Instruction or intention? Investigating eHMIs' Intuitiveness as Allocentric or Egocentric Messages for different Light Animations, Road Priorities and Vehicle Behaviours.

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Keywords:, Automated Vehicles, AVs, eHMIs, Human-Computer Interaction, Pedestrians, VRUs

1. INTRODUCTION

Transitioning to Automated Vehicles (AVs) is predicted to lead to significant social changes besides technological innovation, with the responsibility of communication shifting from the car occupant to the vehicle itself (Clamann et al., 2017). Research recognises the road as a social environment where non-verbal implicit and explicit communication cues are exchanged between road users, which support informal interactions and help resolve traffic conflicts (Hermann et al., 2018; Markkula et al., 2020). Evidence shows that when pedestrians decide to cross the road they often rely on visual information including eye contact with the driver (Guéguen et al., 2015; Rasouli et al., 2017), from which they can infer important clues e.g. whether they have been detected, if the driver intends to give them right of way, as well as vehicle's behavioural cues i.e. speed and deceleration (Ackermann et al., 2019).

In order to ensure smooth coordination between pedestrians and automated vehicles, research has emerged around AV's external Human Machine Interfaces (eHMIs) which can be designed to communicate the vehicle's intended actions. When it comes to deciding eHMI's message content, experts suggest that messages which implicate an instruction to cross (egocentric messages i.e. from the pedestrian's perspective) should be avoided and messages which communicate the AV's intentions (allocentric messages) are to be preferred instead (Bazilinskyy et al. 2019; Habibovic et al., 2018). One of the reasons behind this, is that eHMIs should only be supporting pedestrians' judgement, leaving them in charge of making safe crossing decisions. Additionally, it is possible for the message to be received by the wrong road user leading to potentially dangerous scenarios (Dietrich et al., 2018).

It is yet unclear if the context in which an eHMI is presented can dictate the extent to which the message is perceived as an instruction or an intention as well as the message intuitiveness. This paper presents the results from an online survey study where the intuitiveness of intention and instruction messages for different light-based eHMIs were evaluated across different scenarios varying for road priority, message design and vehicle's behaviour.

2. METHOD

2.1 Design

The study was conducted with a within-subject design with four independent variables. These were: *eHMI light pattern* with three levels (fast pulsing (2.0 Hz), slow pulsing (0.4 Hz) sweeping (3s)), *road priority* with three levels (pedestrian has priority, vehicle has priority, undefined priority), *vehicle behaviour* with two levels (vehicle is stationary in proximity of the crossings, vehicle is decelerating while approaching the crossing) and *message type*, with two levels, egocentric message ("safe to cross") and allocentric message ("I am giving way"). Similar messages were investigated by Dey et al. (2020) for different eHMI colours and animations. The decelerating distance, within six metres from where the pedestrian would be standing, was based on rule 126 of The Highway Code (GOV.UK, 2021). Score of signal intuitiveness rating constituted the independent variable, which was measured on a Likert scale of 1 to 5, with 1 being "Not intuitive at all" and 5 meaning "Completely intuitive". Open-ended questions were asked at the end of the survey to investigate participants' views on what contributed in the presented scenarios to a signal being more or less intuitive as intention or instruction information.

2.2 Experimental setup

An online survey was developed where participants were shown animations for a total of 36 different road scenarios, created from the four independent variables. Participants were told that they would be presented with different animations featuring an AV which would have either reached a standstill, or still be approaching the crossing, in both cases intending to stop for the pedestrian. No speed information was provided in the survey (i.e. the vehicle was shown as stationary), to avoid the intuitiveness ratings being influenced by this additional factor. A brief introduction to AVs was provided at the beginning of the survey and a description was given for each scenario, where the supposed meaning of the eHMI was shown either in the form of an instruction or in the form of an intention, followed by the intuitiveness rating scale. The order of scenarios and messages was randomised to reduce the potential for confounding effects. The vehicle, an Audi A7, was modelled in Solidworks 2020, and the animations were created using Luxion KeyShot 2020 and Autodesk Maya 2019.

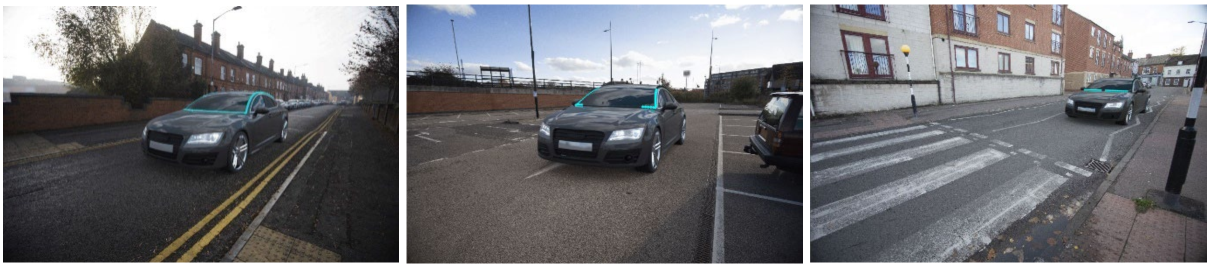

Figure 1: Examples of the scenarios presented to the participants.

