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1 Pedestrian interactions with Automated Vehicles: does the presence of a zebra
2 crossing affect how eHMI and movement patterns are interpreted?

3

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14

15 Abstract

16 Previous research has shown that the use of an eHMI can lead pedestrians to make earlier, and
17 more, crossing decisions in front of an AV. However, there has been little exploration of the impact
18 of crossing infrastructure or AV approach direction on pedestrian behaviour. This CAVE-based
19 pedestrian simulator study investigated the individual, and combined, effects of a pedestrian
20 crossing, automated vehicle (AV) approach direction, AV yielding behaviour, and a novel external
21 Human Machine Interface (eHMI) on pedestrian crossing decisions at a four-way crossroads. Thirty
22 eight participants took part in a multi-method study consisting of a pedestrian simulator experiment,
23 an online interview, and a short questionnaire. The main independent variables were: (1) presence
24 or absence of a zebra crossing; (2) the direction from which the AV approached (oncoming/right); (3)
25 the AV's yielding behaviour (yielding/not yielding); and (4) the presence or absence of a light-based
26 eHMI. The AV's yielding behaviour was the most important source of information for pedestrians,
27 followed by the crossing infrastructure. Participants showed a greater willingness to cross in front of
28 yielding than non-yielding vehicles, and were more likely to cross in the presence of a zebra crossing.
29 The eHMI had the most impact in the absence of a zebra crossing, promoting earlier crossings, and
30 encouraging more participants to cross while the approaching AV was still moving. The results of this
31 study show the importance of eHMIs for situations associated with uncertainty about right-of-way
32 between an AV and other road users, and highlights the interaction between formal traffic
33 infrastructure and explicit forms of communication for future AVs. This knowledge increases our
34 knowledge of when and where explicit communication from AVs can reduce the likelihood of
35 pedestrian misunderstanding of AV intentions, thus reducing the likelihood of accidents occurring
36 around these vehicles.

37 **Keywords:** Human Factors, Automated Vehicles, eHMIs, Pedestrian Safety

38 1. Introduction

39 The introduction of increasingly automated vehicles (AVs) onto our roads is leading to a new set of
40 challenges for traffic participants. One of the key questions in this space is understanding how these
41 vehicles should interact and communicate with other road users in mixed traffic environments
42 (Fuest et al., 2018; Schieben et al., 2019). Video based studies of road user interactions with
43 automated shuttles have found that interaction requirements will vary across different
44 environments, with infrastructural factors such as road width, zebra crossing points, and traffic
45 direction having an impact (Madigan et al., 2019). The lack of any driver to communicate with will
46 also change the nature of these interactions (Velasco et al., 2021)

47 Studies of current road user interactions with conventional vehicles have shown that pedestrians'
48 understanding of a vehicle's intentions is strongly informed by implicit longitudinal cues such as
49 speed, time-to-arrival, and stopping distance, along with lateral cues such as lane positioning (Dey &
50 Terken, 2017; Lee et al., 2020; Rasouli et al., 2017; Rettenmaier et al., 2021; Sucha et al., 2017; Wang
51 et al., 2021). In addition, for slow-moving traffic, or when movement priority is unclear, human road
52 users also seek explicit communication from a driver, such as hand movements, head movements, or
53 flashing lights (Rasouli et al., 2017; Sucha et al., 2017; Uttley et al., 2020). However, at higher levels
54 of vehicle automation (SAE Level 4 and 5; SAE, 2018), where humans will not have control of the
55 driving task, this type of explicit communication may no longer be possible. Thus, OEMs and
56 researchers have been working on designing a range of externally presented communication
57 concepts for future AVs, to facilitate the communication capabilities of these vehicles with other
58 road users (e.g. Dey, Habibovic, et al., 2020; Fridman et al., 2017; Lee et al., 2019, 2021; see Figure 1;
59 Nissan Motor Corporation, 2015; Semcon, 2016; see Figure 1). These are collectively referred to as
60 external Human Machine Interfaces (eHMIs). Although there is debate around the best design
61 concepts, and ideal locations of these eHMIs, studies evaluating the efficacy of different colours for
62 visibility, discriminability and sense of safety have advocated the use of light based signals in

63 turquoise or cyan to convey messages from AVs (Faas & Baumann, 2019; Werner, 2018).
64 Organisations such as the International Organisation for Standardization (ISO/TC 22/SC 39/WG 8),
65 have adopted this research in their recommendations about how external communication for AV's
66 should be designed ([ISO], 2018; SAE, 2019; UNECE, 2019). Research studies have used a range of
67 these light-based signals to successfully communicate AV intentions in experimental studies (Lee et
68 al., 2021; Weber, Chadowitz, et al., 2019). However it is currently unclear whether the meaning of
69 these signals are intuitive and easily understood by human road users (Fridman et al., 2017; Lee et
70 al., 2021).



71
72 *Figure 1: Example of eHMI concepts from (a) [Jaguar Land Rover](#), (b) [Drive AI](#), (c) [Mercedes Benz](#), (d) [Semcon](#), (e) [Nissan](#)*
73 *[Motor Corporation](#), and (f) [interACT project](#)*

74 In the past five years, there has been a huge rise in the number of studies investigating pedestrian
75 responses to different eHMIs, with researchers conducting studies in virtual environments (Böckle et
76 al., 2017; Dey & Terken, 2017; Lee et al., 2021; Otherston et al., 2018), test tracks (e.g. Clamann,
77 2015; Habibovic et al., 2018; Horn et al., 2021), and real-world environments (e.g. Dey, Matviienko,
78 et al., 2020). While results have been mixed, there is an emerging consensus that pedestrians show
79 greater willingness to cross, and cross earlier, in front of a vehicle which includes an eHMI,
80 compared to no-eHMI conditions (Böckle et al., 2017; Deb et al., 2018; Dey, Matviienko, et al., 2020;
81 Holländer, Colley, et al., 2019). They also express higher levels of comfort, trust, acceptance,

82 receptivity, and perceived safety (e.g. Böckle et al., 2017; Deb et al., 2018; Holländer, Wintersberger,
83 et al., 2019).

84 To date, much of the research into AV-pedestrian interactions has focused on straight, one-way,
85 road environments, with no additional/supporting cues from road- and traffic-based infrastructure.

86 Currently, little is known about pedestrian decision-making during interactions with AVs at
87 crossroads or intersections, where the planned path of the vehicle may not always be clear.

88 However, a number of recent studies have begun to address this issue. For example, using a virtual
89 reality (VR) head-mounted display (HMD) study, Jayaraman et al. (2018) explored the impact of AV

90 driving style (defensive, normal, and aggressive) and type of pedestrian crossing (signalised vs

91 unsignalised) on pedestrians' ratings of trust in an AV. The driving style was manipulated by varying
92 whether the vehicle stopped (defensive), slowed down (normal) or continued at full speed

93 (aggressive) on approach to the pedestrian's position. Results showed that the impact of driving

94 style on propensity to trust was dependent on the type of crossing infrastructure present, with

95 pedestrians displaying higher levels of trust towards an aggressive AV when they were crossing at a
96 signalised crossing, compared to an unsignalised one. This study also reports a strong link between

97 subjective measures of trust, and trusting behaviours such as reduced distance between the AV and
98 pedestrian at crossing time, increased jaywalking time, and increased average waiting time.

99 However, there was no effect on average crossing time or speed. Velasco et al. (2019) conducted a
100 VR study using videos presented on an HMD, where pedestrians were presented with a series of

101 scenarios and asked to make a decision on whether or not they would cross the road. Results

102 showed that the presence of a zebra crossing and a larger gap size between the pedestrian and the

103 AV increased the pedestrian's intention to cross. Taken together, the results of these studies show

104 that the presence of supporting traffic infrastructure, such as a zebra crossing, can have an impact

105 on pedestrians' levels of trust and willingness to cross in front of AVs, particularly in situations where

106 they are reliant on the implicit cues of the vehicle. One recent study has also investigated the

107 potential impact of context on pedestrians' interpretation of and confidence in eHMI

108 communication. In an online, picture-based study, Eisele and Petzoldt (2022) explored the impact of
109 context on the comprehensibility and accuracy of response to three eHMIs. Context was
110 manipulated through the presence of traffic signals such as road markings and pedestrian traffic
111 lights, and the presence of other pedestrians who were acting in accordance with the relevant traffic
112 signals. Results indicated that relevant contextual information influenced the comprehensibility of
113 eHMIs, and that this was particularly beneficial at the first encounter. However, it is not yet known
114 how pedestrians use the combined information from explicit and implicit communication to inform
115 their crossing decisions. In addition, to date, there has been little investigation of how the direction
116 of approach of an AV affects pedestrians' crossing decisions.

