A two-agent study: the effects of driver eye gaze visualisation on AV-pedestrian interaction

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by

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Chun Sang Mok
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Contents

Paper: A two-agent VR study: the effects of driver eye gaze visualisation on AV-pedestrian interaction

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Abstract

Problem statement. The introduction of automated vehicles (AVs) changes the role of the driver and may cause a lack of social interaction with pedestrians. This study proposes a concept where the AV is manoeuvre-based controlled via eye gaze, and the AV driver's gaze is visualised for the driver and pedestrians. However, it was unknown if gaze-based AV control is a viable concept and how the AV's yielding behaviour should depend on the eye driver's gaze. **Method.** A two-agent virtual-reality-based experiment was conducted using two Varjo VR2-PRO head-mounted displays (HMDs). Seventeen pairs of participants (a pedestrian and a driver) each interacted in a road crossing scenario. The pedestrians' task was to hold a button when they felt safe to cross the road, and the drivers' task was to direct their gaze according to the instructions. Each session consisted of three blocks of 16 trials: the baseline block, in which the AV driver did not communicate with the pedestrian, and two other blocks in which the driver's gaze was visualised, namely "gaze at the pedestrian to yield" (GTY) and "look away to yield" (LATY). The effectiveness of the interaction was examined using the pedestrians' button presses. Acceptance and preference were measured using questionnaires. **Results.** Pedestrians showed the highest crossing performance and acceptance in the GTY mapping, followed by the LATY mapping and the baseline. The eye gaze visualisation caused pedestrians to spend more time looking at the AV; this effect was particularly dominant when the driver looked at the pedestrian. **Conclusion.** Gaze visualisation in combination with GTY mapping has the potential to be used as a communication tool for AVs at intersections until full automation of driving (SAE level 5) is technically feasible.

Keywords: intent communication; virtual reality; eye-tracking; AV-pedestrian interaction; multi-agent interaction.

Introduction

Vehicle-pedestrian interactions are complex. Although there are formal traffic rules, informal rules are regarded as vital in unambiguous situations where formal rules cannot be determined (1). Pedestrians are known to base their decision to cross in front of a vehicle on vehicle-centric cues, as well as non-verbal cues from the driver in the vehicle. Vehicle-centric cues consist of the vehicle's movement, including speed, acceleration, and stopping distance (2). Non-verbal cues include head movements, hand gestures, and eye contact (3–5). It has been reported that pedestrians use some form of attention to communicate their intention to cross in more than 90% of cases before crossing the road on a non-signalled crosswalk (6,7). At high speeds (50 km/h and higher), pedestrians rely mainly on vehicle-centric cues to cross, whereas eye contact and gestures play a more prominent role during deadlock scenarios or encounters at short distances, where road users have to negotiate priority (8,9).

The introduction of automated vehicles (AV) affects the vehicle-pedestrian interaction. The transition to automated driving is an evolutionary process in which an increasing number of computer systems appear in vehicles. In current deployed AVs, the human supervises the automation system (10). For this purpose, some AVs feature a driving monitoring system to track the driver's gaze movement (11,12). One way to keep the human in the control loop is through manoeuvre-based control (13–20).

With manoeuvre-based control, the driver commands specific vehicle actions (e.g., “stop the vehicle”) and does not control the vehicle at a fine-grained level (e.g., checking mirrors, braking, turning the steering wheel).

State of the art

One approach to enhance AV-pedestrian interaction is to provide information through wearables, such as mobile phones (21,22) and wristbands (23). Another approach is to use external Human-Machine Interfaces (eHMIs) on the exterior of the AV. A wide range of eHMIs has been proposed by industry and academia, mostly in the form of electronic displays on the front of the AV (24). These displays can show text, such as WALK and DON’T WALK (24–29), whereas others are icon-based, such as a “smiling” display on the front of the vehicle (27,30–33) or a hand symbol (28,34). Other eHMIs are light-based, such as projections on the street surface or windshield (25). Furthermore, some eHMIs add physical objects to the vehicle, such as a printed hand mounted on top of the vehicle that can signal a pedestrian to cross (35). Researchers have even tried to create eye contact communication between vehicle and pedestrian by putting artificial eyes onto the vehicle’s headlamps (32,33,36). Moreover, some eHMIs communicate via audio, such as speech (“please cross”), nonspeech audio (horns, beepers (37), bells (38)), or music (39). However, there is no agreement within academia and industry on which eHMI is most suitable for intent communication (26,40).

Eye gaze visualisation

In environments that require collaboration, visual attention can be shared between the participants to enhance teamwork. Sharing visual attention through eye gaze position can be used to convey intent (41).

In this study, we propose to visualise the driver’s eye gaze as a means to communicate the driver’s attention allocation. This approach could prove effective as it could fill the social interaction void by reintroducing communication between the driver and pedestrian. The concept of eye gaze visualisation conveys the attention and intention of the occupant of the AV but does not instruct the pedestrian, which is in line with the recommendation of Tabone et al., amongst others (42).

For the experiment, eye gaze visualisation was rendered as a laser. This laser confirmed for the AV drivers where they were looking and verified that their eyes were tracked correctly by the eye tracking system. In addition, it could help the pedestrians predict the AV’s intent.

Urban cross roads could have many visual distractions, e.g. advertisement signs and other traffic. A previous study (43) has found that high visual clutter can lead to pedestrians missing opportunities to cross the road. It may be expected that the gaze-based control is less clear to pedestrians when there are competing visual demands, e.g. other traffic.

Manoeuvre-based control

The majority of the interfaces for AV control are based on physical interaction, such as touchscreens (16,18–20) or modified steering wheels (15). Several contactless interfaces that do not require a physical interface have been proposed as well. These contactless interfaces for controlling automated vehicles rely on voice and mid-air gestures (13,14). The manoeuvre-based control in the current study was controlled using eye movements. This type of control is direct without requiring a physical interface or extra movements on behalf of the driver (17,44,45).

In current traffic interaction with manually driven vehicles, a driver may gaze at the pedestrian to signal to the pedestrians that they can cross the road (4). If the driver has not gazed at the pedestrian, it may mean that the driver has not seen the pedestrian and will not yield. When considering a pedestrian-crossing situation, a gaze-controlled AV can have two strategies of behaviour that it can follow. The strategy based on gaze behaviour will be called ‘mapping’ in this study. The first mapping is the same as manual drivers: AV yielding when gazing at the pedestrian and not yielding when not gazing at the pedestrian.

The opposite mapping defines interaction from a safety perspective (SAE level 4 'minimal risk condition'). If the driver in the AV is *not* paying attention to the pedestrian, then the AV automatically stops before the crossroad, out of precaution. Conversely, if the driver in the AV is paying attention to the road, then the AV can continue to drive because the AV can assume that the driver has assessed the road situation.

Aim of the study

The study aims to determine whether eye gaze visualisation of AV's driver can improve the road crossing interaction between an AV and a pedestrian, and to investigate which mapping is accepted by pedestrians. For this purpose, the effectiveness, acceptance, and preference of the two mappings of the eye gaze visualisations were examined and compared with the baseline.

Method

Participants

Thirty-four participants (driver: 13 males, 4 females; pedestrian: 10 males, 7 females) participated in the experiment. The drivers had a mean age of 23.7 years (SD = 2.0), and the pedestrians had a mean age of 23.4 years (SD = 1.8). The nationalities of the participants were Chinese (4), Dutch (28), and Indian (2) (traffic in India is left-sided, but the participants resided in the Netherlands for more than a year). Nine of the drivers wore seeing aids (7 glasses and 2 contact lenses), and 10 of the pedestrians wore seeing aids (5 glasses and 5 contact lenses). Moreover, 12 of the drivers and 12 of the pedestrians had a driving license. Furthermore, 12 of the drivers and 11 of the pedestrians had previous experiences with virtual reality. All participants read and signed an informed consent form. The research was approved by the Human Research Ethics Committee of the Delft University of Technology.

Virtual Reality Environment

The virtual environment was based on the open source coupled simulator project of Bazilinskyy et al. (46). Figure 1 illustrates the top view of the zebra crossing, including the pedestrian, the AV, and the distraction vehicle. A distraction vehicle was added to consider the effects of visual distraction from the environment on the effectiveness of the eye gaze visualisation system. The AV approached the zebra crossing from the pedestrian's left side, and the distraction vehicle approached from the pedestrian's right side. Both the participants wore a head-mounted display (HMD). The pedestrian's camera was placed 1.7 m (global average height for men (47)) above the 0.22 m high curb and at a perpendicular distance of 1 m away from the edge of the road. The lane width was 5 m wide. The pedestrian and driver could rotate their head in all directions but could not move their body freely in the virtual world. The driver did move through the virtual environment because they were transported by the AV.

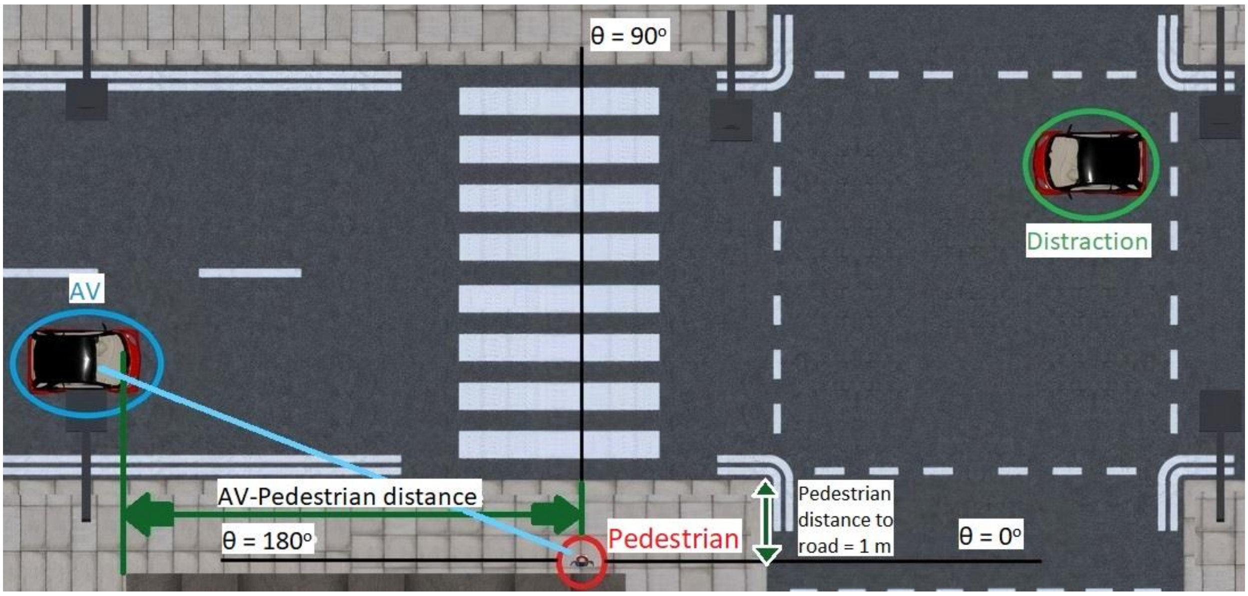

Figure 1: Top view of the simulation environment. The vehicle in the blue circle is the AV that approached the zebra crossing from the left. The light blue line represents the eye gaze visualisation of the driver. The vehicle in the green circle is the distraction vehicle and approaches the zebra crossing from the right. The AV-Pedestrian distance is illustrated in the figure as a green arrow line and is defined as the distance along the road measured from the middle point of the pedestrian to the windshield of the AV. Furthermore, pedestrian gaze orientation is illustrated in the figure. Gaze orientation θ is positive counter-clockwise, and straight ahead equals 90^0.

Visual attention sharing

The driver's visual attention was rendered as a laser. In the VR environment, a 7 cm wide semi-transparent ($\alpha = 0.2$) cyan laser was drawn between the middle point between the driver's eyes and a point 100 m away in the direction of the gazing direction, see Figure *2*A for the pedestrian's perspective and Figure *2*B for the driver's perspective. The laser was a different colour (green) from the driver's perspective to separate the rendered cyan laser for the pedestrian and the original laser from the driver. The pedestrian was only able to see the cyan laser and the driver could only see the green laser.

The eye gaze visualisation was realised by using the eye-tracking capability of the Varjo VR-2 Pro HMD. The HMD was equipped with industrial-grade, 0.2^0 accuracy integrated 100 Hz stereo eye trackers (48). The HMDs provided a field of view (FOV) of 87^0 for the participants on a display with resolution at over 20/20 vision (over 60 pixels per degrees / 3000 pixels per inch). The view was provided by two low-persistence micro-OLEDs with a display resolution of 1920x1080 pixels and two low persistence AMOLEDs with a display resolution of 1440x1600.

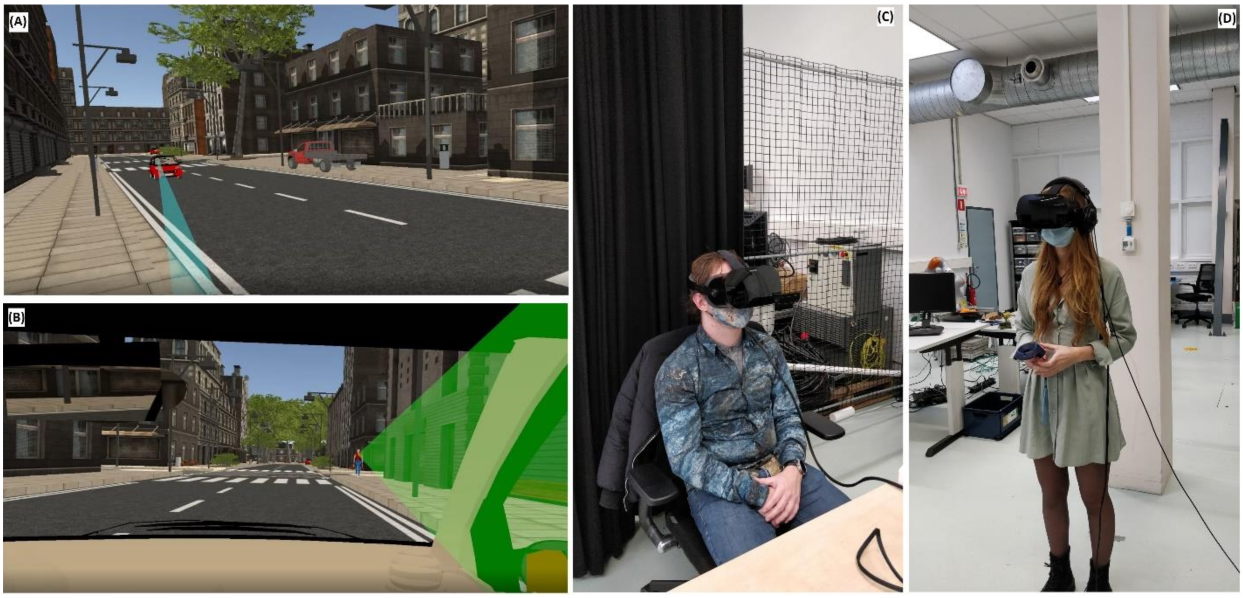

Figure 2: (A) Eye gaze visualisation of the driver, as shown in simulation from the pedestrian's perspective. (B) Eye gaze visualisation from the driver, as shown in simulation from the driver's perspective. (C) Driver wearing the Varjo VR2-Pro HMD. (D) Pedestrian wearing the Varjo VR2-Pro HMD, headphones, and holding an HTC Vive 2.0 controller.