Photos were used as backgrounds, to provide the context for the different scenarios, which were taken at selected locations in the town of Loughborough, UK. A Sony A7ii. was used to take the photos, with a 12mm f/2.0 lens which made it possible to capture a wide shot of the road site.

The light patterns have been adapted from those investigated by Lee et al. (2019) and Dey et al. (2020) and were shown in turquoise colour, RGB (0,255,255) as this has been found to be neutral in the context of AV's eHMI, for it has not any associated meaning in current traffic (Faas & Baumann, 2019; Dey et al., 2020).

It should be noted that the study had been designed originally as a field experiment. However, due to the Covid-19 pandemic, it was adapted to be carried out as a survey instead. Using photos of existing road sites, made it possible to retain a higher level of realism in the animations.

2.3 Participants

Ninety-six participants took part in the study (ages 18-64 years, mean age = 31.41 years, *SD*=11.72). The sample included 57 women (59%) and 39 men (41%). Responses by seven participants were excluded from the analysis as they failed to answer the consistency check questions correctly, and therefore a total of eighty-nine participants were included in the analysis. All participants had normal or corrected-to normal vision and lived in the UK. Participants were recruited through different online and social media advertising. and incentives were offered in the form of a £10 Amazon Voucher assigned randomly to four participants.

The study protocol was reviewed and approved by the Loughborough University Ethics Human Participant Sub-Committee. All participants provided informed consent to take part in the study.

3. RESULTS

A repeated measures ANOVA was performed on the data to examine the effect of light animation, message type, vehicle behaviour and road priority on eHMI intuitiveness ratings. Post-hoc pairwise comparisons were performed where significant effects have been found and interaction effects were investigated for the message variable interaction with the other variables. A Bonferroni correction was applied. The statistical analysis was carried in SPSS Statistics (Version 25) and statistical significance was set at p≤0.05 level. Quotes from the participants answers to the open-ended questions are also reported.

3.1 Effect of Road priority, Vehicle Behaviour and Light Pattern on eHMI Intuitiveness Ratings

There was a statistically significant effect of vehicle behaviour and light animation pattern on the eHMI intuitiveness ratings, $F(1, 88) = 20.46$, $p < .001$, $\eta_p^2 = .19$, $F(2, 176) = 20.26$, $p < .001$, $\eta_p^2 = .19$ respectively. Mean intuitiveness ratings for a stationary vehicle in proximity of the crossing were higher than for a moving vehicle approaching the crossing from a distance, respectively 3.07 (*SD* = 1.22), 3. 34 (*SD* = 1.23). Some participants explained that the vehicle being stationary, as well as it being in proximity to the crossings, made it clearer that the vehicle intended to give them right of way. The following comments illustrate this point: "*the vehicle needs to have stopped completely to send a message*", "*If the vehicle is still moving, it is not sending the message 'safe to cross'*", and "*(the) lights gave me more confidence when the car was stopped close to a line*". For some, an eHMI presented for a vehicle which was still approaching the crossing, especially a fast pulsing light, denoted a decelerating behaviour rather than an explicit indication that the vehicle was intending to give way as the following comments explain "*higher frequency signify `some action` going on - in this case slowing down*", "*more constant light pattern but when its faster its more intuitive of a vehicle moving but slowing down".*

The pairwise comparisons between the different light patterns, revealed that the fast-pulsing light animation scored significantly higher intuitiveness ratings (*M* = 3.56, *SD* = 1.24) compared to the slow-pulsing light animation (*M* = 2.94, *SD* = 1.16), *p* <.001 and the sweeping light animation (*M = 2.90, SD* = 1.21), *p* <.001. No significant differences were found between a slow pulsing light and a sweeping light. Opinions differed on signal preference; pulsing lights, fast or slow, seemed to appear more intuitive to the majority of participants compared to the light moving sideways which was associated to a different meaning i.e., "*the vehicle is looking around*" "*is scanning and observing the environment*". Elements which were particularly appreciated about the fast pulsing lights were their constant and dynamic pace, the higher visibility, and the familiarity with existing road communication strategies. Below are some examples of comments which elucidate these aspects. "*a more continuous and faster paced light sequence makes it easier to understand*", "*any signal needs to be quick to spot for everyone, out of the three signals only one conveys this: the signal that blinks quickly*", "*faster flashing lights made it easier to see the car was signalling and the situation was clear what the car was saying*". *"(the fast pulsing light) is more like what cars do in everyday life when they let you cross*", "*while it is not part of the DVSA test, common practise for allowing someone to pass is to flash your head lights at them*".