117 The current study aimed to address this research gap by investigating the impact of an AV's implicit
118 cues i.e. speed and acceleration profile, and additional explicit messages from an eHMI in a number
119 of different traffic settings. Specifically, we investigated the individual, and combined, effects of a
120 zebra crossing, vehicle approach direction, vehicle yielding behaviour, and a novel eHMI on
121 pedestrian crossing decisions at a four-way crossroads. In the UK, regulations at the time of this
122 study meant that drivers were only required to give way when a pedestrian stepped onto a zebra
123 crossing, while pedestrians should not start to cross until vehicles on the road have stopped (RAC,
124 2021). However, in practice it is common for pedestrians to step out while approaching vehicles are
125 still moving. Thus the inclusion of an eHMI to clarify an AV's intention could help to improve the
126 efficiency of an interaction for both the vehicle and the pedestrian (Pekkanen et al., 2021). It was
127 anticipated that the crossroad junction scenario, where there is increased uncertainty about a
128 vehicle's intended trajectory, would provide further insights into the potential benefits of an eHMI in
129 clarifying an AV's intentions. Although there is much research outlining the potential benefits of
130 eHMIs in terms of changing pedestrians' attitudes and behaviours, as stated earlier, there is little
131 knowledge about the factors that improve the intuitive comprehension of these novel signals
132 (Fridman et al., 2017; Lee et al., 2021). Clearly, the more intuitive the message, the higher the
133 likelihood that an AV's intention is correctly understood and responded to by other road users; and

134 the impact of this seems to be most important for the first encounter with a novel vehicle (Eisele &
135 Petzoldt, 2022). Previous research has shown that the same eHMI format could convey different
136 messages equally well in a non-meaningful environment (Lee et al., 2019). Thus, a final aim of this
137 study was to investigate whether the traffic context and movement behaviour of an AV could effect
138 how quickly the meaning of messages conveyed from a novel, light-based, cyan eHMI can be learned
139 by crossing pedestrians.

140 2. Method

141 2.1 Participants

142 Following approval from the University of Leeds Ethics board (Ref: LTTRAN-107), 38 participants (20
143 female, 18 male) were recruited to take part in the experiment using a database of volunteers who
144 had signed up to take part in simulator studies. Participants' age ranged from 22 to 58 years
145 (M=33.82, SD=10.30). All participants had lived in the UK for a minimum of 1 year prior to
146 participation. 21 (71%) participants held a driving license, with an average driving experience of
147 15.04 years (SD = 12.13). Participants were given £30 for their participation in the experiment, which
148 involved one visit to the University of Leeds HIKER lab, two online questionnaires, and a short
149 interview.

150 2.2 Pedestrian Simulator Study

151 The experiment was conducted in the Highly Immersive Kinematic Experimental Research (HIKER)
152 lab at University of Leeds, a CAVE-based pedestrian simulator. The HIKER lab provides walking space
153 in a 9 m × 4 m room, formed by three glass panel walls and a wooden floor, which can present the
154 virtual road environment and respond to the pedestrians' position, using a set of body trackers and a
155 lightweight pair of glasses with integrated reflective trackers. The glasses provide appropriate visual
156 cues of the stereo virtual environment, adjusted to the pedestrians' height, and track the
157 pedestrians' head movements over time. Unity 3D software was used to incorporate the vehicle
158 parameters and pedestrian state into the virtual environment (see Figure 2).



Figure 2: The HIKER Lab showing the full room (left) and body trackers and glasses (right)

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The experimental scenario consisted of a crossroads in a residential area, where two one-way, single-lane roads met (3.6 metres wide, see Figure 3). Participants began the experiment standing at the edge of the road on the spot marked X in Figure 3. A single vehicle approached from either the pedestrian's right (marked A on the overhead schematic in Figure 3) or from the oncoming road (marked B on the overhead schematic). The pedestrian's task was to cross the road at any time they felt comfortable to do so. This could be before or after the vehicle had passed. Once a road crossing was completed, the trial ended and the pedestrian returned to the yellow X to start the next trial.



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Figure 3: Overhead schematic of the roadway design with blue and red arrows denoting the pedestrian's range of vision (left) and pedestrians' view of an AV approaching from the right (right). Pedestrians' starting position at the beginning of each scenario was marked with a yellow x. A broken white line was used to indicate that vehicles would have to stop at the junction.

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This study utilised a within-subjects, repeated-measures design, where all participants experienced 52 trials involving 4 independent variables (see Table 1) as follows:

- 175 • Zebra Crossing (present / absent),
- 176 • Vehicle approach direction (oncoming / right),
- 177 • Vehicle yielding behaviour (Yielding / Not yielding / No encounter i.e. AV does not enter
- 178 pedestrian's path),
- 179 • eHMI (present / absent).

180 The 52 trials were presented across two counterbalanced blocks. To reduce confusion for the
 181 participants all of the zebra-crossing trials were included in one block, and all trials without a zebra-
 182 crossing were included in the other block. The order of trials within each block was randomised.

183 *Table 1: Experimental Design - Number of trials in each condition*

Presence of Zebra	Vehicle approaching direction	Vehicle yielding behaviour	Presence of eHMI	No. of trials
Zebra	Oncoming	Yielding	eHMI	3
		Yielding	No eHMI	3
		Not Yielding	n/a	6
		No encounter	n/a	1
	Right	Yielding	eHMI	3
		Yielding	No eHMI	3
		Not Yielding	n/a	6
		No encounter	n/a	1
NoZebra	Oncoming	Yielding	eHMI	3
		Yielding	No eHMI	3
		Not Yielding	n/a	6
		No encounter	n/a	1
	Right	Yielding	eHMI	3
		Yielding	No eHMI	3
		Not Yielding	n/a	6
		No encounter	n/a	1

184

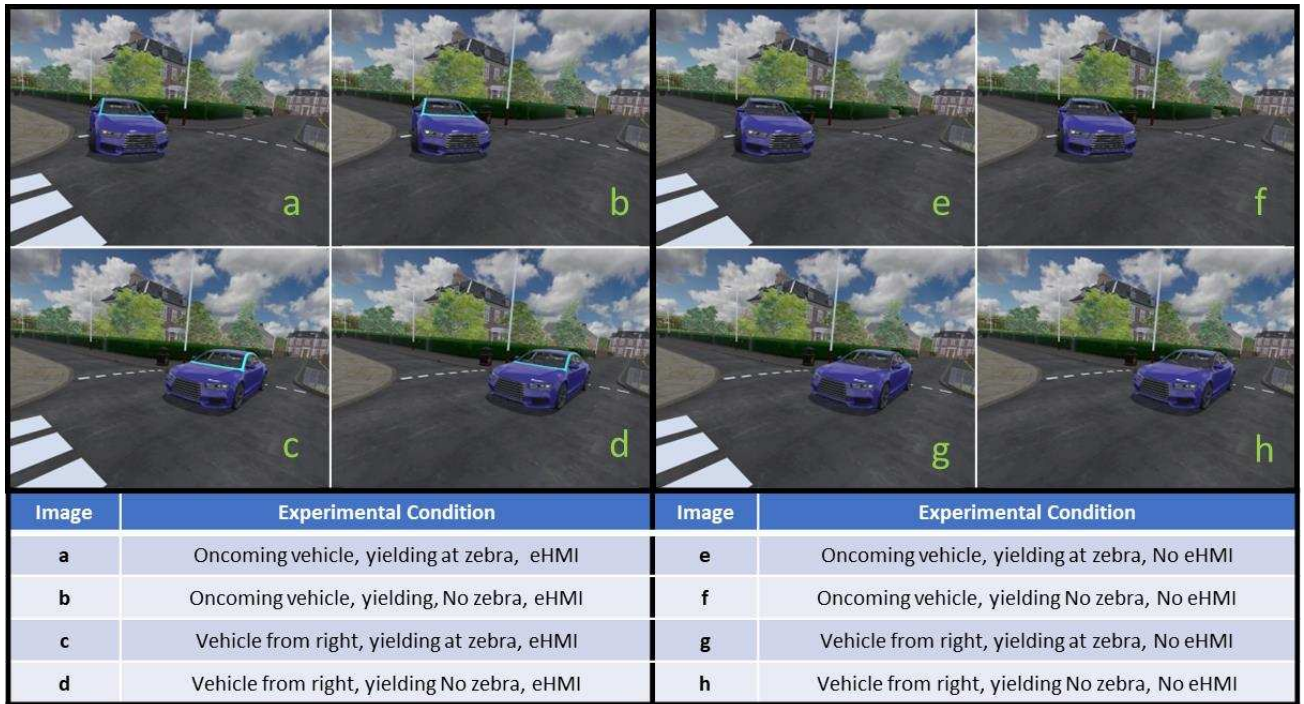
185 *2.2.1 AV Behaviour*

186 In this experiment, the AV either approached from the oncoming road (see Figure 3 and top images
187 in Figure 4) or from the pedestrian's right (bottom images in Figure 4). The initial approaching speed
188 was always 25 mph.