Experimental design

Participants were divided into the roles of either driver or pedestrian before the session began. The pedestrian's task was to press and hold a button when they felt safe to cross the road and release the button when they did not feel safe to cross the road. The task of the AV driver was to follow the instructions given to him at the beginning of each trial in the form of "Stop the AV" and "Do not stop the AV". The sessions were divided into three blocks, and each block contained one mapping, see Figure 3. The definitions of the mappings are given in the rightmost column of Figure *3*. Block 1 consisted of the baseline conditions (yellow), Block 2 consisted of the "gaze to yield" (GTY) conditions (green), and Block 3 consisted of the "look away to yield" (LATY) conditions (purple). Each block contained the same four conditions: "Distraction – Yielding" (D-Y), "No Distraction – Yielding" (ND-Y), "Distraction – No Yielding" (D-NY), and "No Distraction – No Yielding" (ND-NY). The order of trials within the block was randomised for each participant. The randomisation was done using the Xorshift algorithm (49). The randomisation can be counted as random counterbalanced, due to the large number of possible combinations. All participants began with the baseline block. This was followed by either the GTY block or the LATY block, depending on the participant number. Participants with an odd participant number started with GTY, and participants with an even participant number started with the LATY block. Together, the two participants performed 48 trials (i.e., each condition four times).

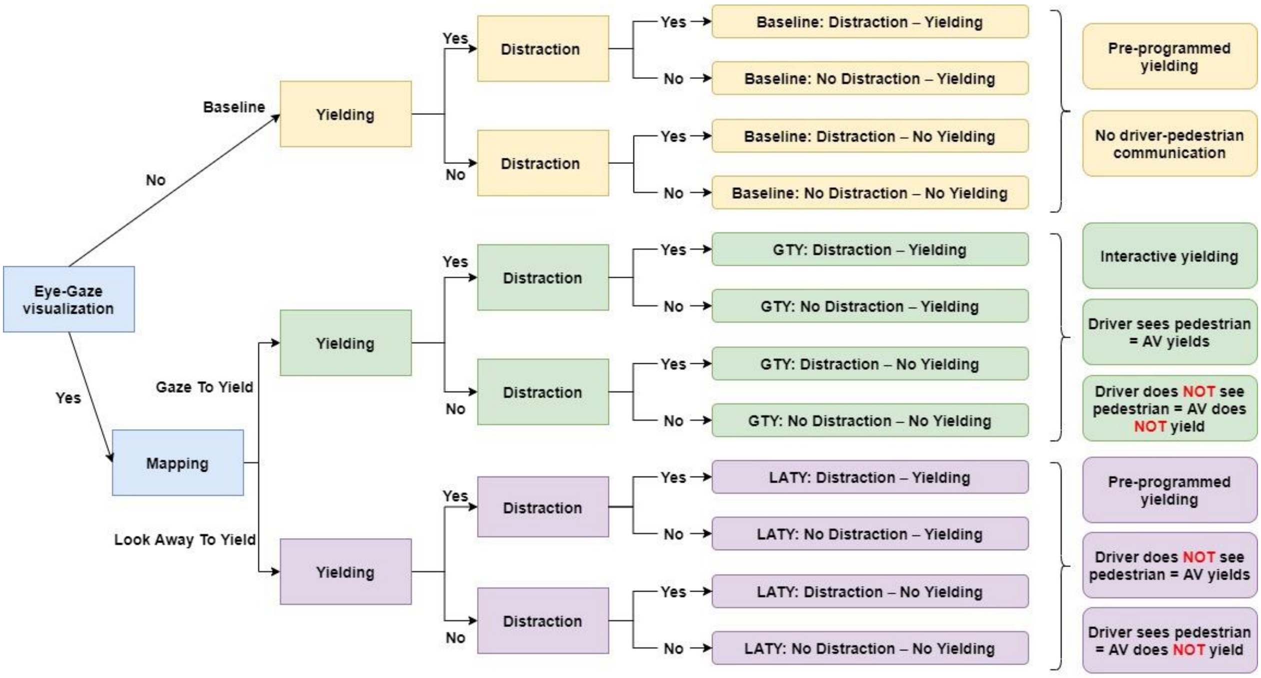

Figure 3: Overview of all possible combinations of the independent variables resulting in 12 experiment conditions. Yellow representing the baseline conditions, green the GTY mapping conditions, and purple the LATY mapping conditions. The mapping definitions are shown in the rightmost column. The baseline condition has no driver-pedestrian communication, and the yielding is pre-programmed. The AV yielding is interactive in GTY. The AV yields when the driver sees the pedestrian. Conversely, the AV does not yield when the driver does not see the pedestrian. Lastly, in the LATY mapping, the yielding is pre-programmed. The driver should look away when the AV yields and the driver should look at the pedestrian when the AV does not yield.

The yielding variable refers to the yielding of the AV. The mapping variable refers to the behaviour of the vehicle in relation to the AV driver's gaze behaviour. The distraction variable refers to the presence of a distraction vehicle in the trials. The distraction vehicle maintained a constant speed of 30 km/h. In the no yielding condition, the distraction vehicle reached the pedestrian 0.87 s later than the AV, and in the yielding condition of the AV, the distraction vehicle reached the zebra crossing at the same time as the AV, see Figure A4-Figure A6 in Appendix C.

"Seeing the pedestrian" was defined as directing the eye gaze at the pedestrian avatar's hitbox (an invisible shape used for real-time collision detection), see Figure *4*. The rectangle was as tall as the avatar, and the width was about 1.9 m, equal to the length of the arms stretched horizontally. At a distance of 25 m, the rectangle width of 1.9 m is equal to 4.35^0 of the visual field, fitting inside the anatomical fovea of the human visual field, which is equal to 5^0 (50).

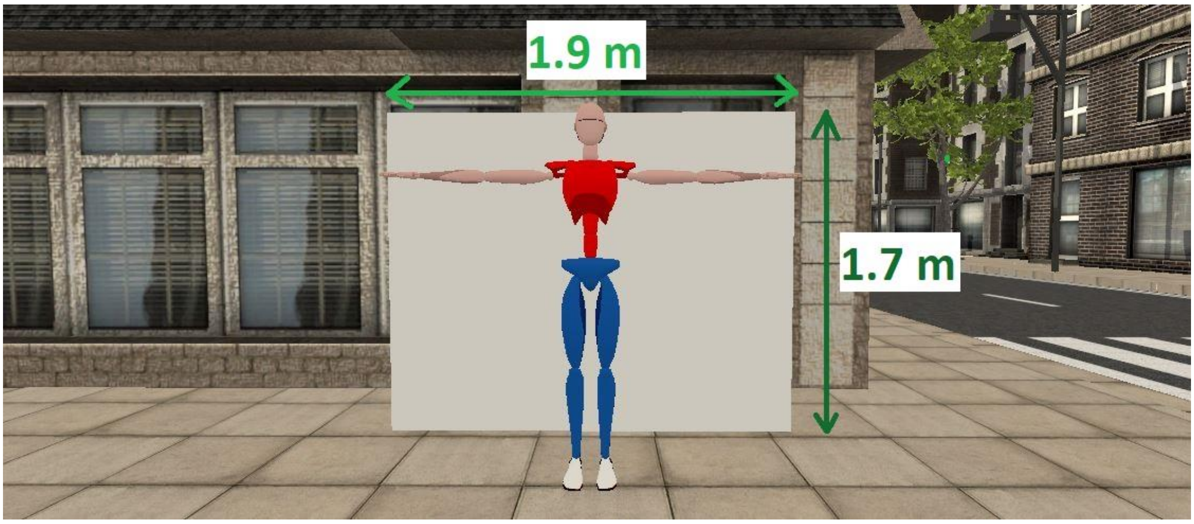

Figure 4: Pedestrian avatar in front of the avatar hitbox size depicted as a white rectangle. The hitbox is placed behind the avatar and coloured for illustration purposes in this figure. The hitbox is not visible in the simulation and was placed inside the avatar.

The yielding behaviour of the AV in the baseline and LATY conditions was noninteractive. Braking in LATY was not interactive because the driver in the experiment was instructed to follow the LATY instructions and was expected not to look at the pedestrian. Thus, there would be no trigger point for yielding.

In real traffic, drivers tend to make their yielding decision at about 30 m before the crosswalk at a vehicle speed of 30 km/h (51). To copy human deceleration behaviour, it was chosen to start the deceleration at a distance shorter than 30 m between the pedestrian and the driver. More specifically, the pre-programmed braking was initiated at the distance of 22.54 m between the AV and the pedestrian, resulting in the AV coming to a standstill at a distance of 6.23 m to the pedestrian.

For mapping GTY, the yielding of the AV was interactive. The AV braked when the driver looked at the pedestrian while the distance between the two was greater than 14.4 m and less than 25 m. This means that the AV would not brake if the driver gazes at the pedestrian from a too far distance or when the driver gazes too late (i.e., when the AV is already too close to the pedestrian). Adaptive deceleration was used so that the AV would always stop at a distance of 6.23 m from the pedestrian. The yielding trigger needed to be activated before 14.4 m to ensure that the deceleration does not exceed the critical deceleration for comfort of 3 m/s^2 (52). There was no time constraint associated with the braking; in other words, a single glance of the driver was enough to initiate the deceleration of the AV.

Figure 5 depicts the AV trajectory of every trial and onsets of changes in vehicle behaviour. Three distinct phases are extracted from the AV trajectory. These phases were chosen based on the AV position as multiple studies have shown that (in VR) pedestrians mainly base their crossing decision on the distance between the AV and the pedestrian (53–60). Phase 1 represents the approaching phase and is defined as the period after the start signal “press now” till the start of the yielding trigger detection range (AV-pedestrian distance of 25 m). Phase 2 represents the deceleration phase of the yielding AVs and is defined as the period from the start of the yielding trigger detection range till the standstill of the AV. Phase 2 in GTY shows a variation in distance-time combination for the yielding condition because of the differences in the start of deceleration and deceleration rates. Lastly, Phase 3 represents the period during which the AV was standing still for 2.6 s.

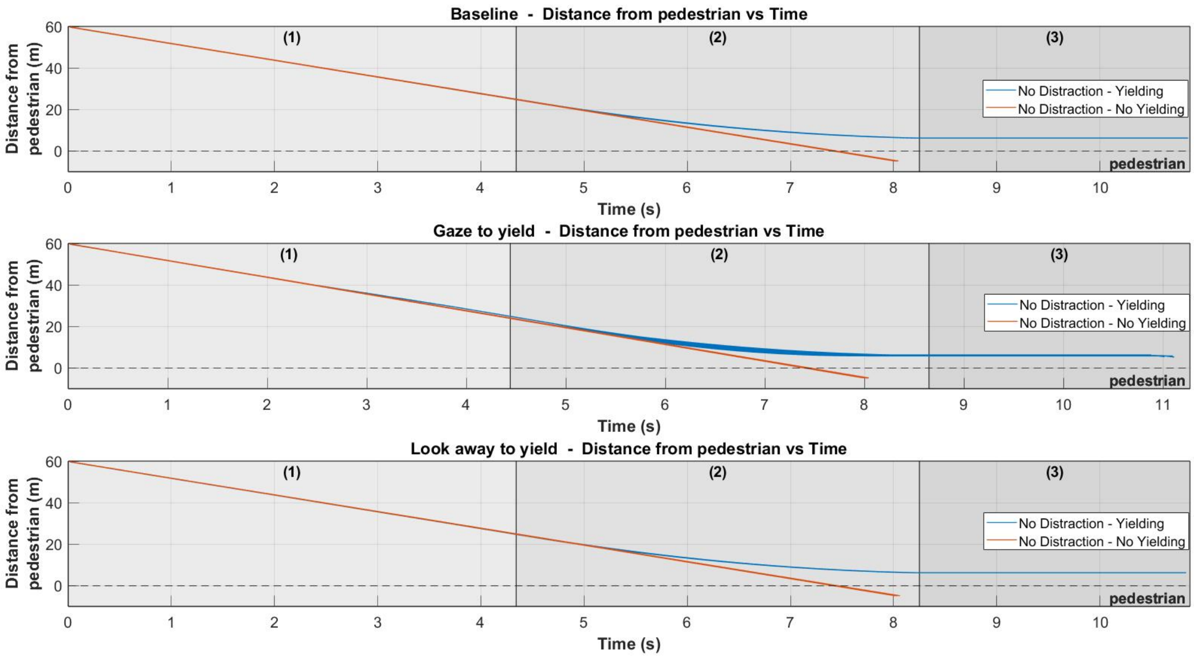

Figure 5: AV trajectory and onsets of changes in vehicle behaviour. (1) represents the period after the start signal "press now" till the start of the yielding trigger detection range, which is equal to a distance of 25 m between the AV and the pedestrian (2) is the start of the yielding trigger detection range till the standstill of the AV, and (3) is the period when the AV was at a standstill for 2.6 s. In the GTY condition (mid subfigure) the vertical line at the start of Phase 3 is plotted as the end of the slowest Phase 2. The number of trials contained in the subfigures: top 68 yielding and 68 no yielding, middle 64 yielding and 65 no yielding, and bottom 67 yielding and 66 no yielding.

The effectiveness was defined through the participant's button press behaviour, quantified through a performance score. A post-block questionnaire (61) was used to determine the acceptance of the system (Appendix A). Lastly, a post-experiment questionnaire was given to indicate the participants' preference between the mappings (Appendix A).

