, the eHMI would facilitate the crossing of pedestrians [15] since it will make it possible to defuse, just like the non-verbal communication of current drivers [16], situations of uncertainty, and will allow pedestrians to anticipate their crossing [17].

The street-crossing is one of those uncertain situations from a pedestrian's perspective since drivers do not always yield to them. Across three European countries, Lee et al. [18] demonstrated that 36% of observed drivers did not allow pedestrians to cross at pedestrian crossings. Our results showed that pedestrians perceived a better control sense at the pedestrian crossing in front of a conventional vehicle than with automated vehicles. We attribute this result to the participants' low level of familiarity with the automated vehicle. The vast majority of respondents (79%) said they were not familiar with automated vehicle technologies. Not having defined automated vehicles and their behavior to participants is one of our observations' limits. It would have modified the results since prior knowledge of the system is a situational factor influencing trust in automation [1].

Contrary to what was expected, there was no significant change in the level of trust in AV after the study. Also, although the drivers' initial trust level was lower than that in the automated vehicles, this difference was not observed in the results. We assume that this high level of initial/learned trust and these deviations from measurements are related to the current over-trust phenomenon in automation [19] and the difference in quality with the natural situation caused by the virtual reality method. Note that the small number of participants did not allow any conclusion on the impact of dispositional factors such as gender or age.

From a theoretical point of view, applying the model of Hoff and Bashir (2015) in a dynamic context made it possible to specify the effective inter-level influences during human-machine interaction. Given the preliminary results, the interconnection between situational trust and learned trust - initial and dynamic - seems to be the critical point in understanding the dynamics of trust in automation in a dynamic environment. However, these results do not allow us to claim an adaptation of Hoff and Bashir's theoretical model for dynamic human-machine interaction contexts.

Thus, the study of the relevant elements [19] - before and during - the interaction with automated systems is of paramount importance in a dynamic context, especially when it has an adverse potential for users. We encourage future research to apply and test this theoretical model in dynamic contexts to refine the understanding of trust in automation and ensure users' safety. Real-life research could clarify the effectiveness of these HMIs on the real activity of pedestrian crossing and guarantee their future safety when being confronted with automated vehicles.

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