189 If the AV was approaching from the oncoming road, it always travelled in one of two directions: (i) it
190 turned right, intersecting pedestrians' crossing path (yielding or not, depending on the trial), or (ii) it
191 continued to drive straight through the intersection (no encounter). Similarly, for AVs which
192 approached from the right, they either (i) continued along the road, and therefore intersected with
193 the pedestrians' crossing path (yielding or not), or (ii) they turned left (no encounter). Table 1
194 provides an overview of the number of trials in each condition.

195 The aim of including "no encounter trials", was to include variability and reduce pedestrians' ability
196 to predict the AV behaviour. However, these trials were not included in the analyses. For those trials
197 where the AV did cross the pedestrians' path, 50% were yielding trials and 50% were non-yielding
198 trials. A turn indicator was used for all turning trials, and this was activated when the AV was 15 m
199 from the centre of the crossroads. All movement patterns of the oncoming and right vehicles were
200 designed to provide as realistic an experience for participants as possible. Thus, there were some
201 differences in how these vehicles moved which will be discussed in detail in the coming sections. The
202 eHMI used in this study was based on the design selected in the interACT project (see Weber,
203 Sorokin, et al., 2019) of a slow pulsing cyan light-band, presented at a pulsing rate of 0.4 Hz, and
204 placed around the front windscreen of the vehicle, as shown in the pictures on the left of Figure 4.
205 Depending on the angle of the vehicle, it was not always possible to see the whole of this lightband,
206 and the light at the side furthest away from the participant may not have been visible at all times.
207 This eHMI was switched on for the yielding trials as the vehicle started to move away from the
208 junction (more details in Section 2.2.1.1). A video showing all of the experimental trials can be
209 accessed at <https://youtu.be/1t1svxGlghk>.

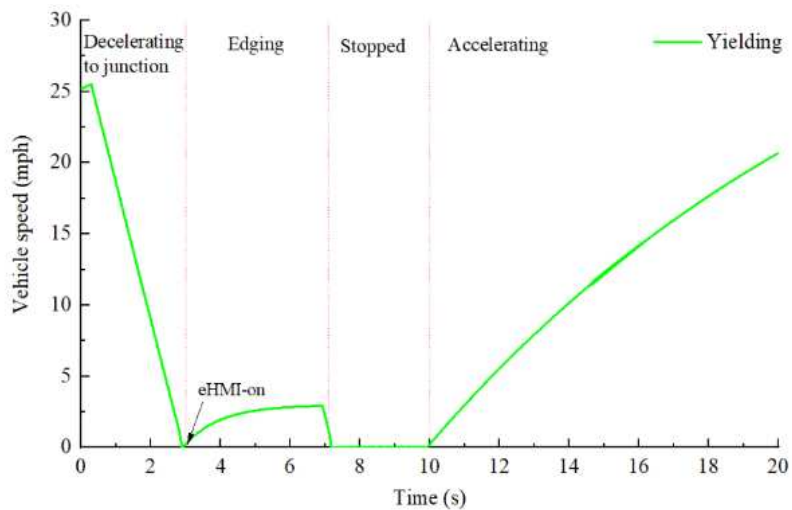
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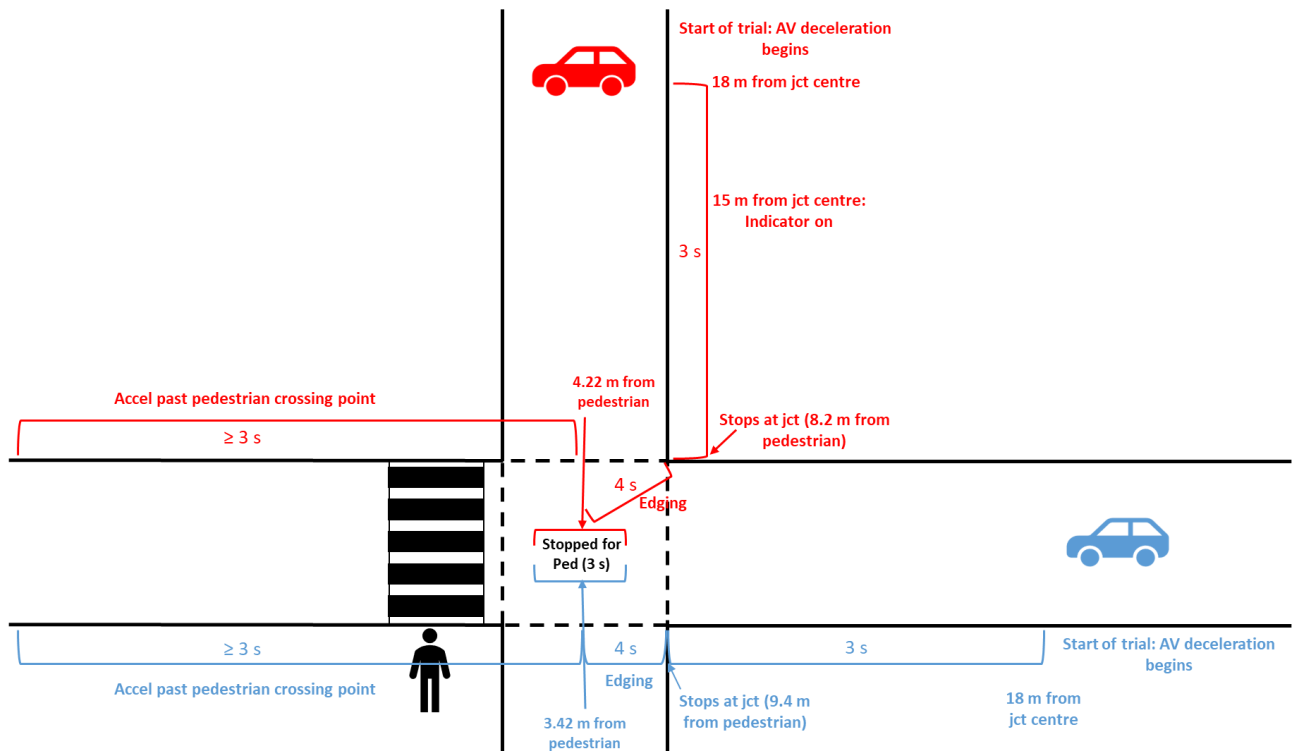
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212 *Figure 4: Examples of yielding AVs approaching the pedestrian from the oncoming road (top) and from the right (bottom).*
 213 *In half of the yielding trials, the AV displayed an eHMI (see images a, b, c, d) while in the other half it did not (images e, f, g,*
 214 *h). In addition, in half of all of the trials, there was a zebra crossing to indicate the pedestrian's crossing path, whereas for*
 215 *the other half, there was no pedestrian crossing infrastructure.*

216 **2.2.1.1 Yielding Trials**



217



218

219 *Figure 5: Vehicle speed pattern (top) and timings (bottom) for yielding trials. For all measures up until the vehicle stops at*
 220 *the junction, distances are calculated based on the centre of the crossroads. For all measures from the junction onwards,*
 221 *distances are calculated in relation to the pedestrian, who was located 5.6m from the centre of the junction. The eHMI was*
 222 *switched on for half of the yielding trials.*

223 The vehicle speed pattern and timings for **yielding trials** are shown in Figure 5.

224 To understand pedestrian responses to different vehicle behaviours, the AV engaged in four
 225 separate movement phases, regardless of approach direction, and whether or not there was a zebra
 226 crossing present:

227 1. **Decelerating** to come to a stop at the junction:

228 To simulate how vehicles behave in the real world while approaching junctions, the AV always
 229 decelerated and came to a stop at the junction. This deceleration took place over a 3-second
 230 period, whereby the AV decelerated from 25 mph to 0 mph, at a rate of -8.33 m/s^2 , to come to a
 231 complete stop at the white lines of the junction (see Figures 3 and 4), which was located 9.4 m
 232 from the pedestrian for AVs approaching from the right (marked A in Figure 3), and 8.2 m from
 233 the pedestrian for vehicles approaching from the oncoming road (marked B in Figure 3).

234

235 2. **Edging** towards the participant:

236 After stopping at the junction, the AV then immediately started moving extremely slowly
237 between the junction and the pedestrian crossing point, for a period of 4 seconds, to indicate
238 yielding intent (we term this behaviour edging). The aim of this edging behaviour was to
239 replicate real-world yielding behaviour at similar junctions (Dietrich et al., 2018), which is
240 thought to provide an implicit cue for pedestrians, allowing more time for them to cross. For
241 oncoming vehicles, the edging speed was 1.5 mph, while for vehicles approaching from the right,
242 the edging speed was 3 mph. This discrepancy was to ensure that the vehicles reached their
243 stopping point within the same time period.