Hardware

In addition to two Varjo VR2-Pro HMDs, two Alienware PCs with the same specifications were used for the experiment. The PCs used a Intel Core i9-9900K 3.60GHz CPU; had 64.0 GB RAM; and used two GPUs: Intel UHD Graphics 630 and NVIDIA GeForce RTX 2081 Ti. An HTC Vive Controller 2.0 was used by the pedestrians to indicate whether they felt safe to cross the road. The driver and pedestrian setups are shown in Figure *2*C and D, respectively. Two SteamVR base stations were used to track the HMDs and the controller. Finally, a Beyerdynamic DT 770 PRO headset was used by the pedestrian.

Procedure

Due to the COVID-19 pandemic, participants were requested to disinfect their hands and wear non-medical facemasks before entering the lab. After taking the necessary precautions, the participants were informed about the purpose of the study and were given an informed consent form to read and sign. Next, the participants read the instructions and completed a pre-experiment questionnaire asking about demographics, gaming and VR experience, driving behaviour, and crossing behaviour, see Appendix A.

The instructions for both participants contained the same schedule and mapping details, but the tasks were role-specific, see Appendix B. The GTY and LATY mappings were numbered 1 and 2, respectively. Both participants were informed that the driver's gaze was visualised as a laser in mapping 1 (GTY) and mapping 2 (LATY). Drivers were informed that in the baseline, the AV did not communicate at all. They could look around as if they were in a manually controlled vehicle in real life.

For mapping 1, drivers were informed that the AV would yield if they looked at the pedestrian in time, and that the AV would not yield if they did not look at the pedestrian. For mapping 2, drivers were informed that the AV would yield if they did not look at the pedestrian, and that the AV would not yield if they looked at the pedestrian. The pedestrians were informed that in the baseline, the AV did not communicate at all. They had to determine for themselves whether the AV stopping for them. For mapping 1, pedestrians were informed that the AV would yield if drivers looked at them, and that the AV would not yield if drivers did not look at them. For mapping 2, pedestrians were informed that the AV would yield if drivers did not look at them, and that the AV would not yield if drivers looked at them. Before the start of each session block, the instructor reiterated which mapping was to be used and what was expected of the participants. The instructor also mentioned to the pedestrian that the AV with the driver came from the left side of the pedestrian, and the other (distraction) vehicle came from the right side.

First, the participants performed a practice round in which one trial per mapping was practised. Then, three blocks of trials were presented to the participants. Between each block, there was a break in which participants were asked to complete a questionnaire regarding their cybersickness state using a misery scale (MISC; (62)) and acceptance of the system (61), see Appendix A. At the end of the experiment, participants were asked to complete a questionnaire about their mapping preference and level of presence (63), see Appendix A.

Data filtering

All trials in which the driver did not act in accordance with the instructions were excluded. The excluded trials correspond to one of four scenarios. (1) In the GTY mapping, the instruction "Stop the AV" was given, but the driver did not look at the pedestrian. (2) In the GTY mapping, the instruction "Do not stop the AV" was given, but the driver looked at the pedestrian. (3) In the LATY mapping, the instruction "Stop the AV" was given, but the driver looked at the pedestrian. (4) In the LATY mapping, the instruction "Do not stop the AV" was given, but the driver did not look at the pedestrian.

Data analysis

Four periods were used for the analysis.

- YieldingApproach (YA): period between the point when there was a distance of 25 m left between the AV and the pedestrian (t = 4.3 s) and the point where the AV was at standstill for 2.6 s (t = 10.9 s).
- NonYieldingApproach (NYA): period between the point when there is a distance of 25 m left between the AV and the pedestrian (t = 4.3 s) and the point in which the AV has passed the zebra crossing (t = 8.1 s).
- YieldingWhole (YW): period between the "press now" signal (t = 0 s) and the point where the AV was at standstill for 2.6 s (t = 10.9 s).
- NonYieldingWhole (NYW): period between the "press now" signal (t = 0 s) and the point in which the AV has passed the zebra crossing (t = 8.1 s).

Two objective and one subjective measure were used:

- *Crossing performance score*, defined as the average of the feel-safe button press percentage over the analysis period. This measure allowed us to understand when participants felt safe to cross the road (24). Moreover, the measure quantifies the crossing effectiveness as a higher crossing performance score corresponds to better identification of crossing opportunities.
  - ND-Y: The performance score per participant was computed by averaging the button press percentage over the YA period and, after that, computing the mean over the trials.
  - ND-NY: The performance score per participant was computed by averaging the button press percentage over the NYA period, subtracting the percentage from 100, and computing the mean over the trials.

- D-Y: Due to the trajectory of the distraction vehicle, the pedestrian should refrain from crossing the road during the approach of the AV till standstill. During the standstill period, the distraction vehicle has already passed the zebra crossing, thus, the pedestrian should cross the road during the standstill period. Hence, not pressing the button during the approach (Phase 2) and pressing the button during the standstill period (Phase 3) correspond to a high performance score.
- D-NY: the performance score was defined the same as the ND-NY condition.

- *Decision certainty* was defined as the average button reversals over the YW period for the yielding condition. Button reversal is defined as a change in the state of the button, e.g. from pressed to released and vice versa. For the non-yielding condition, decision certainty was calculated over the NYW period. This measure reflects how clearly participants understood the AV's intention. It also reflects the participant's trust in automation. More decision reversals would indicate uncertainty, but fewer than the minimum number of reversals would indicate a lack of vigilance.
- *Subjective acceptance*, to rate the subjective acceptance, an acceptance questionnaire (61) was used. This questionnaire assessed the acceptance on two subscales: usefulness and satisfaction.

To illustrate the driver's gaze behaviour, a distribution of all the driver's gaze yaw data pooled at 60 Hz was used. To do this, the yaw occurrence was calculated as the percentage of the total number of pedestrians looking at a given yaw angle over the total number of trials. The calculation was done over the YW or NYW period, depending on the yielding condition. A yaw angle of 90^0 means that the driver was looking straight ahead. A yaw angle less than 90^0 represents the right side and greater than 90^0 represents the left side of the driver.

Finally, to illustrate the gaze behaviour of the pedestrian, a distribution of the yaw difference between the gaze yaw and the angle between the AV and the pedestrian position was used: $YawDifference = GazeYaw - AVYaw$. To illustrate the yaw difference, the occurrence of the yaw difference was calculated in the same way as the yaw occurrence. The calculation was done over the YW or NYW period, depending on the yielding condition. When the yaw difference is zero, the pedestrian looked at the AV. A positive yaw difference means that the pedestrian looked to the left of the AV, and a negative yaw difference means that the pedestrian looked to the right of the AV.

Results

Eleven out of 272 trials (4%) were removed from the GTY mapping: nine in the yielding trials where the driver was supposed to gaze at the pedestrian but did not, and two in the no yielding trials where the driver was supposed to not gaze at the pedestrian but did. Six out of 272 trials (2%) were removed from the LATY mapping: one in the yielding trial, where the driver was supposed to not gaze at the pedestrian, and five in the no yielding trials, where the driver was supposed to gaze at the pedestrian.

Figure *6* shows the driver's gaze yaw distribution during the experiment. The driver's yaw indicates that the mapping and instruction affect the driver's gaze yaw angle. In the yielding conditions (left two subfigures), the gaze in the GTY was directed to the right (the pedestrian) and has two peaks. The first peak at about 80^0 represents the driver looking at the pedestrian during the approach and the second peak at about 65^0 represents the driver looking at the pedestrian during the standstill. The gaze in the LATY was directed to the left and middle, away from the pedestrian. Conversely, in the no yielding conditions (right two subfigures), the gaze in the LATY was directed to the right, while the gaze in the GTY was directed to the left and middle.

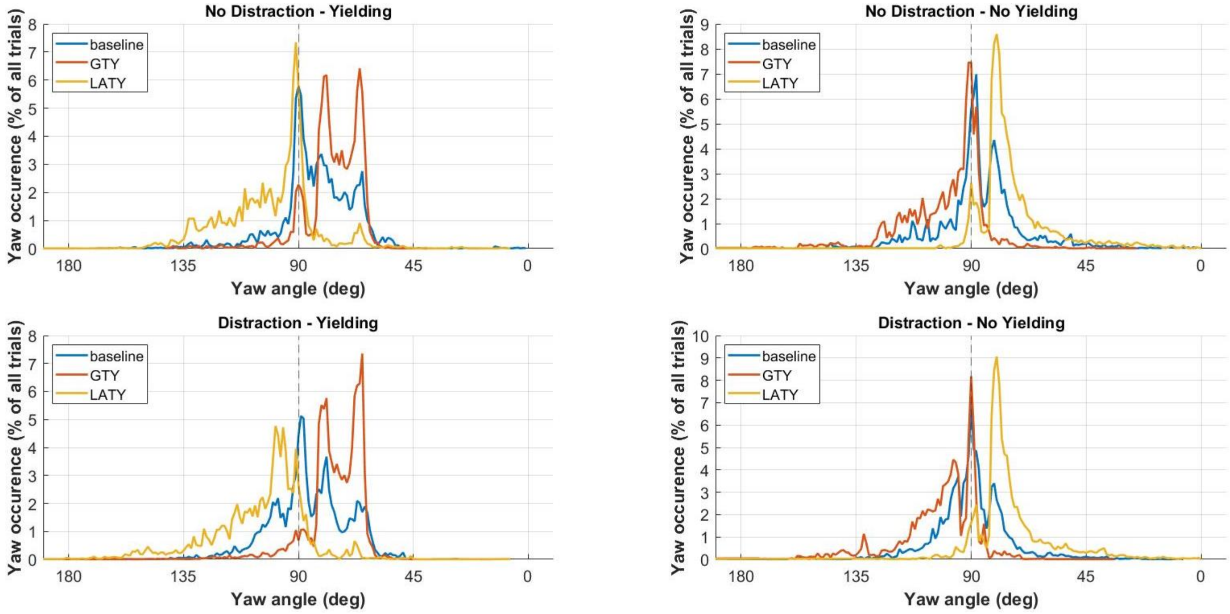

Figure 6: Distribution of the driver gaze yaw. Gaze yaw of 90^0 represents the driver looking straight ahead. Gaze yaw angles smaller than 90^0 represent the right side, and larger than 90^0 represents the left side of the driver. In the yielding conditions (left subfigures), the GTY yaw was directed to the right, as the driver had to look at the pedestrian to yield. The drivers show similar behaviour in the no yielding condition for the LATY mapping.

In Figure 7, the button press data for the no distraction vehicle condition is shown. First, a large decrease in button presses was found in Phase 2 for the yielding scenario of the baseline mapping (solid blue line). This decrease is smaller for the mappings with eye gaze visualisation by about 40% (red and yellow solid lines). Secondly, for the non-yielding scenarios, an earlier drop in button presses is found at the end of Phase 1 and beginning of Phase 2 among the eye gaze visualisation mappings (red and yellow dashed lines) compared to the baseline mapping (blue dashed line).

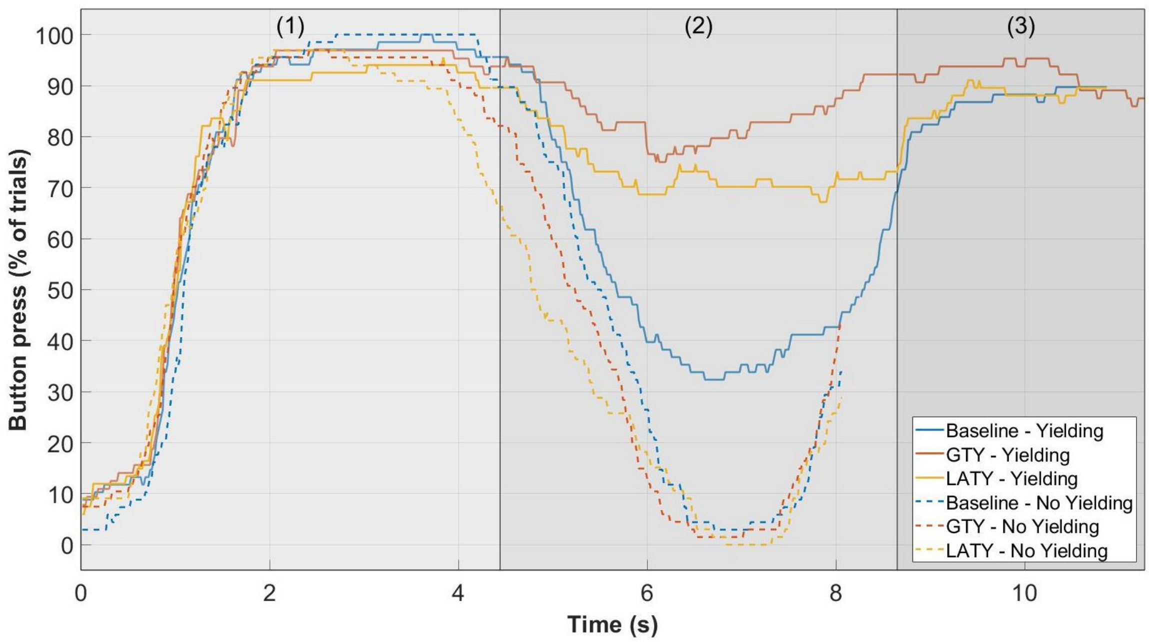

Figure 7: Button press data for the no distraction vehicle condition. (1) represents the period after the start signal "press now" till the start of the yielding trigger detection range, which is equal to a distance of 25 m between the AV and the pedestrian (2) is the start of the yielding trigger detection range till the

standstill of the AV, and (3) is the period when the AV was at a standstill for 2.6 s. In the non-yielding case, the start point is the same, but the trial ends when the back of the AV is past the zebra crossing.

Figure 8 shows the button press data for the condition with the distraction vehicle. Good pedestrian performance in Phase 2 is characterised by the pedestrian releasing the button. In Phase 3, good pedestrian performance is characterised by the pedestrian holding the button. Figure *8* shows a sharp drop in button presses in Phase 2. The minimum button press rate is about 10% lower for the mappings with gaze visualisation (red and yellow solid lines) compared to the baseline condition (solid blue line). For the non-yielding scenarios, an earlier drop in button presses is again observed at the end of Phase 1 and at the beginning of Phase 2 for the mappings with gaze visualisation (red and yellow dashed lines) compared to the baseline mapping (blue dashed line).