The flashing light was also perceived as delivering a stronger message "*to me, the speed of the flashing gave a stronger message that it was safe to cross*" implicating for some an urgency to cross the road "*faster implies 'hurry up'*", *"the faster lights just made me feel hurried"* and "*fast flashing feels like a sense of urgency*". On the other hand, a slow pulsing pattern was appreciated for conveying a sense of calm and an intention to wait as the following comments highlight: "*slow and gentle flashes or motion indicate safety*", "*the slow pulsing light looks like a calmer message so to me it looks like could communicate a giving way message to the pedestrian*" and "*I think a calmer pace of lights, to indicate the car is not planning on going anywhere".* Road priority did not have a statistically significant effect on eHMI intuitiveness ratings, $F(2, 176) = .36$, $p = .695$, $\eta_p^2 = .004$. Almost no reference to road priority was made by participants when describing elements which contributed to signal intuitiveness. Only one respondent reported "*in the carpark is the worst as it could mean anything - the car could be about to make numerous manoeuvres*". A participant also reported "*personally, the variation in the scenarios didn't matter too much to me - my view on whether to proceed as a pedestrian would always be based on what I thought the vehicle was doing*".

3.2 Effect of Message type on intuitiveness ratings

Message type did not have any significant effect on eHMI intuitiveness ratings, $F(2, 176) = 1.98$, $p = .141$, $\eta_p^2 = .052$ and the interaction between message type and vehicle behaviour, light animation and road priority did not have any significant effect on eHMI intuitiveness ratings, $F(1, 88) = 1.97$, $p = .164$, $\eta_p^2 = .024$, $F(2, 176) = 1.98$, $p = .141$, $\eta_p^2 < .023$, $F(1.78, 156.99) = .26$, $p = .772$, $\eta_p^2 = .002$. respectively.

Participants' responses are in line with these results. In fact, similar statements were made for the two types of messages and participants indicated that they would find the same answer to be true for either message types as indicated by comments as "*same as above*" "*again*(...)", "*same as previous answer*".

4. CONCLUSION

The findings showed that eHMIs in the form of light animations can be interpreted equally well as instruction and intention messages for different light patterns, road priorities and vehicle behaviours.

Since independently of these different aspects, a message can be perceived as either egocentric or allocentric, as eHMIs are developed it might be wise to educate pedestrians about the capabilities and limitations of AVs, regardless of the concept design, to avoid creating erroneous expectations as well as overreliance on these signals when making road-crossing decisions. A recent study by Lee et al. (2021) showed how eHMIs can negatively impact pedestrians' exploratory behaviour when crossing, leading to less careful crossing practices. Also of concern is the potential for eHMIs to override existing regulations for different road priorities and become relied upon by pedestrians as official road signals in scenarios where the right of way is uncertain. More research is needed to investigate this further, for different traffic scenarios and eHMIs.

It would also be good practice to ensure that eHMIs do not convey a sense of urgency making pedestrians feel hurried or pressured to cross the road, while preserving eHMIs visibility. Research has shown that the presence of eHMIs can stimulate early crossing (Kaleefathullah et al., 2020), especially in the presence of a dynamic eHMI (Wilbrink et al., 2021), and quicker walking pace (Kooijman et al., 2019). Whether this could be due in part to pedestrians feeling pressured to cross the road or to how "strong" and authoritative a message is perceived has not yet been investigated. Research is needed to determine which elements, besides eHMIs pulsing pace in the case of light patterns, might have such effects.

The results also showed that a vehicle's proxemics and kinetics can be important cues for pedestrians when deciphering an AV's intentions. This finding is in line with previous research which indicates that vehicle behaviour and proximity to the pedestrian can impact message intuitiveness and meaning (Dey et al., 2020; Domeyer et al., 2019; Sripada et al., 2021). It is crucial that eHMIs are designed which reflect the vehicle's behaviour and are presented at the right point in time and space (distance from the pedestrian).

Finally, elements such as visibility and familiarity with existing road communication cues are contributing elements to message intuitiveness and should be considered when designing AV's messages to pedestrians.

A major limitation of the current study is the experiment being online. Although consistency checks were used to ensure that only participants who understood the questions correctly were included in the analysis, control over the quality of the responses is limited. A further limitation is the lack of other traffic participants in the selected scenarios. In situations with multiple road users, the presence of an eHMI for different conditions could be interpreted together with the surrounding traffic. Thus, multi-road user scenarios should be considered in future studies. More research is also needed to investigate whether eHMIs can have negative effects on pedestrians' behaviours and attitudes on the road.

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