244 For half of the yielding trials, the vehicle displayed an eHMI to provide further evidence of its
245 yielding intentions. This consisted of a cyan pulsing light-band around the vehicle windscreen
246 (see Figure 4), which switched on at the start of the “edging” phase, as prior to this stage any
247 deceleration was due to the need to stop at the junction stop line, rather than yielding for the
248 pedestrian. Participants were not provided with any information about the meaning of this
249 eHMI.

250 3. **Stopping** to allow the pedestrian to cross:

251 After 4 seconds of edging behaviour, the AV stopped completely, to allow pedestrians to
252 complete, or initiate, their road crossing. If the pedestrian had initiated a crossing, the vehicle
253 remained stopped until they had reached the opposite side of the road. However, if the
254 pedestrian had not moved, the AV remained stopped for a total of 3 seconds, before starting to
255 move forwards again. This time limit was set to avoid a stand-off situation, where neither actor
256 moved for a long period of time.

257 When the AV was approaching from the right, the front centre-point of the vehicle was 3.42 m
258 from the pedestrian when it came to a complete stop. When the AV was approaching from the
259 oncoming road, the distance from the front centre-point of the AV to the pedestrian was 4.22 m,

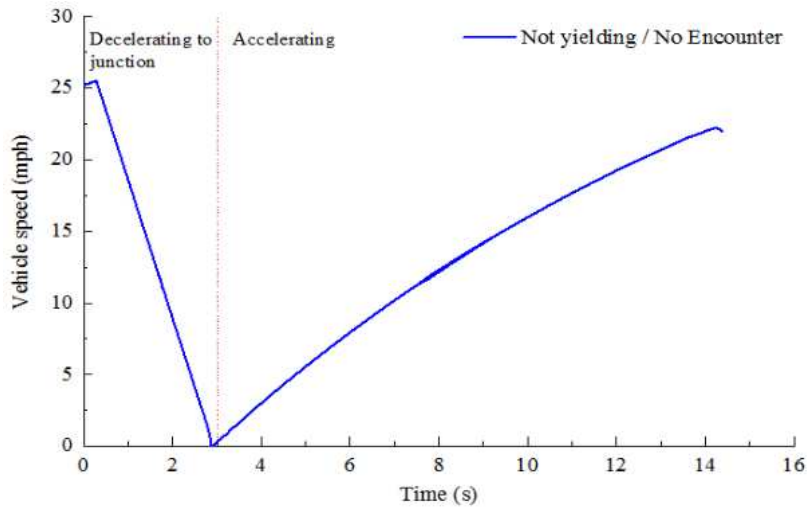
260 but the vehicle was angled so that the front right-hand side of the vehicle was closer to the
261 crossing path (see Figure 4). This variation was due to the fact that AVs approaching from the
262 right were located in the centre of the lane in which the crossing path was located, whereas, the
263 position of AVs approaching from the oncoming road was based on the turning angle from that
264 road.

265 4. **Accelerating** away to drive past the pedestrian crossing point:

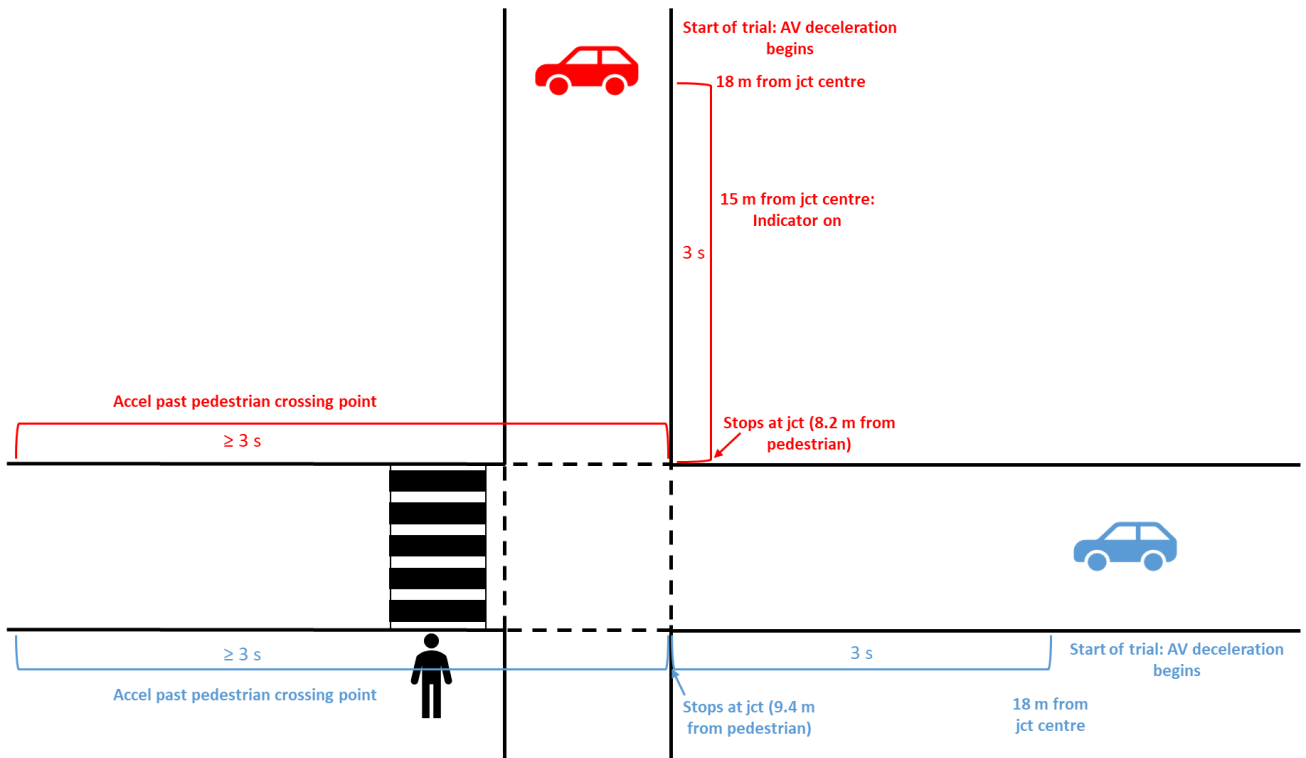
266 Once the pedestrian crossing movement was complete and/or the 3-second waiting period was
267 over, the AV accelerated away from its stopping position, at a rate of 0.89 m/s^2 , moving past the
268 pedestrian crossing point. Any pedestrian who had not yet crossed had the opportunity to do so
269 once the AV had passed.

270

271 2.2.1.2 Non-Yielding Trials



272



273

274 Figure 6: Vehicle speed pattern (top) and timings (bottom) for non-yielding trials. There was no eHMI in non-yielding trials.

275 The vehicle speed pattern and timings for **non-yielding trials** are shown in Figure 6.

276 In these trials, the AV engaged in two separate movement phases, regardless of approach direction,
 277 and whether or not there was a zebra crossing present:

- 278 1. **Decelerating** to come to a stop at the junction:

279 Similar to the yielding trials, this deceleration took place over a 3-second period, whereby the AV
280 decelerated from 25 mph to 0 mph to come to a momentary stop at the white lines of the
281 junction (see Figures 3 and 4), which denote a requirement for drivers to stop.

282

283 2. **Accelerating** away to drive past the pedestrian crossing point:

284 The AV then immediately accelerated away from the junction, at a rate of 0.89 m/s^2 , moving
285 past the pedestrian crossing point without any change in behaviour.

286 2.3 Questionnaires and Interview

287 Due to Covid19 restrictions, all efforts were made to minimise the time participants spent in the
288 HIKER lab, along with minimising their interactions with the experimenter. Therefore, prior to
289 scheduling an experiment time, participants were sent a copy of the information sheet, consent
290 form, and a short questionnaire to complete online, through the University of Leeds Qualtrics
291 platform. This online questionnaire requested demographic information such as participants' age,
292 gender, nationality, and driving experience.

293 Once participants had completed the experiment, they were asked to take part in a short online
294 interview, using Microsoft Teams, to gain additional insights into the factors influencing participants'
295 crossing decisions. This interview was scheduled within 48 hours of completing the experiment, and
296 lasted between 5 and 10 minutes. The questions were semi-structured, covering the following
297 topics:

- 298 • What information did you use to decide whether or not to cross the road?
- 299 • Did this change over time or across trials?
- 300 • Did the direction of the vehicle approach have an impact on your crossing decision?
- 301 • Did the presence of a zebra crossing have an impact on your crossing decision?
- 302 • Did the light-band have an impact on your crossing decision?
- 303 • How did you interpret the light-band?