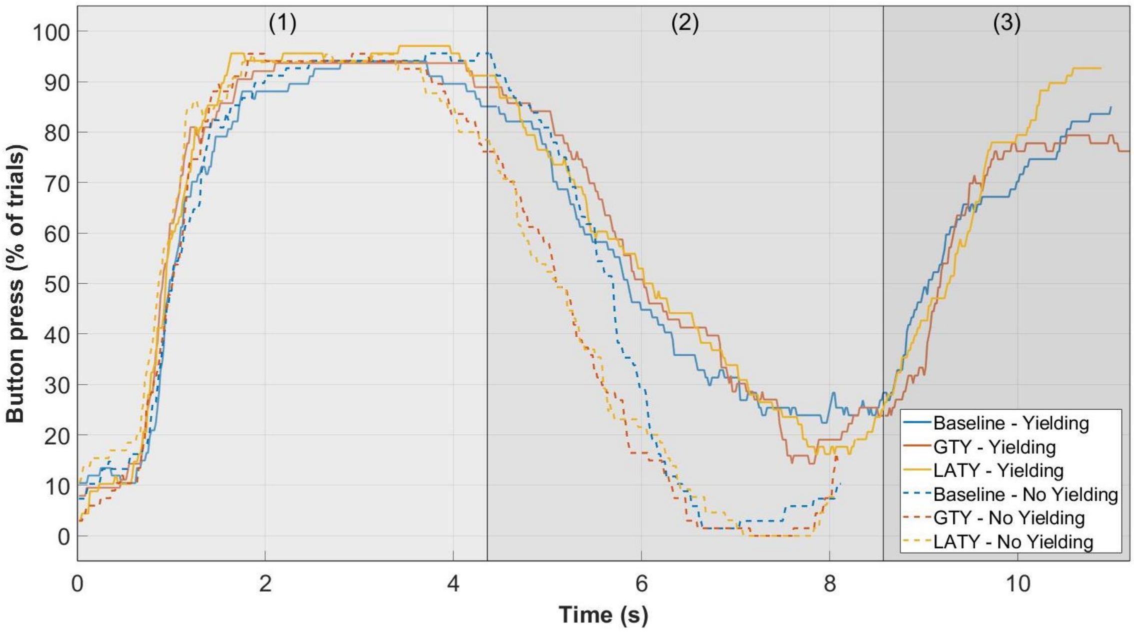

Figure 8: Button press data for the distraction vehicle condition. (1) represents the period after the start signal "press now" till the start of the yielding trigger detection range, which is equal to a distance of 25 m between the AV and the pedestrian (2) is the start of the yielding trigger detection range till the standstill of the AV, and (3) is the period when the AV was at a standstill for 2.6 s. In the non-yielding case, the start point is the same, but the trial ends when the back of the AV is past the zebra crossing.

Table *1* shows the mean crossing performance score and standard deviation inside the parenthesis. The GTY mapping scored the best in three of the scenarios: ND – Y (88.48, SD = 14.66), D – Y (58.69, SD = 20.52), and D – NY (76.76, SD = 18.27). The LATY mapping attained the highest mean performance score for the ND – NY scenario (77.07, SD = 20.40). The baseline mapping attained the lowest mean performance score for all four conditions.

Table 1:Mean crossing performance score per mapping and condition. The standard deviation is noted inside the parentheses.

Mapping	Mean crossing performance score (standard deviation)			
	ND – Y	**ND – NY**	**D – Y**	**D – NY**
Baseline	67.11 (24.50)	65.78 (17.06)	58.56 (22.27)	66.62 (17.40)
GTY	**88.48 (14.66)**	71.42 (16.05)	**58.69 (20.52)**	**76.76 (18.17)**
LATY	79.69 (24.14)	**77.07 (20.40)**	57.14 (20.35)	76.37 (18.64)

Table *2* shows the statistical test results for the crossing performance scores. The crossing performance score differences found in the ND – Y condition were found to be significant between the baseline and the GTY mapping, $t(16) = -3.842$, $p = 0.002$, and between the baseline and the LATY mapping, $t(16) = -3.406$, $p = 0.004$. In the ND – NY condition, significant difference was found between the baseline and

LATY, t(16) = -2.825, p = 0.012. In the D – NY condition, significant difference was found between the baseline and GTY, t(16) = -3.531, p = 0.003, and baseline and LATY, t(16) = -2.259, p = 0.038.

Table 2: Paired samples t-test results for crossing performance per condition. The significant differences are made bold.

Mapping	Crossing performance			
	D – NY	**D – Y**	**ND – NY**	**ND – Y**
Baseline – GTY	**t(16) = -3.531, p = 0.003**	t(16) = -0.404, p = 0.692	t(16) = -1.677, p = 0.113	**t(16) = -3.842, p = 0.002**
Baseline – LATY	**t(16) = -2.259, p = 0.038**	t(16) = -0.529, p = 0.604	**t(16) = -2.825, p = 0.012**	**t(16) = -3.406, p = 0.004**
GTY - LATY	t(16) = 0.487, p = 0.633	t(16) = 0.050, p = 0.961	t(16) = -1.493, p = 0.155	t(16) = 1.412, p = 0.177

Table *3* shows the mean decision certainty of the pedestrians, including the standard deviation. In the ND – Y condition, the GTY (1.95, SD = 1.19) has the fewest decision reversals, followed by LATY (2.00, SD = 1.08), and the baseline (2.40, SD = 0.93) the most. In the ND – NY condition, the number of decision reversals were close to each other for all the mappings (baseline 2.37, SD = 0.57, GTY 2.36, SD = 0.43, LATY 2.29, SD = 0.52). In the D – Y condition, GTY (3.03, SD = 0.60) has the most decision reversals, and the LATY (2.90, SD = 0.64) and the baseline (2.90, SD = 0.58) have about the same number of decision reversals. Lastly, in the D – NY condition, GTY (2.18, SD = 0.37) has the most decision reversals, and the LATY (2.09, SD = 0.37) and the baseline (2.09, SD = 0.39) have about the same number of decision reversals. No significant differences were found, see Appendix D.

A strong significant negative correlation was found between the crossing performance and the decision certainty in the condition ND – Y, r(15) = -0.57, p < 0.001. A medium significant negative correlation was found in the D – Y condition, r(15) = -0.47, p < 0.001. However, a nonsignificant low positive correlation was found in the D – NY condition (r(15) = 0.05, p = 0.708), and a nonsignificant low negative correlation was found in the ND – NY condition (r(15) = 0.006, p = 0.965), see Appendix D.

Table 3: Mean decision certainty of the pedestrians per mapping and condition. The standard deviation is noted inside the parentheses.

Mapping	Mean crossing decision reversals per condition (standard deviation)			
	ND – Y	**ND – NY**	**D – Y**	**D – NY**
Baseline	2.40 (0.93)	2.37 (0.57)	2.90 (0.58)	2.09 (0.39)
GTY	1.95 (1.19)	2.36 (0.43)	3.03 (0.60)	2.18 (0.37)
LATY	2.00 (1.08)	2.29 (0.52)	2.90 (0.64)	2.09 (0.37)

Figure 9 shows the yaw difference in the yielding conditions. The peak at 0^0 in all of the subfigures was caused by the pedestrian looking at the AV. For the ND – Y condition (top three subfigures), GTY (red line) has a higher peak than the other two mappings in all three phases. In Phase 1 (left top subfigure) and Phase 3 (right top subfigure), the small peak at ~170^0 and ~150^0, respectively, represent the pedestrian checking for the distraction vehicle. In Phase 2 (mid top subfigure), only one peak is present, and LATY (yellow line) peaks higher than the baseline (blue line).

In the D – Y condition in Phase 1 (left bottom subfigure), the baseline (blue line) peaks higher at 0^0 than the other two mappings, while the GTY (red line) and LATY (blue line) peak higher at ~170^0. In Phase 2 (mid bottom subfigure), GTY (red line) peaks lowest, meaning that the pedestrian spent less time looking at the AV as compared to LATY (yellow line) and baseline (blue line). In Phase 3 (right bottom subfigure), GTY (red line) peaks the highest, meaning that the pedestrian spent more time looking at the AV as compared to LATY (yellow line) and baseline (blue line). Furthermore, yaw occurrence increases in the range of 0^0 to 150^0 as the AV and distraction vehicle approach the pedestrian.

This indicates that the pedestrian spent more time switching their gaze between the AV and the distraction vehicle.

Furthermore, the yaw difference occurrence is higher for the conditions excluding distraction (top three subfigures) as compared to the conditions including distraction (bottom three subfigures). This indicates that pedestrian spent less time looking at the AV when the distraction vehicle was present.

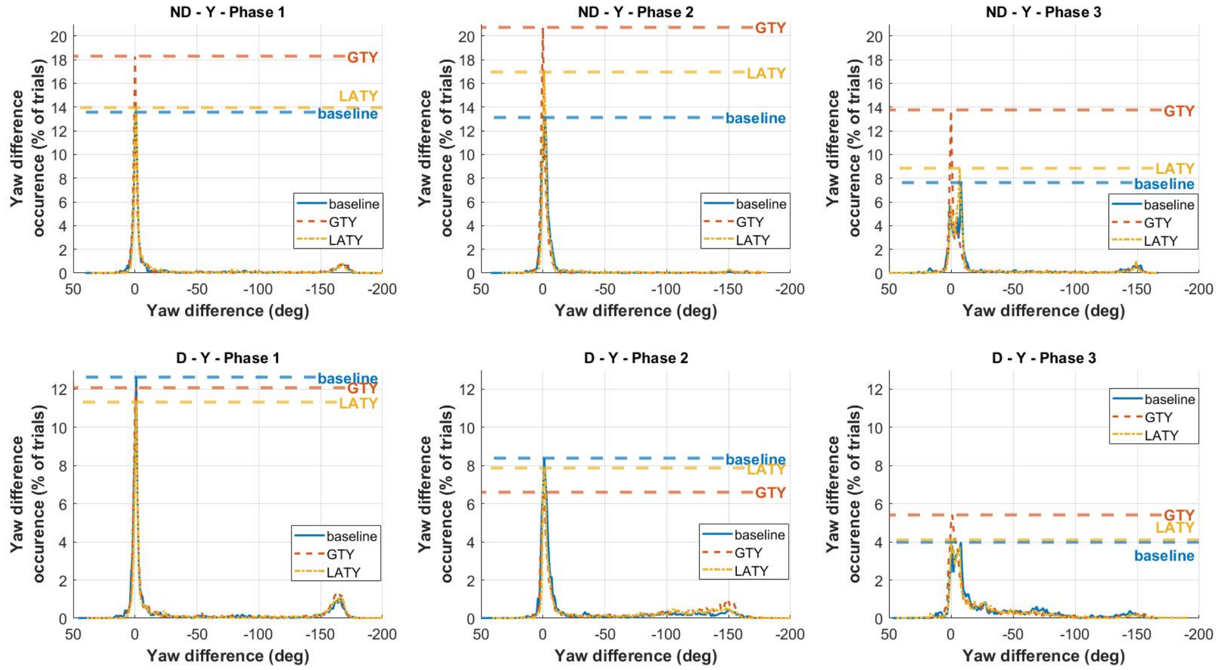

Figure 9: Yaw difference per yielding condition per mapping. The horizontal striped line highlights the top of the highest peak. Number of data points per condition and mapping: ND-Y baseline Phase 1 = 17673, Phase 2 = 15905, Phase 3 = 10676. ND-Y GTY Phase 1 = 16636, Phase 2 = 15256, Phase 3 = 10048. ND-Y LATY Phase 1 = 17410, Phase 2 = 15675, Phase 3 = 10519. D-Y baseline Phase 1 = 17421, Phase 2 = 15674, Phase 3 = 10519. D-Y GTY Phase 1 = 16380, Phase 2 = 14853, Phase 3 = 9891. D-Y LATY Phase 1 = 17680, Phase 2 = 15906, Phase 3 = 10676.

Figure *10* shows the yaw difference in the no yielding conditions. The peak at 0^0 in all of the subfigures was caused by the pedestrian looking at the AV. The small peak at around $\sim 170^0$ represents the pedestrian checking the distraction vehicle. In the ND-NY condition in Phase 1 (left top subfigure), GTY (red line) peaks lower at 0^0 than LATY (yellow line) and baseline (blue line), meaning that the pedestrians spent less time gazing at the AV. In Phase 2 (right top subfigure), LATY (yellow line) peaks higher at 0^0 than GTY (blue line) and baseline (blue line), meaning that the pedestrians spent more time gazing at the AV.

For the D-NY condition in Phase 1 (left bottom subfigure) and Phase 2 (right bottom subfigure), LATY (yellow line) peaks highest at 0^0 followed by baseline (blue line) and GTY (red line). Surprisingly, yaw occurrence did not increase in the range of 0^0 to 150^0. This indicates that the pedestrian spent most of their time gazing at the AV rather than the distraction vehicle when the AV did not yield.

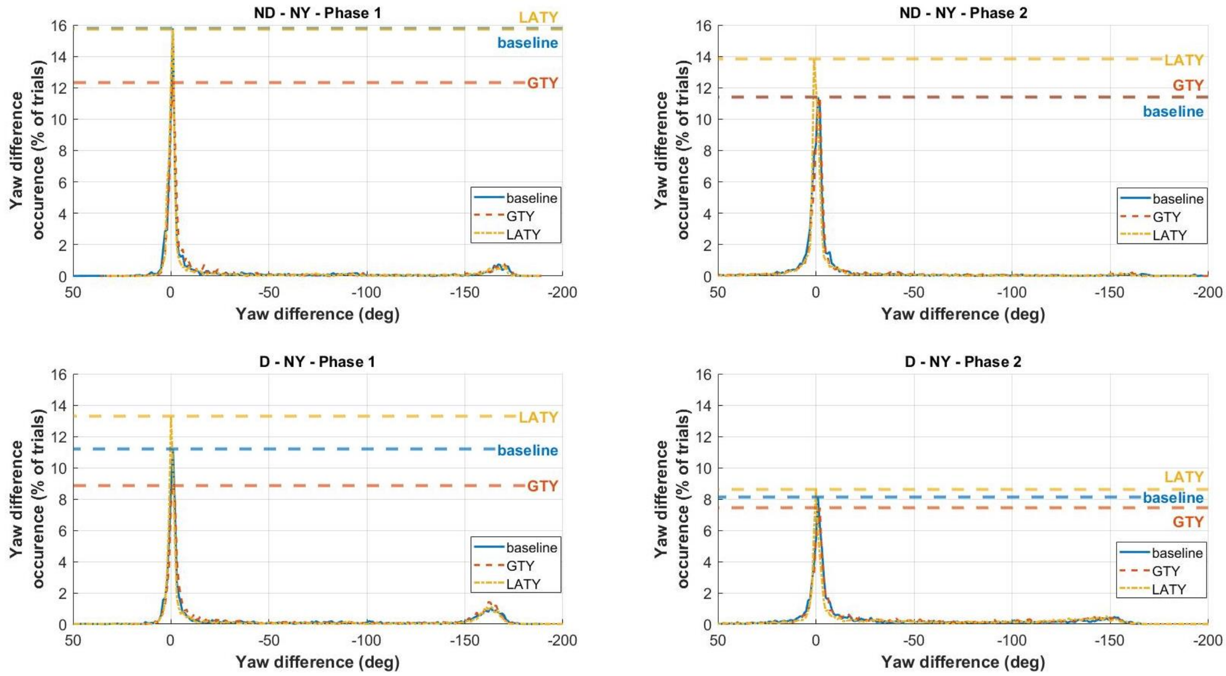

Figure 10: Yaw difference per no yielding condition per mapping. The horizontal striped line highlights the top of the highest peak. Number of data points per condition and mapping: ND-NY baseline Phase 1 = 17673, Phase 2 = 15123. ND-NY GTY Phase 1 = 17407, Phase 2 = 14903. ND-NY LATY Phase 1 = 17160, Phase 2 = 14673. D-NY baseline Phase 1 = 17680, Phase 2 = 15144. D-NY GTY Phase 1 = 17421, Phase 2 = 14924. D-NY LATY Phase 1 = 16900, Phase 2 = 14483.

Figure *11* shows the mean acceptance rating of the eye gaze visualisation system, along with the subscales usefulness and satisfaction for the pedestrian and driver. The pedestrians and the drivers experienced the GTY mapping as the most satisfying and useful, followed by the LATY mapping and, lastly, the baseline.

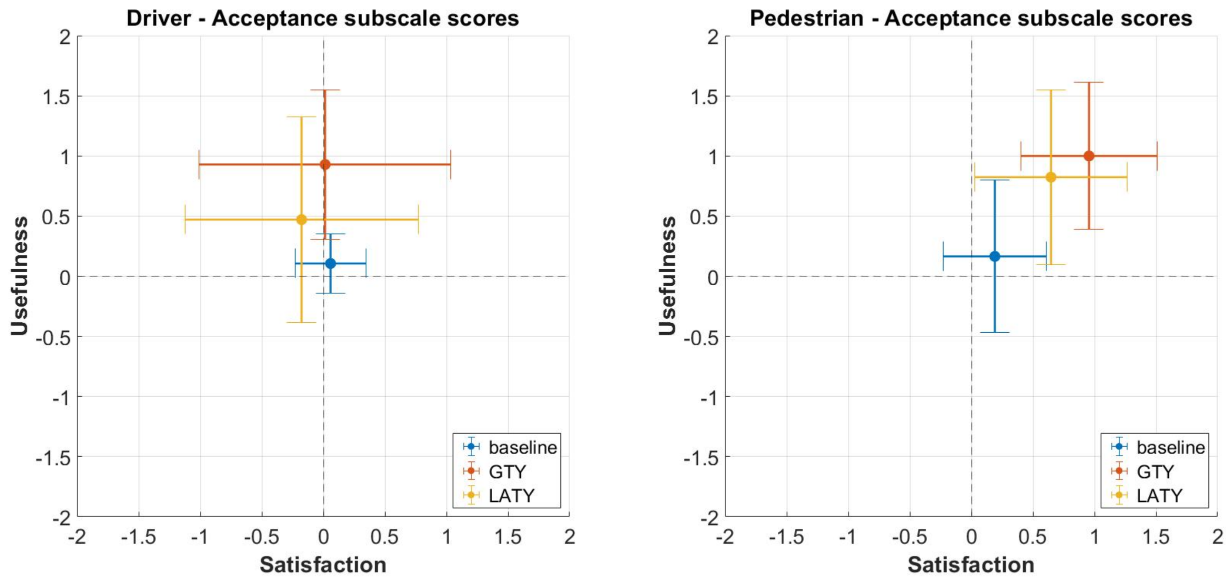

Figure 11: Mean acceptance ratings plotted from the pedestrians and passengers along with the standard deviation illustrated as error bars. The scores range from -2 (unfavourable) to +2 (favourable).

Table A1 (in Appendix D) shows significant difference for usefulness rated by the pedestrians between the mappings baseline and GTY, $t(16) = -4.301$, $p < 0.001$, and baseline and LATY, $t(16) = -3.618$, p =

0.002. No significant difference was found for pedestrian usefulness between GTY and LATY. A significant difference was found for the pedestrian satisfaction between the mappings baseline and GTY, $t(16) = -4.790$, $p < 0.001$, GTY and LATY, $t(16) = 2.811$, $p = 0.013$, and between the baseline and the LATY, $t(16) = 3.917$, $p < 0.001$.

For the driver, both GTY and LATY scored higher on usefulness compared to the baseline. However, the satisfaction score for the GTY and LATY conditions were rated lower than baseline. The GTY had the highest acceptance score among the drivers, followed by the baseline, with LATY in the last place. Table A2 (in Appendix D) shows significant difference in usefulness among the drivers between the mappings baseline and GTY, $t(16) = -5.828$, $p < 0.001$, and GTY and LATY, $t(16) = 2.194$, $p = 0.043$. No significant difference was found for the driver usefulness between the baseline and LATY. Moreover, no significant difference was found between all of the mappings for the drivers' satisfaction. Overall, the acceptance of the GTY was rated the best by both the pedestrians and drivers.

Table *4* shows, firstly, the clarity of the AV's intention rated on a 7-point Likert scale. The GTY mapping was rated the best, followed by the LATY, with the baseline in the last place. Secondly, Table *4* shows the mean preference of the participants. The pedestrians and the drivers ranked the GTY mapping as the most preferred and the LATY mapping as the least preferred.

Table 4: Mean score and standard deviations in the parentheses of the pedestrians' clarity on the AV's intention rated on a 7-point Likert scale (7=best, 1=worst) in the middle column. Mean rank and standard deviations in the parentheses of the pedestrians and drivers personal mapping preference (1 = best, 3 = worst)

Mapping	**Mean clarity score AV intention (7 = best, 1 = worst)**	**Mean preference ranking (1 = best, 3 = worst)**	
	Pedestrian	Pedestrian	Driver
Baseline	4.71 (1.40)	2.35 (0.79)	1.94 (0.66)
Gaze to Yield	5.65 (1.22)	1.18 (0.39)	1.65 (0.86)
Look Away to Yield	5.00 (1.70)	2.47 (0.51)	2.41 (0.80)

Table A10 and Table A11 in Appendix F show the drivers' and pedestrians' comments respectively to the free-response question in the post-block questionnaire: "Anything you would like to share regarding this mapping?". The responses for the LATY mapping all stated that the LATY mapping felt counterintuitive (3 drivers; 3 pedestrians). For the GTY mapping, one driver mentioned that it was easier to follow the instructions than with the LATY mapping. Moreover, one pedestrian mentioned that the eye gaze visualisation made it clearer when the vehicle was going to stop. Furthermore, one pedestrian mentioned in after the baseline block that the equipment was quite heavy, which is a problem that more participants reported during the breaks.

Discussion

The aim of this study is to determine whether eye gaze visualisation of AV's driver can improve the road crossing interaction between an AV and a pedestrian, and to investigate which mapping is accepted by pedestrians. To this end, the effectiveness, acceptance, and preference of the two mappings of gaze visualisations were examined and compared to the baseline. Effectiveness was quantified in terms of a crossing performance score, whereas acceptance was determined via an acceptance questionnaire after each block of trials. Each block contained one of the mappings: baseline, GTY, or LATY. In addition, participants were asked to rate the two eye gaze visualisation mappings and the baseline according to their preference.

Pedestrians attained higher performance scores with eye gaze visualisation compared to without. This result is consistent with previous research showing that signalling the intent improves crossing performance (24,32,38). The GTY mapping yielded higher crossing performance than the LATY mapping in all conditions except the ND – NY condition. This non-significant effect could be due to the driver looking at the pedestrian in the LATY mapping, as eye contact serves as an antecedent for compliant behaviour (64,65). GTY mapping was rated higher than LATY mapping in terms of usefulness and satisfaction, presumably because the LATY mapping was less intuitive. One pedestrian made the following comments in a free-response question in the post-block questionnaire: *"This map (LATY) was confusing me a bit. When the spotlights (the lasers) were on me, I was thinking that it was my turn to cross the road, while I actually should wait."* This counterintuitive logic compared to current driver behaviour was also evident in the preference ratings. Pedestrians rated LATY mapping as the least preferred mapping among all three, followed by baseline and GTY mapping as the most preferred.

Drivers rated the mappings in the same rank order as pedestrians, with the GTY mapping as most preferred, followed by the baseline and the LATY mapping as least preferred. Driver satisfaction scores indicated that baseline scored the highest (0.06), followed by GTY (0.01), and lastly LATY (-0.18). Nonetheless, drivers found gaze visualisation to be a useful way to communicate their intent. However, in the case of LATY, drivers indicated that it felt counterintuitive. One driver mentioned in the post-block questionnaire: *"I had to think hard about if I had to look away or not. It was not logical to me."*

For decision certainty, pedestrians were expected to be more certain of their decision when they knew the intention of the AV, resulting in fewer decision reversals in the trials with eye-gaze visualisation (66). In addition, a lower number of decision reversals was expected when the crossing performance score was high, as confident pedestrians who achieve a high crossing performance score are more certain of their decision. However, no correlation is found in the non-yielding conditions, see Table A8 in Appendix D. This raises the question of whether decision certainty is a good measure at all. An important factor missing in the measure is the duration of the button press and the moment of decision reversal. Figure *7* shows that pedestrians in the mappings with eye-gaze visualisation let go of the button earlier compared to the baseline when they knew that the AV would not yield, but this behaviour was not captured by decision certainty.

The yaw difference (Figure *9* and Figure *10*) indicated that the eye gaze visualisation attracted the attention of the pedestrian, which resulted in the pedestrian spending more time gazing at the AV itself compared to without the gaze visualisation. The effect was dominant when the gaze visualisation was pointed at the pedestrian. Interestingly, the pedestrians spent less time gazing at the AV in the D-Y GTY condition in Phase 2. The pedestrians could see that the AV would yield from the position of the eye gaze visualisation while looking at the distraction vehicle due to the length of the eye gaze visualisation. It should be noted that participants may have learned to understand the pre-programmed behaviour of the vehicles, as both vehicles reached the zebra crossing at the same time. Furthermore, the lower peaks at 0^0 in the no yielding conditions GTY indicate that no yielding and looking away discourages pedestrians from looking at the AV.

In ambiguous situations, undirected signalling confuses pedestrians; with eye gaze visualisation, the communicated message can be directed towards specific pedestrian(s) (66). Furthermore, in mixed traffic, it may inform the pedestrian that the vehicle equipped with the eye gaze visualisation is an AV, as manually driven vehicles can be assumed not to be equipped with the eye gaze visualisation system.

The baseline block was not considered in the randomisation of the block order. It was expected that the pedestrian could not learn from the baseline block, unlike GTY and LATY where pedestrians could become accustomed to the novel eye gaze visualisation. Figure A3 shows the pedestrian's mean button presses per block order group. The differences in button presses between the two pedestrian groups appear to be negligible, as the differences in the button presses in GTY and LATY were of approximately the same magnitude as the differences in the baseline. There should have been no learning effects in the baseline block since the baseline was always the first block. Furthermore, the differences could have been due to individual differences. The effect per participant in their respective group was large as the number of participants per group was small, 8 and 9.

During data filtering, nine trials were removed from the GTY mapping, and four trials were removed from the LATY mapping, due to the driver not complying with the instructions. This lack of compliance may have been due to a misunderstanding of the mapping, loss of focus, or curiosity manifested by testing whether the AV acted based on their gazing behaviour. Another reason is eye tracking inaccuracy. During the experiment, the eye tracking of several drivers had to be recalibrated several times due to eye tracking inaccuracies. The drivers were unable to point the gaze visualisation. Adding a margin to the height of the pedestrian avatar's hitbox would have prevented some of this undesired vehicle behaviour.

A noteworthy aspect of the experiment is the use of two participants in an AV-pedestrian interaction study, an approach that is relatively rare but gaining popularity in human factors research (67–74). The inclusion of a second participant to provide the human gaze may have contributed to more natural and realistic situations. However, this does introduce more variation and complexity as every person behaves differently.

Another notable aspect is the combination of eye tracking and head tracking in HMD. Head tracking in the HMD allowed the pedestrian to observe the environment in 360^0. Meaning that the eye gaze behaviour is also tracked in 360^0, as opposed to fixed FOV in monitor screens.

Limitations and recommendations

A small number of people participated in the experiment due to the COVID-19 pandemic. A larger sample size is needed to get significant results to draw conclusions regarding the validity of decision certainty. Furthermore, the sample of participants lacks diversity in terms of age and nationality. These two factors have been shown to influence crossing behaviour. The increase of age contributes to cognitive and sensory decline, also resulting in older people taking fewer risks (75). Conversely, young adults are more likely to take higher risks (76). Lastly, nationality may influence crossing behaviour due to differences in cultural and social norms across countries (34,77,78).

Another two limitations are the restricted movement of the pedestrians, and the lack of vehicle sounds in the VR. The pedestrians could only rotate their heads to observe their environment. These two factors contribute to the sense of the presence of the participants, where the presence can be defined as "the subjective experience of being in one place or environment, even when one is physically situated in another" (63). Presence is an important aspect of VR studies as it has often been linked to the behavioural validity of VR environments (63). However, even with a high level of presence in VR, it is still unclear whether testing in VR is as valid as naturalistic testing (42).

Like many other AV-pedestrian interaction studies, the experiment addressed the use case of a single pedestrian crossing in front of one or two vehicles. In reality, however, a pedestrian crossing is much more complex. In actual (future) traffic, pedestrians may have to deal with a large number of other pedestrians and AVs at different levels of automation, as well as different crossing configurations and different weather conditions (40). The effect of eye gaze visualisation on pedestrian gaze behaviour requires further research. In addition, gaze visualisation uses a single modality, which is a problem for individuals with visual impairments.

Another aspect is the design of the eye gaze visualisation. The effects of the visualisation colour, position, and activation distance have not been examined. A previous study (79) showed that these factors have a significant effect on the crossing behaviour of pedestrians in the framework of more classical visual eHMIs. It could be interesting to investigate the effect of these factors on the eye gaze visualisation system.