304 Interviewers supplemented these questions with follow-up probes and explorations of any
305 interesting comments. Due to scheduling and recording issues, interview data is only available for 31
306 out of the 38 participants. Interviews were automatically transcribed using the transcription function
307 on MS Teams, and these transcripts were then manually checked and revised by one of the authors.
308 Finally, after the interview had been completed, participants were asked to fill out a second online
309 questionnaire. This 37-item questionnaire included questions about what information participants
310 had used to make their crossing decisions, how they had interpreted the eHMI, their knowledge of
311 automated vehicles, and the Sensation Seeking Scale (Arnett, 1994). Due to space constraints, only
312 information about participant responses to the eHMI questions are included in the current paper.

313 2.4 Procedure

314 Upon arrival at the HIKER lab, the instructions for the study were briefly repeated by the
315 experimenter, and participants were given an opportunity to practice the crossing task over 8 trials.
316 The practice trials consisted of four trials with a zebra crossing, where the vehicle approached from
317 the oncoming road, and four trials without a zebra crossing, where the vehicle approached from the
318 right. Within these eight trials, participants experienced two trials where the vehicle yielded with
319 eHMI, two trials where it yielded without eHMI, and four trials where it did not yield.

320 For the experimental blocks, participants started each trial by standing on a yellow cross, which was
321 marked on the ground in HIKER at the edge of the road to the left of the crossroads (See X marked in
322 Figure 3). They were instructed to cross the road when they felt safe to do so, either before or after
323 the approaching vehicle. After crossing the road, they had to walk back to the initial position to
324 trigger the next trial. The experiment was presented in two blocks of 26 trials each – one block with
325 a zebra crossing, and the other block with no zebra crossing, presented in a counterbalanced order.
326 Participants were given a short break between blocks. The total experiment lasted for approximately
327 30 minutes. Within 48 hours of completing the experiment, the participant attended an online

328 interview lasting approximately 5-10 minutes. The final step in the study was the completion of
329 another short online questionnaire, after which participant payments were processed.

330 2.5 Data Analysis

331 This study adopted a mixed methodology approach to investigate four main research questions.

332 Firstly, in order to understand the individual and combined effects of (1) zebra crossing presence, (2)
333 vehicle approach direction, (3) vehicle yielding behaviour, and (4) novel eHMI on pedestrian crossing
334 behaviour at a four-way crossroads, two within-groups analyses of variance were run, with one
335 examining yielding trials and one investigating non-yielding trials. The independent variables were
336 *Zebra Presence* (Zebra/No Zebra), *Vehicle Approach Direction* (Oncoming/Right), *eHMI Presence*
337 (eHMI/no eHMI), and *Encounter Number* (either 3 or 6 depending on whether they were yielding or
338 non-yielding trials); and the dependent variable was *Crossing Initiation Time* (CIT). CIT was calculated
339 as the time from the initiation of a new trial to the time at which participants started to cross the
340 road (see Section 2.4).

341 Three sets of chi-squared analyses were used to investigate the relationship between *Zebra Presence*
342 (Zebra/No Zebra), *Vehicle Approach Direction* (Oncoming/Right), *eHMI Presence* (eHMI/no eHMI),
343 and the *Percentage of Road Crossings* during each of the four AV movement phases (Decelerating /
344 Edging / Stopping / Accelerating; see Section 2.2.1.1) during yielding trials. The *Zebra Presence* and
345 *Vehicle Approach Direction* analyses were also conducted for non-yielding trials.

346 In order to gain additional insights into the factors that informed pedestrians' decision making
347 during the experiment, interview and questionnaire data were used. Within 48 hours of completing
348 the road-crossing experiment, all participants took part in a short semi-structured online interview
349 to help us understand their experiences during the experiment. A basic qualitative content analysis
350 (see Schreier, 2012) was conducted to code participant responses. The interview questions were
351 separated into five main question topics i.e. main influences on crossing decisions, changes across
352 the experiment, impact of vehicle approach direction, impact of zebra crossing, and impact of eHMI.

353 Responses to each of these five topics were analysed separately by two coders. The main author
354 began by reading the responses of the first five participants to build a coding frame and generate
355 response categories for each of the five topics. This was achieved by reading an individual
356 participant's response, extracting raw quotes of interest, and identifying the underlying meaning or
357 category of the quote. Each time a new concept was encountered it was checked against the existing
358 coding framework and new categories were added if there was no suitable existing one. Once the
359 initial coding framework was developed based on the first five responses, the same process was
360 then repeated by two coders for the remaining participants.

361 Interrater reliability was calculated using the procedure set out by Miles and Huberman (1994) by
362 dividing the number of agreements by the total number of agreements plus disagreements
363 (agreements + disagreements). The overall interrater reliability was 0.95, indicating a high level of
364 agreement between the coders. In instances where there was a discrepancy in the codes selected,
365 the first author went back to the initial text to review the content once more, and then discussed the
366 coding with the second coder to reach a consensus.

367 Finally, in order to understand the link between participants' understanding of the eHMI and their
368 objective crossing decisions, a mixed between-within groups ANOVA was conducted to evaluate the
369 impact of *eHMI Presence* (Present/Absent) and *eHMI Influence* (eHMI influenced crossing
370 decisions/eHMI did not influence crossing decisions) on *Crossing Initiation Time (CIT)*.

371 3. Results

372 In the following sections we present data on participants' crossing behaviour (Sections 3.1 and 3.2)
373 and the factors affecting their decision making (Sections 3.3 and 3.4). As we were mainly interested
374 in understanding the impact of eHMIs and zebra crossings on pedestrian actions, the "no encounter"
375 trials are not included in the analyses.

376 3.1 Crossing Initiation Time (CIT)

377 Pedestrians crossed before the AV in 77.03% of yielding trials, compared to 25.93% non-yielding
378 trials.

379 For **yielding trials**, a 4-way ANOVA was conducted to examine the impact of *Zebra Presence*
380 (*Zebra/No Zebra*), *Vehicle Approach Direction* (*Oncoming/Right*), *eHMI Presence* (*eHMI/no eHMI*),
381 and *Encounter Number* ($1^{st}/2^{nd}/3^{rd}$ – participants encountered each of the two eHMI conditions 3
382 times) on *Crossing Initiation Time* (CIT).

383 Results indicated a significant effect of Zebra Presence ($F(1, 36) = 26.05, p < 0.001, \eta p^2 = 0.42$), with
384 participants having a significantly shorter CIT when there was a zebra crossing ($M = 6.08\text{ s}, SE = 0.65,$
385 $95\% CI [4.77, 7.40]$) than when there was not ($M = 8.93\text{ s}, SE = 0.56, 95\% CI [7.80, 10.07]$). There was
386 also a significant effect of eHMI Presence ($F(1,36) = 5.70, p < 0.05, \eta p^2 = 0.14$), with shorter CITs
387 when there was an eHMI ($M = 7.21\text{ s}, SE = 0.55, 95\% CI [6.10, 8.31]$) than when there was not ($M =$
388 $7.81\text{ s}, SE = 0.56$). Finally, there was a significant main effect of Encounter ($F(2,72) = 3.95, p < 0.05,$
389 $\eta p^2 = 0.09$), with participants' CIT reducing between the first encounter with a particular trial type
390 i.e. eHMI vs no eHMI trials ($M = 7.78\text{ s}, SE = 0.53, 95\% CI [6.70, 8.86]$) and the last ($M = 7.33\text{ s}, SE =$
391 $0.57, 95\% CI [6.19, 8.48]$). There was no main effect of Approach Direction on CIT ($F(1,36) = 0.33, p =$
392 0.57).

393 There was also a significant interaction between Zebra Presence and eHMI Presence ($F(1,36) = 6.66,$
394 $p < 0.05, \eta p^2 = 0.16$), which is shown in Figure 7 below. For the No Zebra condition, participants
395 crossed significantly earlier when the vehicle was displaying an eHMI than when it was not. There
396 was no significant effect of eHMI in the zebra condition.