Regarding the experiment, the block order randomisation did not include the baseline block. As it was expected that there would be no learning effects in the baseline block due to the addition of a practice round. It would be a welcome addition to the present study to investigate whether learning effect assumption was correct.

In our study, the eye gaze visualisation system was compared to a baseline condition without eye gaze visualisation. A comparison between the eye gaze visualisation systems and existing eHMIs would be a welcome addition to the present study.

The technical and practical feasibility of the eye gaze visualisations were not considered in the design process. Actual visualisation of the driver's eye gaze brings many challenges. Eye-trackers and a laser projector system would need to be installed on the AV. Moreover, the eye gaze visualisation could distract other drivers and potentially lead to accidents. In real-life scenarios, one also needs to consider the visibility of the eye gaze visualisation in changing weather conditions (40) as well as the visibility of the visualisation based on the distance. Another approach to implementing eye gaze visualisation is via augmented reality (AR). AR would solve the problem of distracting other road users and visibility in changing weather conditions as the visualisation is displayed directly on the wearable. However, many challenges regarding augmented reality need to be addressed in future traffic, such as challenges of privacy, invasiveness, user-friendliness, technological feasibility, and inclusiveness (42).

Conclusions

This study aimed to determine whether eye gaze visualisation of AV's driver can improve the road crossing interaction between an AV and a pedestrian, and to find out which mapping is accepted by pedestrians. The eye gaze visualisation improved the crossing interaction as the crossing performance was higher for both GTY and LATY compared to the baseline. The GTY mapping achieved the highest acceptance among all mappings. Eye gaze visualisation combined with GTY mapping (and AR) could be used as a communication tool for AVs. However, the effectiveness compared to other eHMIs is unknown, and many limitations still need to be addressed.

Supplementary material

Supplementary material that includes the questionnaire used, videos, anonymous data, and MATLAB code used for analysis may be found at:
https://www.dropbox.com/sh/02nqge0wgujtxfq/AACIs53go8czVUo7ssIOA84Va.
Additionally:

- Open-source code of the simulator: https://github.com/bazilinskyy/coupled-sim.
- Demo video of the GTY mapping: https://youtu.be/nMoNtOy5QHs.
- Demo video of the LATY mapping: https://youtu.be/v3zbc64ScEg.
- Animations of the videos of the top view for all conditions with percentage button presses: https://www.youtube.com/playlist?list=PLczQzN50Cj1i1P2jfUWe1sJo1r061_cB_.

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References

1. Färber B. Communication and Communication Problems Between Autonomous Vehicles and Human Drivers. Autonomous Driving: Technical, Legal and Social Aspects. 2016;125–43.

2. Risto M, Emmenegger C, Vinkhuyzen E, Cefkin M, Hollan J. Human-Vehicle Interfaces: The Power of Vehicle Movement Gestures in Human Road User Coordination. 2017;(November 2017):186–92.

3. Ren Z, Jiang X, Wang W. Analysis of the Influence of Pedestrians' eye Contact on Drivers' Comfort Boundary during the Crossing Conflict. Procedia Engineering. 2016;137:399–406.

4. Sucha M. Road users' strategies and communication: driver-pedestrian interaction. Transport Research Arena (TRA). 2014;12.

5. Sandt L, Owens J. Discussion Guide for Automated and Connected Vehicles, Pedestrians, and Bicyclists [Internet]. 2017. Available from: http://www.pedbikeinfo.org/pdf/PBIC_AV.pdf

6. Rasouli A, Kotseruba I, Tsotsos JK. Agreeing to cross: How drivers and pedestrians communicate. IEEE Intelligent Vehicles Symposium, Proceedings. 2017;264–9.

7. Sucha M, Dostal D, Risser R. Pedestrian-driver communication and decision strategies at marked crossings. Accident Analysis and Prevention [Internet]. 2017;102:41–50. Available from: http://dx.doi.org/10.1016/j.aap.2017.02.018

8. Lee YM, Madigan R, Giles O, Garach-Morcillo L, Markkula G, Fox C, et al. Road users rarely use explicit communication when interacting in today's traffic: implications for automated vehicles. Cognition, Technology and Work [Internet]. 2020;23(2):367–80. Available from: https://doi.org/10.1007/s10111-020-00635-y

9. Rasouli A, Tsotsos JK. Autonomous vehicles that interact with pedestrians: A survey of theory and practice. IEEE Transactions on Intelligent Transportation Systems. 2020;21(3):900–18.

10. Lu Z, Zhang B, Feldhütter A, Happee R, Martens M, de Winter JCF. Beyond mere take-over requests: The effects of monitoring requests on driver attention, take-over performance, and acceptance. Transportation Research Part F: Traffic Psychology and Behaviour. 2019;63(March):22–37.

11. Hawkins AJ. GM working on major upgrades to Super Cruise before kicking off 2020 rollout - The Verge [Internet]. The Verge. 2019 [cited 2021 Apr 6]. Available from: https://www.theverge.com/2019/4/28/18515802/cadillac-super-cruise-ct5-ny-auto-show-2019

12. Reiner M, Hilel S, Hadar Z. DRIVER PREDICTIVE MENTAL RESPONSE PROFILE AND APPLICATION TO AUTOMATED VEHICLE BRAIN INTERFACE CONTROL [Internet]. 2019. Available from: https://patentimages.storage.googleapis.com/38/14/40/db151c85bc3c2f/WO2019220436A3.pdf

13. Vijayan I, Laur MH, Absmeier JP. Automated vehicle operation based on gesture to pedestrian. United States; 14/987,188, 2017.

14. Detjen H, Geisler S, Schneegass S. Maneuver-based Control Interventions during Automated Driving: Comparing Touch, Voice, and Mid-Air Gestures as Input Modalities. IEEE Transactions on Systems, Man, and Cybernetics: Systems. 2020;2020-Octob:3268–74.

15. Flemisch F, Diederichs F, Meyer R, Herzberger N, Baier R, Altendorf E, et al. Vorreiter: Manoeuvre-Based Steering Gestures for Partially and Highly Automated Driving. 2020. 231–304.

16. Kauer M, Schreiber M, Bruder R. How to conduct a car? A design example for maneuver based driver-vehicle interaction. IEEE Intelligent Vehicles Symposium, Proceedings. 2010;1214–21.

17. Wang C, Krüger M, Wiebel-Herboth CB. "Watch out!": Prediction-Level Intervention for Automated. Proceedings - 12th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2020. 2020;169–80.

18. Detjen H, Geisler S, Schneegass S. Maneuver-based Driving for Intervention in Autonomous Cars. arXiv. 2020;(May 2019).

19. Flemisch F, Bengler K, Bubb H, Winner H, Bruder R. Towards cooperative guidance and control of highly automated vehicles: H-Mode and Conduct-by-Wire [Internet]. Vol. 57, Ergonomics. Taylor & Francis; 2014. p. 343–60. Available from: http://dx.doi.org/10.1080/00140139.2013.869355

20. Walch M, Sieber T, Hock P, Baumann M, Weber M. Towards cooperative driving: Involving the driver in an autonomous vehicle's decision making. AutomotiveUI 2016 - 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Proceedings. 2016;261–8.

21. Bagheri M, Siekkinen M, Nurminen JK. Cellular-based vehicle to pedestrian (V2P) adaptive communication for collision avoidance. 2014 International Conference on Connected Vehicles and Expo, ICCVE 2014 - Proceedings. 2014;450–6.

22. Hussein A, García F, Armingol JM, Olaverri-Monreal C. P2V and V2P communication for pedestrian warning on the basis of autonomous vehicles. IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC. 2016;2034–9.

23. Cœugnet S, Dommes A, Panëels S, Chevalier A, Vienne F, Dang NT, et al. A vibrotactile wristband to help older pedestrians make safer street-crossing decisions. Accident Analysis and Prevention. 2017;109(January):1–9.

24. de Clercq K, Dietrich A, Núñez Velasco JP, de Winter J, Happee R. External Human-Machine Interfaces on Automated Vehicles: Effects on Pedestrian Crossing Decisions. Human Factors. 2019;61(8):1353–70.

25. Ackermann C, Beggiato M, Schubert S, Krems JF. An experimental study to investigate design and assessment criteria: What is important for communication between pedestrians and automated vehicles? Applied Ergonomics [Internet]. 2019;75(November 2018):272–82. Available from: https://doi.org/10.1016/j.apergo.2018.11.002

26. Bazilinskyy P, Dodou D, de Winter J. Survey on eHMI concepts: The effect of text, color, and perspective. Transportation Research Part F: Traffic Psychology and Behaviour [Internet]. 2019;67:175–94. Available from: https://doi.org/10.1016/j.trf.2019.10.013

27. Deb S, Strawderman LJ, Carruth DW. Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. Transportation Research Part F: Traffic Psychology and Behaviour [Internet]. 2018;59:135–49. Available from: https://doi.org/10.1016/j.trf.2018.08.016

28. Fridman L, Mehler B, Xia L, Yang Y, Facusse, Laura Yvonne Reimer B. To Walk or Not to Walk: Crowdsourced Assessment of External Vehicle-to-Pedestrian Displays. Journal of Chemical Information and Modeling. 2017;

29. Hudson CR, Deb S, Carruth DW, McGinley J, Frey D. Pedestrian perception of autonomous vehicles with external interacting features. In: Advances in Intelligent Systems and Computing. Springer Verlag; 2019. p. 33–9.

30. Semcon. The Smiling Car - Self driving car that sees you | Semcon [Internet]. Semcon. 2021 [cited 2021 Apr 6]. Available from: https://semcon.com/smilingcar/

31. Chang CM. A Gender Study of Communication Interfaces between an Autonomous Car and a Pedestrian. Adjunct Proceedings - 12th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2020. 2020;42–5.

32. Chang CM, Toda K, Sakamoto D, Igarashi T. Eyes on a car: An interface design for communication between an autonomous car and a pedestrian. AutomotiveUI 2017 - 9th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, Proceedings. 2017;(Figure 1):65–73.

33. Löcken A, Golling C, Riener A. How should automated vehicles interact with pedestrians? A comparative analysis of interaction concepts in virtual reality. Proceedings - 11th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2019. 2019;262–74.

34. Weber F, Chadowitz R, Schmidt K, Messerschmidt J, Fuest T. Crossing the Street Across the Globe: A Study on the Effects of eHMI on Pedestrians in the US, Germany and China [Internet]. Vol. 11596 LNCS, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Springer International Publishing; 2019. 515–530. Available from: http://dx.doi.org/10.1007/978-3-030-22666-4_37

35. Mahadevan K, Somanath S, Sharlin E. Communicating awareness and intent in autonomous vehicle-pedestrian interaction. Conference on Human Factors in Computing Systems - Proceedings. 2018;2018-April:1–12.

36. Jaguar, Land-Rover. THE VIRTUAL EYES HAVE IT | JLR Corporate Website [Internet]. jaguarlandrover. 2021 [cited 2021 Apr 6]. Available from: https://www.jaguarlandrover.com/2018/virtual-eyes-have-it

37. Urmson CP, Mahon IJ, Dolgov DA, Zhu J. Pedestran Notifications. Unites States: Google Patents; US8954252B1, 2015.

38. Böckle MP, Klingegard M, Habibovic A, Bout M. SAV2P - Exploring the impact of an interface for shared automated vehicles on pedestrians' experience. AutomotiveUI 2017 - 9th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, Adjunct Proceedings. 2017;136–40.

39. Hudson CR, Deb S, Carruth DW, McGinley J, Frey D. Advances in Human Factors and Systems Interaction. In: Advances in Intelligent Systems and Computing [Internet]. Springer International Publishing; 2019. p. 33–9. Available from: http://link.springer.com/10.1007/978-3-319-94334-3

40. Dey D, Habibovic A, Löcken A, Wintersberger P, Pfleging B, Riener A, et al. Taming the eHMI jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces. Transportation Research Interdisciplinary Perspectives. 2020;7.

41. Špakov O, Istance H, Räihä KJ, Viitanen T, Siirtola H. Eye gaze and head gaze in collaborative games. Eye Tracking Research and Applications Symposium (ETRA). 2019;(January 2020).

42. Tabone W, de Winter J, Ackermann C, Bärgman J, Baumann M, Deb S, et al. Vulnerable road users and the coming wave of automated vehicles: Expert perspectives. Transportation Research Interdisciplinary Perspectives. 2020;9(October).

43. Tapiro H, Oron-Gilad T, Parmet Y. Pedestrian distraction: The effects of road environment complexity and age on pedestrian’s visual attention and crossing behavior. Journal of Safety Research [Internet]. 2020;72:101–9. Available from: https://doi.org/10.1016/j.jsr.2019.12.003

44. Jiang YS, Warnell G, Munera E, Stone P. A Study of Human-Robot Copilot Systems for En-route Destination Changing. RO-MAN 2018 - 27th IEEE International Symposium on Robot and Human Interactive Communication. 2018;997–1004.

45. Wu M, Louw T, Lahijanian M, Ruan W, Huang X, Merat N, et al. Gaze-based Intention Anticipation over Driving Manoeuvres in Semi-Autonomous Vehicles. IEEE International Conference on Intelligent Robots and Systems. 2019;6210–6.

46. Bazilinskyy P, Kooijman L, Dodou D, de Winter JCF. Coupled simulator for research on the interaction between pedestrians and (automated) vehicles. 19th Driving Simulation Conference (DSC). 2020;(September).

47. Roser M, Appel C, Ritchie H. Human Height [Internet]. Our world in Data. 2013 [cited 2021 May 7]. Available from: https://ourworldindata.org/human-height#citation

48. Schenker. Varjo VR-2 & VR-2 Pro - The World’s Sharpest VR Headsets [Internet]. schenker-tech. 2021 [cited 2021 May 28]. Available from: https://www.schenker-tech.de/en/varjo-vr-2-en

49. Marsaglia G. Xorshift RNGs. Journal of Statistical Software. 2003;8:1–6.

50. Millodot M. Dictionary of Optometry and Vision Science - 8th Edition [Internet]. 8th ed. Elsevier; 2017 [cited 2021 Apr 6]. Available from: https://www.elsevier.com/books/dictionary-of-optometry-and-vision-science/millodot/978-0-7020-7222-2

51. Schneemann F, Gohl I. Analyzing driver-pedestrian interaction at crosswalks: A contribution to autonomous driving in urban environments. IEEE Intelligent Vehicles Symposium, Proceedings. 2016;2016-Augus(Iv):38–43.