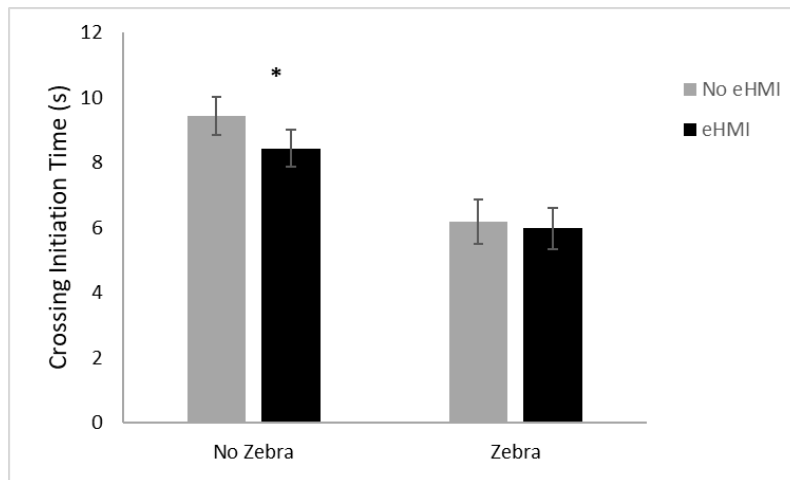


Figure 7: Interaction between Zebra Presence and eHMI Presence on CIT (error bars represent SE)

397

398

399 For the **non-yielding trials**, a 3-way ANOVA was conducted to examine the impact of *Zebra Presence*

400 (*Zebra/No Zebra*), *Vehicle Approach Direction* (Oncoming/Right), and *Encounter Number*

401 (1st/2nd/3rd/4th/ 5th/ 6th – there were 6 encounters with no eHMI) on *Crossing Initiation Time* (CIT).

402 There was a significant main effect of Zebra Presence ($F(1, 36) = 17.88, p < 0.001, \eta^2 = 0.33$), with

403 participants crossing significantly earlier when there was a zebra crossing ($M = 5.22\text{ s}, SE = 0.45, 95\%$

404 $CI [4.30, 6.13]$) than when there was not ($M = 6.75\text{ s}, SE = 0.30, 95\% CI [6.13, 7.36]$). There was also a

405 significant effect of Approach Direction ($F(1,36) = 6.24, p < 0.05, \eta^2 = 0.15$), with participants

406 crossing significantly earlier when the vehicle was oncoming ($M = 5.84\text{ s}, SE = 0.34, 95\% CI [5.15,$

407 $6.52]$) than when it was approaching from their right ($M = 6.13\text{ s}, SE = 0.35, 95\% CI [5.42, 6.84]$).

408 There was no significant effect of Encounter Number ($F(5,180) = 0.52, p = 0.77$), and no significant

409 interaction effects.

410 3.2 Impact of AV Movement Phase on Pedestrian Crossing

411 In order to understand whether pedestrians' crossing decisions were impacted by an AV's kinematic

412 behaviour, a series of chi squared tests were conducted to explore the effect of AV movement phase

413 on pedestrian crossings.

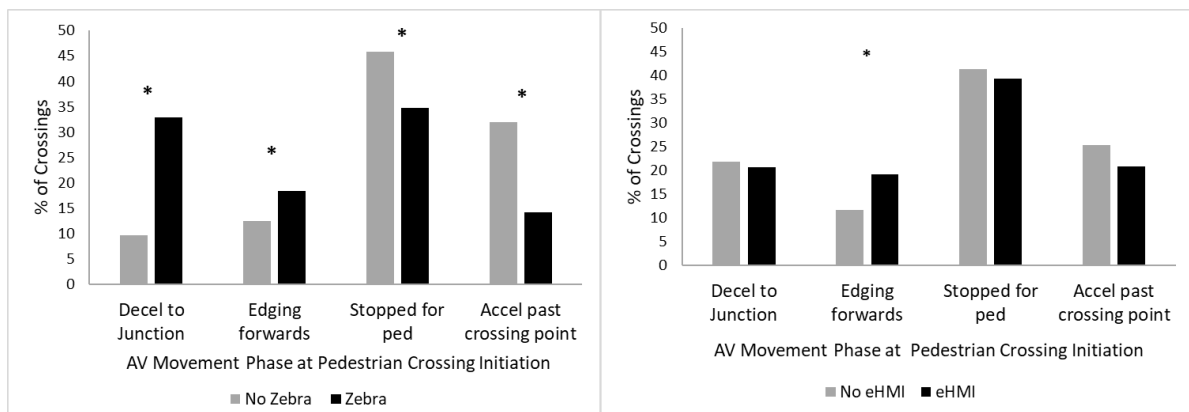
414 Chi-squared analyses were conducted to explore the relationship between the *AV movement phase*

415 *at which pedestrians decided to cross (Decelerating / Edging / Stopping / Accelerating)* and *Zebra*

416 Presence (Zebra / No Zebra), Vehicle Approach Direction (Oncoming / Right), and eHMI Presence
 417 (eHMI / no eHMI).

418 For **yielding trials**, there was a significant relationship between AV Movement Phase at pedestrian
 419 crossing initiation and Zebra Presence ($\chi^2(3) = 101.06, p < .001$). As Figure 8 shows, when there was
 420 a zebra crossing, participants were more likely to cross while the vehicle was decelerating to the
 421 junction, or edging towards the crossing point. However, when there was no zebra crossing, they
 422 were more likely to wait until the AV had stopped or had passed them.

423 There was also a significant relationship between AV Movement Phase at pedestrian crossing
 424 initiation and eHMI Presence ($\chi^2(3) = 10.51, p < .05$; See Figure 8 right). Compared to the no eHMI
 425 condition, when there was an eHMI, pedestrians were significantly more likely to cross while the AV
 426 was edging towards the crossing point. An additional chi-square analysis showed that this effect only
 427 emerged in the no-zebra condition ($\chi^2(3) = 8.69, p < .05$). There was no significant effect of Vehicle
 428 Approach Direction in yielding trials ($\chi^2(3) = 2.70, p = 0.44$).



429
 430 *Figure 8: Vehicle state at crossing initiation time for Zebra and No Zebra trials (Left), and eHMI and no eHMI trials (right)*

431 Results showed that, for **non-yielding trials**, there was a significant relationship between AV
 432 Movement Phase at pedestrian crossing initiation and Zebra Presence ($\chi^2(1) = 63.15, p < 0.001$).
 433 Participants were significantly more likely to cross while the vehicle was decelerating to the junction
 434 when there was a zebra crossing (33% total crossings), than when there was not (11.2% total
 435 crossings). There was no significant effect of Vehicle Approach Direction ($\chi^2(1) = 0.01, p = 0.908$).

436 3.3 Interview analysis: Participant decision making

437 Within 48 hours of completing the road-crossing experiment, all participants took part in a short
438 semi-structured online interview to help us understand their experiences during the experiment. As
439 described in the Methods section, a basic qualitative content analysis (see Schreier, 2012) was
440 conducted to code participant responses, allowing us to group the main topics identified by
441 participants as influencing their crossing decisions.

442 The first question we asked participants was what information they used to decide whether or not
443 to cross the road. Table 2 provides an overview of the main factors participants identified. Data from
444 31 participants are included, and each participant could mention multiple factors in their responses.

Table 2: Factors influencing participants' crossing decisions

Code	Example quotes	No. of participants
Vehicle Speed	"Speed of the car"; "how fast it was going"; "if it was slowing down"	18
Turn Indicator	"if they had the turn signal on"; "whether they were indicating"	13
Presence of Zebra Crossing	"if there is a zebra"; "If there was a zebra I was confident I could cross"; "the presence of a zebra I think made a difference"	12
Vehicle Stopped	"whether or not the car had stopped"; "if the car came to a complete stop and it didn't move then I felt happy to cross"; "making sure the car stopped"	11
eHMI	"the illuminated area around the windshield"; "I realised there was a blue light indicating they would let me cross"; "blinking light – probably indicate it detected me"	6
Approach Direction	"Direction"; "First the car drives on the right or the left is very important"; "when the car was turning right";	5
Distance	"the distance between the vehicle and me"; "How far away the car was when I first spotted it"	4
Vehicle Hesitating / Edging	"Then noticed floating so realised the car was letting me past"	3
Vehicle positioning	"positioning of car at the junction"	3
Waited for car to pass	"Waited for car to pass"	2
Road markings	"Markings on the road"	1

446

447 As shown in Table 2 , vehicle speed was the most commonly identified factor influencing
448 participants' crossing decisions, with participants describing a search for acceleration and
449 deceleration patterns to understand the vehicle's intentions. 13 participants also mentioned
450 checking the turn indicator as an important way of understanding if the vehicle would be crossing
451 their path. 12 participants mentioned the presence of a zebra crossing as a factor which increased
452 their likelihood of crossing, and 11 participants said that they generally waited until the vehicle had
453 stopped before starting to cross, regardless of other factors. Less commonly mentioned factors
454 included the vehicle eHMI or lightband, the approach direction and distance of the vehicle, and its'
455 "nudging"/edging behaviour in some trials. Of the three participants who mentioned the edging
456 behaviour of the vehicle, two people said that it made them more likely to cross, while another
457 person said that it made them hesitate.