52. Schroeder BJBJ. A Behavior-Based Methodology for Evaluating Pedestrian-Vehicle Interaction at Crosswalks. Analysis [Internet]. 2008;332. Available from: https://books.google.com/books?id=JV4FaLrTmLUC&pgis=1%5Cnhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:A+Behavior-based+methodology+for+evaluating+pedestrian-vehicle+interaction+at+crosswalks#0

53. Cavallo V, Dommes A, Dang NT, Vienne F. A street-crossing simulator for studying and training pedestrians. Transportation Research Part F: Traffic Psychology and Behaviour [Internet]. 2019;61:217–28. Available from: https://doi.org/10.1016/j.trf.2017.04.012

54. Dommes A, Cavallo V. Can simulator-based training improve street-crossing safety for elderly pedestrians? Transportation Research Part F: Traffic Psychology and Behaviour. 2012;15(2):206–18.

55. Feldstein IT, Dyszak GN. Road crossing decisions in real and virtual environments: A comparative study on simulator validity. Accident Analysis and Prevention [Internet]. 2020;137(February):105356. Available from: https://doi.org/10.1016/j.aap.2019.105356

56. Lobjois R, Cavallo V. Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task. Accident Analysis and Prevention. 2007;39(5):934–43.

57. Oxley JA, Ihsen E, Fildes BN, Charlton JL, Day RH. Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. Accident Analysis and Prevention. 2005;37(5):962–71.

58. Simpson G, Johnston L, Richardson M. An investigation of road crossing in a virtual environment. Accident Analysis and Prevention. 2003;35(5):787–96.

59. Soares F, Silva E, Pereira F, Silva C, Sousa E, Freitas E. The Influence of Noise Emitted by Vehicles on Pedestrian Crossing Decision-Making A Study in a Virtual Environment.pdf. Applied Sciences; 2020.

60. Schmidt S, Färber B. Pedestrians at the kerb - Recognising the action intentions of humans. Transportation Research Part F: Traffic Psychology and Behaviour. 2009;12(4):300–10.

61. van der Laan JD, Heino A, de Waard D. A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research Part C: Emerging Technologies. 1997;5(1):1–10.

62. Bos JE, MacKinnon SN, Patterson A. Motion sickness symptoms in a ship motion simulator: Effects of inside, outside, and no view. Aviation Space and Environmental Medicine. 2005;76(12):1111–8.

63. Witmer BG, Singer MJ. Measuring Presence in Virtual Environments: A Presence Questionnaire. Conference on Human Factors in Computing Systems - Proceedings. 1998;7(3):225–40.

64. Hamlet CC, Axelrod S, Kuerschner S. Eye contact as an antecedent to compliant behavior. Journal of Applied Behavior Analysis. 1984;17(4):553–7.

65. Kleinke CL. Compliance to requests made by gazing and touching experimenters in field settings. Journal of Experimental Social Psychology. 1977;13(3):218–23.

66. Dietrich A, Willrodt J-H, Wagner K, Bengler K. Projection-Based External Human Machine Interfaces – Enabling Interaction between Automated Vehicles and Pedestrians. Proceedings of the Driving Simulation Conference 2018 Europe VR. 2018;43–50.

67. Hancock PA, de Ridder SN. Behavioural accident avoidance science: Understanding response in collision incipient conditions. Ergonomics. 2003;46(12):1111–35.

68. Houtenbos M, de Winter JCF, Hale AR, Wieringa PA, Hagenzieker MP. Concurrent audio-visual feedback for supporting drivers at intersections: A study using two linked driving simulators. Applied Ergonomics [Internet]. 2017;60:30–42. Available from: http://dx.doi.org/10.1016/j.apergo.2016.10.010

69. Lehsing C, Kracke A, Bengler K. Urban Perception-A Cross-Correlation Approach to Quantify the Social Interaction in a Multiple Simulator Setting. IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC. 2015;2015-Octob:1014–21.

70. Muehlbacher D, Rittger L, Maag C, Ag AO. Real Vs. Simulated Surrounding Traffic – Does It Matter? Driving Simulation Conference. 2014;(22):1–5.

71. Oeltze K, Schießl C. Benefits and challenges of multi-driver simulator studies. In: IET Intelligent Transport Systems. Institution of Engineering and Technology; 2015. p. 618–25.

72. Preuk K, Stemmler E, Schießl C, Jipp M. Does assisted driving behavior lead to safety-critical encounters with unequipped vehicles' drivers? Accident Analysis and Prevention [Internet]. 2016;95:149–56. Available from: http://dx.doi.org/10.1016/j.aap.2016.07.003

73. Ko J, Jang J, Oh C. A Multi-Agent Driving Simulation Approach for Evaluating the Safety Benefits of Connected Vehicles. IEEE Transactions on Intelligent Transportation Systems. 2021;1–13.

74. Park S, Oh C, Kim Y, Choi S, Park S. Understanding impacts of aggressive driving on freeway safety and mobility: A multi-agent driving simulation approach. Transportation Research Part F: Traffic Psychology and Behaviour [Internet]. 2019;64:377–87. Available from: https://doi.org/10.1016/j.trf.2019.05.017

75. Dunbar G, Holland CA, Maylor EA, Transport TD for. Older pedestrians: a critical review of the literature. Road safety research report. 2004;(37).

76. Parker D, Manstead ASR, Stradling SG, Reason JT. Determinants of intention to commit driving violations. Accident Analysis and Prevention. 1992;24(2):117–31.

77. Pelé M, Bellut C, Debergue E, Gauvin C, Jeanneret A, Leclere T, et al. Cultural influence of social information use in pedestrian road-crossing behaviours. Royal Society Open Science. 2017;4(2).

78. Ranasinghe C, Holländer K, Currano R, Sirkin D, Moore D, Schneegass S, et al. Autonomous vehicle-pedestrian interaction across cultures: Towards designing better external human machine interfaces (eHMIs). Conference on Human Factors in Computing Systems - Proceedings. 2020;1–8.

79. Bazilinskyy P, Kooijman L, Dodou D, de Winter JCF. How should external Human-Machine Interfaces behave? Examining the effects of colour, position, message, activation distance, vehicle yielding, and visual distraction among 1,434 participants. 2020;(March 2021).

Appendix

Appendix A Questionnaires

Five questionnaires are shown in this appendix. The questionnaires were given to the participants digitally in the form of a google form.

- Pre-experiment questionnaire
- Post-block questionnaire – Pedestrian
- Post-block questionnaire – Passenger
- Post-experiment questionnaire – Pedestrian
- Post-experiment questionnaire – Passenger

Pre-experiment questionnaire To be filled in before performing the experiment.	
Demographics	
Participant number? (Ask the instructor)	[Open]
What is your nationality?	[Open]
What is your age?	[Open]
What gender do you identify as?	• Male • Female • I prefer not to respond • Other
Are you wearing any seeing aids during the experiments?	• Yes, glasses • Yes, contact lenses • No
Experience	
Do you have video gaming experience?	• Yes, I play/used to play several times a week. • Yes, I play/used to play several times a month • Yes, I play/used to play less than once a month. • No
Do you have experience with Virtual Reality-glasses? (Select “Yes, I used it a few times” if you played it a few times at a friend's place, VR demonstrations, experiments. Otherwise, select “Yes, I use it very often”.	• Yes, I use it very often. • Yes, I used it a few times. • No
Have you ever participated in any experiment, regarding crossing-behaviour? before?	• Yes • No
Driving behaviour	
In what year did you obtain your license for driving a car or a motorcycle? Answer “no” if you do not have a driver’s license.	[Open]
On average, how often did you drive a vehicle in the last 12 months?	• Every day. • 4 to 6 days a week. • 1 to 3 days a week. • Once a month to once a week. • Less than once a month. • Never • I prefer not to respond
About how many kilometers did you drive in the last 12 months?	• 0 km • 1 - 1.000 km • 1.001 - 5.000 km • 5.001 - 15.000 km • 15.001 - 20.000 km

	• 20.001 - 25.000 km • 25.001 - 35.000 km • 35.001 - 50.000 km • 50.001 - 100.000 km • More than 100.000 km • I prefer not to respond
How many accidents were you involved in when driving a vehicle in the last 3 years? (Please include all accidents, regardless of how they were caused, how slight they were, or where they happened.)	• 0 • 1 • 2 • 3 • 4 • 5 • More than 5 • I prefer not to respond
[As a driver], how likely are you to make eye contact with the pedestrian when you approach [an unsignaled crossing] (crossroad without traffic lights)?	7 points Likert scale. • 1 = Extremely unlikely • 7 = Extremely likely
[As a driver], how likely are you to make eye contact with the pedestrian when you approach a [zebra crossing]?	7 points Likert scale. • 1 = Extremely unlikely • 7 = Extremely likely
[As a driver], how likely are you to make eye contact with the pedestrian when you approach [a signalised crossing] (crossroad with traffic lights)?	7 points Likert scale. • 1 = Extremely unlikely • 7 = Extremely likely
Crossing behaviour	
On average, how often did you travel on foot in the last 12 months?	• Every day. • 4 to 6 days a week. • 1 to 3 days a week. • Once a month to once a week. • Less than once a month. • Never • I prefer not to respond
[As a pedestrian], how likely are you to make eye contact with the driver when you cross an [unsignaled crossing] (crossroad without traffic lights)?	7 points Likert scale. • 1 = Extremely unlikely • 7 = Extremely likely
[As a pedestrian], how likely are you to make eye contact with the driver when you cross a [zebra crossing]?	7 points Likert scale. • 1 = Extremely unlikely • 7 = Extremely likely
[As a pedestrian], how likely are you to make eye contact with the driver when you cross a [signalised road] (crossroad with traffic lights)?	7 points Likert scale. • 1 = Extremely unlikely • 7 = Extremely likely

Post-Block Questionnaire - Pedestrian To be filled-in after every block	
Participant number? (Ask the instructor)	[Open]
What mapping? (Ask the instructor)	• Baseline • Mapping 1 (stop when looking) • Mapping 2 (stop when NOT looking)
MISC score (Take a break if the MISC score >= 4)	0. No Problems

	1. Uneasiness (no typical symptoms) 2. Vague dizziness, warmth, headache, stomach awareness, sweating.. 3. Slight dizziness, warmth, headache, stomach awareness, sweating.. 4. Fairly dizziness, warmth, headache, stomach awareness, sweating.. 5. Severe dizziness, warmth, headache, stomach awareness, sweating.. 6. Slight nausea 7. Fairly nausea 8. Severe nausea 9. (near) retching nausea 10. Vomiting
You prefer the mapping over the baseline.	7 points Likert scale. • 1 = Strongly disagree • 7 = Strongly agree
It was clear to you when the vehicle was going to yield.	7 points Likert scale. • 1 = Strongly disagree • 7 = Strongly agree
Anything you would like to share regarding this mapping?	[open]
Acceptance **Your judgments of the eye gaze visualization system are …**	
Useful / Useless	5 points Likert scale. • 1 = Useful • 5 = Useless
Pleasant / Unpleasant	5 points Likert scale. • 1 = Pleasant • 5 = Unpleasant
Bad / Good	5 points Likert scale. • 1 = Bad • 5 = Good
Nice / Annoying	5 points Likert scale. • 1 = Nice • 5 = Annoying
Effective / Superfluous	5 points Likert scale. • 1 = Effective • 5 = Superfluous
Irritating / Likeable	5 points Likert scale. • 1 = Irritating • 5 = Likeable
Assisting / Worthless	5 points Likert scale. • 1 = Assisting • 5 = Worthless
Undesirable / Desirable	5 points Likert scale. • 1 = Undesirable • 5 = Desirable
Raising Alertness / Sleep inducing	5 points Likert scale.

	• 1 = Raising Alertness • 5 = Sleep inducing

Post-Block Questionnaire - Driver To be filled-in after every block	
Participant number? (Ask the instructor)	[Open]
What mapping? (Ask the instructor)	• Baseline • Mapping 1 (stop when looking) • Mapping 2 (stop when NOT looking)
MISC score (Take a break if the MISC score >= 4)	11. No Problems 12. Uneasiness (no typical symptoms) 13. Vague dizziness, warmth, headache, stomach awareness, sweating.. 14. Slight dizziness, warmth, headache, stomach awareness, sweating.. 15. Fairly dizziness, warmth, headache, stomach awareness, sweating.. 16. Severe dizziness, warmth, headache, stomach awareness, sweating.. 17. Slight nausea 18. Fairly nausea 19. Severe nausea 20. (near) retching nausea 21. Vomiting
It was easy for you to direct the eye gaze visualisation to where you wanted it to be	7 points Likert scale. • 1 = Extremely difficult • 7 = Extremely easy
The eye gaze visualisation was distracting.	7 points Likert scale. • 1 = Strongly disagree • 7 = Strongly agree
The vehicle acted as predicted	7 points Likert scale. • 1 = Strongly disagree • 7 = Strongly agree
Anything you would like to share regarding this mapping?	[open]
Acceptance **Your judgments of the eye gaze visualization system are …**	
Useful / Useless	5 points Likert scale. • 1 = Useful • 5 = Useless
Pleasant / Unpleasant	5 points Likert scale. • 1 = Pleasant • 5 = Unpleasant
Bad / Good	5 points Likert scale. • 1 = Bad • 5 = Good

Nice / Annoying	5 points Likert scale. • 1 = Nice • 5 = Annoying
Effective / Superfluous	5 points Likert scale. • 1 = Effective • 5 = Superfluous
Irritating / Likeable	5 points Likert scale. • 1 = Irritating • 5 = Likeable
Assisting / Worthless	5 points Likert scale. • 1 = Assisting • 5 = Worthless
Undesirable / Desirable	5 points Likert scale. • 1 = Undesirable • 5 = Desirable
Raising Alertness / Sleep inducing	5 points Likert scale. • 1 = Raising Alertness • 5 = Sleep inducing