458 This inconsistency across participants also emerged when it came to the impact of the vehicle
459 approach direction. When asked about the factors influencing their general crossing decisions, only
460 five participants identified this as a factor. However, when specifically asked whether vehicle
461 approach direction had affected their decisions, 23 participants said that it did. Of these 23
462 participants, 12 found it easier to cross when the vehicle was oncoming, 7 found it easier when it
463 was approaching from the right, and 4 were unsure. The common themes which emerged around a
464 preference for the oncoming vehicle included the slow travelling speed (N = 5) and knowing that it
465 needed time to stop for the turn (N = 7). However, others felt that the vehicle was “more
466 aggressive” when turning (N = 2), and that it may not be able to detect them as easily (N = 2). A small
467 number of participants felt that the vehicle approaching from the right was travelling more quickly
468 (N = 3), and that the potential for that vehicle to build up speed was greater. It is possible that these
469 participants had correctly identified the slightly faster travelling speed during the edging phase of
470 the vehicle’s approaching from the right (3 mph vs 1.5 mph for oncoming vehicles).

471 When specifically asked to provide details about the impact of the zebra crossing on their crossing
472 decisions, 23 participants stated that the presence of a zebra crossing affected their decision making.
473 Themes included increased feelings of confidence/safety (N = 12), feelings of “right of way” (N = 9),
474 and permission to behave more forcefully/“boldly” (N = 2). However, two participants noted that
475 they actually felt more hesitant around the zebra, as the right of way is not always obeyed in the UK,
476 and they had more uncertainty about what the vehicle would do. Others (N = 3) noted that the
477 vehicle did not always behave as they would expect around the zebra, and did not always stop when
478 they felt it should.

479 Finally, when asked specifically about the impact of the eHMI, 12 participants claimed that it did
480 affect their crossing decisions, with one unsure, and 18 saying it did not. When participants were
481 asked about how they had interpreted the message conveyed by the eHMI, the most common
482 answer was that the vehicle was yielding/going to stop (N = 9), although almost the same number

483 said that it was an indication from the vehicle telling them to go (N = 10). Other interpretations
484 included: that the light-band provided an additional indicator (N = 6), information on whether the
485 participant had been detected (N = 5), and that it emphasised the existence of the vehicle (N = 2). A
486 total of 10 people said that they were completely unsure of what the light-band meant.

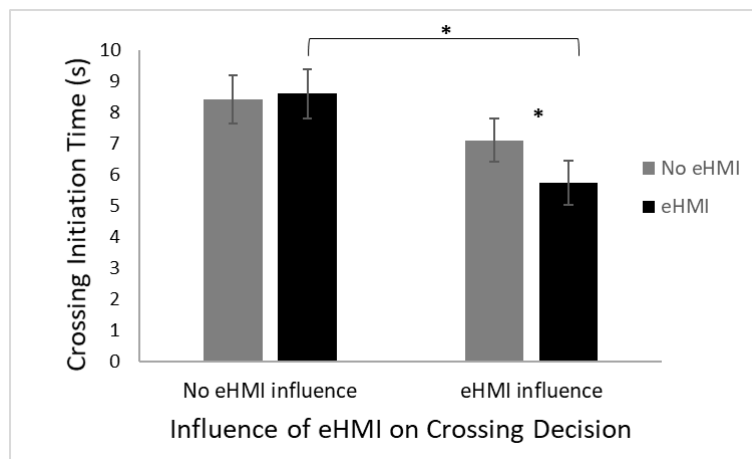
487 3.5 Questionnaire Analysis: Linking participant actions and beliefs

488 After the interviews, participants were asked to fill out a questionnaire about the information they
489 used to make their crossing decisions. As the majority of the questionnaire results supported the
490 findings of the interview analysis, the main focus in this section is on the link between participants'
491 understanding of the eHMIs and their objective crossing decisions.

492 In the questionnaire, participants were asked once again about whether or not they noticed the
493 eHMI, and whether or not it influenced their crossing decisions. 37 out of 38 (97.4%) participants
494 stated that they noticed the eHMI. There was an almost equal split around whether or not it had
495 influenced their crossing decisions, with 18 participants saying it had, and 19 saying it had not
496 (similar to the interviews, which had a smaller number of participants). Of the 18 participants who
497 said that the eHMI had impacted their crossing, 12 correctly interpreted the eHMI as meaning that
498 the AV was yielding to them or it was safe for them to cross, two interpreted it as showing that the
499 AV had seen them, two believed it was an indicator, and the final two participants' responses were
500 unclear.

501 In order to understand the accuracy of participants' interpretation of whether or not the eHMI
502 influenced their crossing decisions, a mixed ANOVA was conducted to evaluate the impact of *eHMI*
503 *Presence* (Present/Absent) and *eHMI Influence* (eHMI influenced crossing decisions/eHMI did not
504 influence crossing decisions) on *Crossing Initiation Time (CIT)*. Results showed a significant main
505 effect of eHMI Influence ($F(1,35) = 4.12, p = 0.05, \eta p^2 = 0.11$) and eHMI Presence ($F(1, 35) = 7.13, p$
506 $< 0.05, \eta p^2 = 0.17$); along with a significant interaction effect ($F(1, 35) = 11.89, p < 0.01, \eta p^2 = 0.25$).
507 As Figure 9 shows, when an eHMI was displayed, participants who claimed that the eHMI had an

508 influence on their crossing behaviour had significantly shorter CITs than those who said they were
 509 not influenced by the eHMI ($t(17) = -3.28, p < 0.01$). However, there was no difference between the
 510 CIT of the two groups when no eHMI was displayed ($t(18) = 0.95, p = 0.36$). The group who used the
 511 eHMI as a cue also had significantly shorter CITs when an eHMI was present, compared to when
 512 there was no eHMI ($t(35) = 2.88, p < 0.01$), while there were no eHMI-related differences in CIT for
 513 the other group ($t(35) = 1.19, p = 0.24$).



514
 515 *Figure 9: A comparison of the impact of claimed eHMI influence on participants' crossing initiation times*

516 **4. Discussion**

517 The purpose of this study was to investigate the impact of an AV's movement pattern and eHMI on
 518 pedestrians' crossing decisions, as well as understanding how this was influenced by the presence of
 519 a zebra crossing. More specifically, the study aimed to gain an understanding of the individual and
 520 combined effects of infrastructure-based information, vehicle approach direction, vehicle yielding
 521 behaviour, and a novel eHMI, on pedestrians' crossing decisions at a four-way crossroads. A
 522 combination of data collection methods was used to understand participants' objective crossing
 523 behaviours, along with how these were influenced by subjective evaluations of the scenario.

524 Overall, the results support the findings of previous studies that vehicle kinematic behaviour is one
 525 of the most important factors influencing pedestrians' decisions about whether or not to cross the
 526 road in front of an approaching vehicle (Dey & Terken, 2017; Lee et al., 2020; Rasouli et al., 2017).
 527 The multi-method data collection approach used in this study provides additional interesting insights

528 about the factors influencing pedestrians' decision-making around AVs. All three data sources
529 provided unique and complementary information. Specifically, the interview data allows us to
530 understand the subjective decision making processes which influenced participants' road crossing
531 behaviours in the experiment, while the combination of the questionnaire and experimental
532 responses to eHMIs allowed us to understand how well participants' interpretation of events
533 matched their actual behaviours. The interview and questionnaire data confirm the experimental
534 findings that vehicle kinematics were the most important source of information for pedestrians,
535 followed by the traffic infrastructure. Participants crossed more often in front of a yielding vehicle
536 than a non-yielding vehicle, and follow-up interviews and questionnaires found that participants
537 identified speed, vehicle stopping/braking behaviour, and vehicle positioning as the most important
538 cues for helping their crossing decisions. Interestingly, however, the impact of the AV's kinematic
539 cues appeared to vary depending on the explicit communication provided by the vehicle, and the
540 presence of a pedestrian crossing. Pedestrians were more willing to cross in front of a vehicle which
541 was decelerating as it approached the junction, or edging forwards from the junction, when there
542 was a zebra crossing or eHMI present.

543 In particular, a key new finding of this study was that the eHMI only appeared to have an impact on
544 pedestrians' crossing behaviour in the absence of a zebra crossing. Specifically, when there was no
545 zebra crossing, the presence of an eHMI led to earlier crossings, and more crossings were made
546 during the vehicle edging stage. This result suggests that even a novel eHMI can influence crossing
547 decisions and aid pedestrians' understanding of the implicit cues provided by the vehicle. Previous
548 research has shown that novel eHMIs tend to be more effective in low speed situations, with shorter
549 time gaps (Lee et al., 2021). The results of the current study build on this finding, by suggesting that
550 eHMIs may be of most benefit to pedestrians in uncertain situations, where there is no clear right of
551 way, and some negotiation between the pedestrian and a vehicle is required. Thus, future research
552 should consider how eHMIs may enhance the impact of kinematic cues, such as edging or slow
553 moving behaviour, in real world situations or around different types of junctions. The

554 implementation of explicit AV communication is likely to reduce the frustration of both road user
555 types, and enhance throughput and traffic flow (Pekkanen et al., 2021).

556 It is interesting that although the light-band eHMI was not identified in the interviews or
557 questionnaires as a key variable for influencing participants' crossing decisions, it still had a tangible
558 impact on behaviour. Participants expressed a lack of certainty about how the eHMI should be
559 interpreted, highlighting the importance of conveying the correct meaning of any light-based
560 communication tools in advance. The fact that almost a quarter of participants had no
561 understanding of the meaning of the eHMI by the end of the experiment shows that this type of
562 communication is unlikely to be intuitively learned or understood. However, for those who correctly
563 interpreted the eHMI as indicating an AV's yielding intentions, it provided a useful cue which led to
564 shorter crossing initiation times. Future research should investigate the impact of education and
565 training about the meaning of different eHMIs on pedestrian crossing behaviours, across different
566 road settings and crossing scenarios.

567 Road infrastructure was also found to be an important factor influencing pedestrians' crossing
568 decisions. Similar to Jayaraman et al. (2018) and Velasco et al. (2019), the current study found that
569 participants had shorter crossing initiation times, and crossed ahead of the AV more often, in the
570 presence of a zebra crossing, regardless of the yielding behaviour of the vehicle, or any explicit
571 communication provided. During the interviews, participants mentioned feeling safer and more
572 confident when there was a zebra crossing. However, some participants noticed that the AV did not
573 necessarily behave as they would expect around the zebra crossing, by not always yielding as
574 anticipated, and this led to some hesitation in crossing. This hesitation highlights the importance of
575 consistent behaviour from the AV (see also Rothenbucher et al., 2016).

576 Finally, it appears that the direction from which a vehicle approaches has an impact on pedestrians'
577 willingness to cross in front an AV, particularly in non-yielding trials. Participants expressed feelings
578 of greater comfort in crossing ahead of AVs approaching from the oncoming road rather than from

579 the right. They also had shorter crossing initiation times in relation to these vehicles in the non-
580 yielding conditions. The interviews found that some participants perceived the oncoming vehicles as
581 moving more slowly, and this, combined with their knowledge that the vehicle had to take some
582 time to make the turn, helped them to feel more comfortable about crossing in this situation. When
583 the vehicle was approaching from the pedestrians' right-hand side, a small number of participants
584 perceived that these vehicles were travelling at a faster speed, and others also believed that the
585 potential for that vehicle to build up speed was greater. These factors once again draw attention to
586 the importance of both current and anticipated vehicle movement patterns in influencing pedestrian
587 decisions.

588 **4.1 Limitations**

589 As with every study, there are limitations which must be acknowledged. First of all, the experiment
590 took place in a virtual environment, which may have led to a greater feeling of safety (REF), and less
591 ecological validity than a real-world study. However, the enhanced simulated realism of the HIKER
592 lab ensured that the road-crossing experience was as realistic as possible, and the fact that
593 participants could move around reduced the risk of cyber sickness commonly associated with VR
594 technology. None of the participants reported any symptoms or had to stop.

595 Another potential study limitation was the inconsistent behaviour of the AV at the zebra crossing. UK
596 regulations at the time this study was conducted meant that drivers were only required to give way
597 when a pedestrian stepped onto a zebra crossing, while pedestrians should not start to cross until
598 vehicles on the road have stopped (RAC, 2021). Thus we felt it was important to investigate if
599 participants would rely more on the road infrastructure, or the vehicle's behaviour and
600 communication, when making their crossing decisions. Participants reported feeling safer and more
601 confident when there was a zebra crossing, and their crossing behaviours showed that they the
602 eHMI had no effect on crossing initiation time when there was a zebra crossing. Taken together,
603 these findings suggest that although manually driven vehicles do not always yield as they should,
604 participants expected the AV to yield to them when obliged to do so, and that this influenced their

605 crossing decision more than any vehicle behaviour or communication. Thus, it is important that AV
606 behaviour takes the traffic infrastructure into account, and that these vehicles obey traffic rules
607 around yielding when required.

608 4.2 Conclusions and Future Research

609 Overall, the results of this study show the importance of considering the traffic environment when
610 deciding where to implement explicit communication solutions for AVs. Previous studies have shown
611 that pedestrians tend to seek out explicit communication with a vehicle in slow moving or uncertain
612 situations (Lee et al., 2021; Rasouli et al., 2017; Sucha et al., 2017; Uttley et al., 2020). The current
613 research supports this finding, showing that eHMIs are most likely to be useful in situations where
614 there is no clear right of way. In addition, the findings show that eHMI can enhance pedestrians'
615 ability to interpret implicit communication cues such as edging behaviour (Dietrich et al., 2018),
616 helping them to make earlier crossing decisions, particularly in situations where there is no zebra
617 crossing. In order to maximise the effectiveness of any explicit communication tools, the meaning of
618 eHMIs should always be advertised or explained in advance. However, it should be noted that this
619 research was conducted in a VR environment and, thus, more research is needed to understand
620 whether similar results would emerge in a real-world scenario, where the degree of risk experienced
621 by pedestrians is greater. In addition, future research should focus on identifying and investigating
622 similar uncertain scenarios, including other junction types, where eHMIs might be of particular
623 benefit.

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762 Appendix A

763 Pre-Study Questionnaire

Name in block letters	
Age	
Gender	
Nationality	
How long have you been living in the UK?	(__ years)
Do you have a driving license?	Y / N
Which country is your driving license from?	
How many years of active driving experience do you have?	
What is your annual mileage (miles)?	
Do you use glasses (or other instruments to improve your vision) in everyday life?	Y/N

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765 Post-Study Questionnaire

1. What information from the vehicle, if any, do you think was important to help with your decision to cross/not cross? Rate how important each of the factors were, leaving the factor blank if you did not use the information:	Unimportant/Slightly unimportant/Neutral/Slightly important/Important
A) Speed	
B) Distance	
C) Braking	
D) Vehicle positioning	
E) Light band	
F) Zebra Crossing	
G) None	
2a. Did you notice the Pulsing Light Band around the vehicle?	Y/N
2b. If so, did this light influence your crossing decisions? if yes, in what way? - Yes - Text	Free Text
3a. Do you think that the pulsing light band was conveying a particular message?	Y/N
3b. If so, please describe what information the pulsing light-band was conveying?	Free Text
4. Do you think the Pulsing Light Band is useful in helping you with your crossing decision?	Y/N
5a. Are you familiar with the concept of self-driving/driverless cars?	Y/N
5b. Do you think the Pulsing Light Band would be useful if implemented in future in self-driving (driverless) cars?	Y/N
5c. Please explain in your own words, why you think the Pulsing Light Band will (will not) be useful.	Free Text
6. Do you have any other thoughts / comments on the experiment?	Free Text
7. Short Sensation Seeking Questionnaire (20 items, see Arnett, 1994)	Does not describe me at all / Does not describe me very well / Describes me

	somewhat / Describes me very well
7a. I can see how it would be interesting to marry someone from a foreign country	
7b. When the water is very cold, I prefer not to swim even if it is a hot day	
7c. If I have to wait in a long line, I'm usually patient about it	
7d. When I listen to music, I like it to be loud	
7e. When taking a trip, I think it is best to make as few plans as possible and just take it as it comes	
7f. I stay away from movies that are said to be frightening or highly suspenseful	
7g. I think it's fun and exciting to perform or speak before a group	
7h. If I were to go to an amusement park, I would prefer to ride the rollercoaster or other fast rides	
7i. I would like to travel to places that are strange and far away	
7j. I would never like to gamble with money, even if I could afford it	
7k. I would have enjoyed being one of the first explorers of an unknown land	
7l. I like a movie where there are a lot of explosions and car chases	
7m. I don't like extremely hot and spicy foods	
7n. In general, I work better when I'm under pressure	
7o. I often like to have the radio or TV on while I'm doing something else, such as reading or cleaning up	
7p. It would be interesting to see a car accident happen	
7q. I think it's best to order something familiar when eating in a restaurant	
7r. I like the feeling of standing next to the edge on a high place and looking down.	
7s. If it were possible to visit another planet or the moon for free, I would be among the first in line to sign up	
7t. I can see how it must be exciting to be in a battle during a war	

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