Post-Experiment Questionnaire - Pedestrian To be filled-in after finishing the experiment	
Participant number? (Ask the instructor)	[Open]
Preference	
What mapping did you prefer the most during the experiments?	[Rank the mappings] • Baseline • Mapping 1 (stop when looking) • Mapping 2 (stop when not looking)
Presence	
(1/32) How much were you able to control events?	7 points Likert scale. • 1 = Not at all • 7 = Completely
(2/32) How responsive was the environment to actions that you initiated (or performed)?	7 points Likert scale. • 1 = Not responsive • 7 = Very responsive
(3/32) How natural did your interactions with the environment seem?	7 points Likert scale. • 1 = Not natural • 7 = Very natural
(4/32) How completely were all of your senses engaged?	7 points Likert scale. • 1 = Not at all • 7 = Completely
(5/32) How much did the visual aspect of the environment involve you?	7 points Likert scale. • 1 = Not at all • 7 = Completely
(6/32) How much did the auditory aspects of the environment involve you?	7 points Likert scale. • 1 = Not at all • 7 = A lot
(7/32) How natural was the mechanism which controlled movement through the environment?	7 points Likert scale. • 1 = Not natural • 7 = Very natural

(8/32) How aware were you of the events occurring in real-world around you?	7 points Likert scale. • 1 = Not aware • 7 = Extremely aware
(9/32) How aware were you of your display and control devices?	7 points Likert scale. • 1 = Not aware • 7 = Extremely aware
(10/32) How compelling was your sense of objects moving through space?	7 points Likert scale. • 1 = Not compelling • 7 = Extremely compelling
(11/32) How inconsistent or disconnected was the information coming from your various senses?	7 points Likert scale. • 1 = Extremely inconsistent • 7 = Extremely consistent
(12/32) How much did your experiences in the virtual environment seem consistent with your real-world experiences?	7 points Likert scale. • 1 = Not consistent • 7 = Extremely consistent
(13/32) Were you able to anticipate what would happen next in response to the actions that you performed?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(14/32) How completely were you able to actively survey or search the environment using vision?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(15/32) How well could you identify sounds?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(16/32) How well could you localize sounds?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(17/32) How well could you actively survey or search the virtual environment using touch?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(18/32) How compelling was your sense of moving around inside the virtual environment?	7 points Likert scale. • 1 = Not compelling • 7 = Extremely compelling
(19/32) How closely were you able to examine objects?	7 points Likert scale. • 1 = Not at all • 7 = Extremely closely
(20/32) How well could you examine objects from multiple viewpoints?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(21/32) How well could you move or manipulate objects in the virtual environment?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(22/32) To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	7 points Likert scale. • 1 = Not confused/disoriented • 7 = Extremely confused/disoriented
(23/32) How involved were you in the virtual environment experience?	7 points Likert scale. • 1 = Not involved • 7 = Extremely involved

(24/32) How distracting was the control mechanism? (Like having to press the controller button to cross the road)	7 points Likert scale. • 1 = Not distracting • 7 = Extremely distracting
(25/32) How much delay did you experience between your actions and expected outcomes?	7 points Likert scale. • 1 = No delay • 7 = A lot of delay
(26/32) How quickly did you adjust to the virtual environment experience?	7 points Likert scale. • 1 = Extremely slow • 7 = Extremely fast
(27/32) How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	7 points Likert scale. • 1 = Not proficient • 7 = Extremely proficient
(28/32) How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	7 points Likert scale. • 1 = Not distracting • 7 = Extremely distracting
(29/32) How much did the control devices interfere with the performance of assigned tasks or with other activities?	7 points Likert scale. • 1 = Not at all • 7 = A lot
(30/32) How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	7 points Likert scale. • 1 = Not concentrated • 7 = Extremely concentrated
(31/32) Did you learn new techniques that enabled you to improve your performance?	7 points Likert scale. • 1 = Not at all • 7 = A lot
(32/32) Were you involved in the experimental task to the extent that you lost track of time?	7 points Likert scale. • 1 = Not at all • 7 = Extremely
Other	
What mapping [would] you prefer the most in real traffic?	[Rank the mappings] • Baseline • Mapping 1 (stop when looking) • Mapping 2 (stop when not looking)
Do you think it would be helpful to visualize eye gaze in real traffic? Explain your answer.	[Open]
Do you think it would be helpful to visualize eye gaze in real traffic with future autonomous vehicles? Explain your answer.	[Open]
Any other comments or advices?	[Open]

Post-Experiment Questionnaire - Driver To be filled-in after finishing the experiment	
Participant number? (Ask the instructor)	[Open]
Were the instructions clear?	7 points Likert scale. • 1 = Not clear • 7 = Extremely clear
Preference	
What mapping did you prefer the most during the experiments?	[Rank the mappings] • Baseline

	• Mapping 1 (stop when looking) • Mapping 2 (stop when not looking)
Presence	
(1/32) How much were you able to control events?	7 points Likert scale. • 1 = Not at all • 7 = Completely
(2/32) How responsive was the environment to actions that you initiated (or performed)?	7 points Likert scale. • 1 = Not responsive • 7 = Very responsive
(3/32) How natural did your interactions with the environment seem?	7 points Likert scale. • 1 = Not natural • 7 = Very natural
(4/32) How completely were all of your senses engaged?	7 points Likert scale. • 1 = Not at all • 7 = Completely
(5/32) How much did the visual aspect of the environment involve you?	7 points Likert scale. • 1 = Not at all • 7 = Completely
(6/32) How much did the auditory aspects of the environment involve you?	7 points Likert scale. • 1 = Not at all • 7 = A lot
(7/32) How natural was the mechanism which controlled movement through the environment?	7 points Likert scale. • 1 = Not natural • 7 = Very natural
(8/32) How aware were you of the events occurring in real-world around you?	7 points Likert scale. • 1 = Not aware • 7 = Extremely aware
(9/32) How aware were you of your display and control devices?	7 points Likert scale. • 1 = Not aware • 7 = Extremely aware
(10/32) How compelling was your sense of objects moving through space?	7 points Likert scale. • 1 = Not compelling • 7 = Extremely compelling
(11/32) How inconsistent or disconnected was the information coming from your various senses?	7 points Likert scale. • 1 = Extremely inconsistent • 7 = Extremely consistent
(12/32) How much did your experiences in the virtual environment seem consistent with your real-world experiences?	7 points Likert scale. • 1 = Not consistent • 7 = Extremely consistent
(13/32) Were you able to anticipate what would happen next in response to the actions that you performed?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(14/32) How completely were you able to actively survey or search the environment using vision?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(15/32) How well could you identify sounds?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(16/32) How well could you localize sounds?	7 points Likert scale.

	• 1 = Not at all • 7 = Extremely well
(17/32) How well could you actively survey or search the virtual environment using touch?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(18/32) How compelling was your sense of moving around inside the virtual environment?	7 points Likert scale. • 1 = Not compelling • 7 = Extremely compelling
(19/32) How closely were you able to examine objects?	7 points Likert scale. • 1 = Not at all • 7 = Extremely closely
(20/32) How well could you examine objects from multiple viewpoints?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(21/32) How well could you move or manipulate objects in the virtual environment?	7 points Likert scale. • 1 = Not at all • 7 = Extremely well
(22/32) To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	7 points Likert scale. • 1 = Not confused/disoriented • 7 = Extremely confused/disoriented
(23/32) How involved were you in the virtual environment experience?	7 points Likert scale. • 1 = Not involved • 7 = Extremely involved
(24/32) How distracting was the control mechanism? (Like having to press the controller button to cross the road)	7 points Likert scale. • 1 = Not distracting • 7 = Extremely distracting
(25/32) How much delay did you experience between your actions and expected outcomes?	7 points Likert scale. • 1 = No delay • 7 = A lot of delay
(26/32) How quickly did you adjust to the virtual environment experience?	7 points Likert scale. • 1 = Extremely slow • 7 = Extremely fast
(27/32) How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	7 points Likert scale. • 1 = Not proficient • 7 = Extremely proficient
(28/32) How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	7 points Likert scale. • 1 = Not distracting • 7 = Extremely distracting
(29/32) How much did the control devices interfere with the performance of assigned tasks or with other activities?	7 points Likert scale. • 1 = Not at all • 7 = A lot
(30/32) How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	7 points Likert scale. • 1 = Not concentrated • 7 = Extremely concentrated
(31/32) Did you learn new techniques that enabled you to improve your performance?	7 points Likert scale. • 1 = Not at all • 7 = A lot
(32/32) Were you involved in the experimental task to the extent that you lost track of time?	7 points Likert scale. • 1 = Not at all

	• 7 = Extremely
Other	
What mapping [would] you prefer the most in real traffic?	[Rank the mappings] • Baseline • Mapping 1 (stop when looking) • Mapping 2 (stop when not looking)
Do you think it would be helpful to visualize eye gaze in real traffic? Explain your answer.	[Open]
Do you think it would be helpful to visualize eye gaze in real traffic with future autonomous vehicles? Explain your answer.	[Open]
Any other comments or advices?	[Open]

Appendix B Instructions

Instructions given to the participants before the start of the experiments.

Instructions - Driver

The experiment investigates the vehicle-pedestrian interaction at a crossing road. You have been assigned to the role of the autonomous vehicle's driver. The other participant has been assigned to be the pedestrian.

As the driver your task is as follows:

- Stop the vehicle when instructed to do so.
- Do not stop the vehicle when instructed to do so.
- Note: the method to stop the vehicle is different in each mapping.
- Note: the vehicle won't stop if you look at the pedestrian too late.

Schedule	
Pre-Experiment Questionnaire	
Block 1	Baseline
Post-Block Questionnaire + optional break	
Block 2	Mapping 1 or 2 (you will be informed at the start of the experiment)
Post-Block Questionnaire + optional break	
Block 3	Mapping 1 or 2 (you will be informed at the start of the experiment)
Post-Block Questionnaire + optional break	
Post-Experiment Questionnaire	

Baseline: The autonomous vehicle (AV) does NOT communicate at all. You can look around as if you're in a manual driven vehicle in real life.

Mapping 1: This time the AV does communicate with you indirectly. On top of that, your eye gaze is visualized in the form of a green laser. The AV yields if you look at the pedestrian in time, and the AV does not yield if you do NOT look at the pedestrian.

- Look at the pedestrian = vehicle yields.
- Do NOT look at the pedestrian = vehicle does NOT yield.

Mapping 2: This time the AV does communicate with you indirectly. On top of that, your eye gaze is visualized in the form of a green laser. The AV yields if you do NOT look at the pedestrian, and the AV does NOT yield if you look at the pedestrian

- Look at the pedestrian = vehicle does NOT yield.
- Do NOT look at the pedestrian = vehicle yields.

Instructions - Pedestrian

The experiment investigates the vehicle-pedestrian interaction at a crossing road. You have been assigned to the role of the pedestrian. The other participant has been assigned to be the driver in the autonomous vehicle.

As the pedestrian your task is as follows:

- **Hold the button whenever you feel safe to cross the road.**
- **Release the button when you do not feel safe to cross the road**

Schedule	
Pre-Experiment Questionnaire	
Block 1	Baseline
Post-Block Questionnaire + optional break	
Block 2	Mapping 1 or 2 (you will be informed at the start of the experiment)
Post-Block Questionnaire + optional break	
Block 3	Mapping 1 or 2 (you will be informed at the start of the experiment)
Post-Block Questionnaire + optional break	
Post-Experiment Questionnaire	

Note: the autonomous vehicle always comes from the left side. In some cases another vehicle might come from the right side too.

Baseline: The AV does not communicate at all, determine by yourself whether the AV is going to stop for you. Hold the button when you feel safe to cross the road. Release the button when you do not feel safe to cross the road.

Mapping 1: This time the AV does communicate with you indirectly. The gaze-direction of the driver is visualized. The AV stops if the driver looks at you, and the AV does not stop when the driver is not looking at you. Again, hold the button when you feel safe to cross the road. Release the button when you do not feel safe to cross the road.

- Driver looks at you = vehicle yields.
- Driver NOT looking at you = vehicle does NOT yield.

Mapping 2: This time the AV does communicate with you indirectly. The gaze-direction of the driver is visualized. The AV stops if the driver does not look at you, and the AV does stop when the driver is not looking at you. Again, hold the button when you feel safe to cross the road. Release the button when you do not feel safe to cross the road.

- Driver looks at you = vehicle does NOT yield.
- Driver NOT looking at you = vehicle yields.

Appendix C Additional results

Learning effects

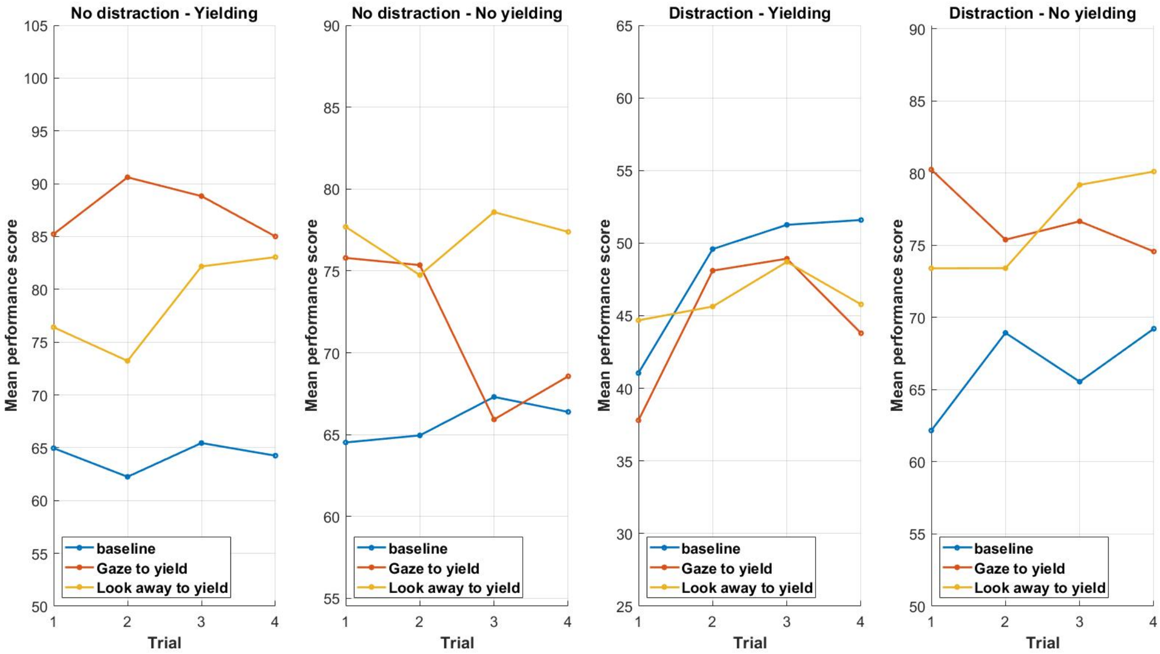


Figure A1: Learning effect of the pedestrian over the trials per condition and mapping.

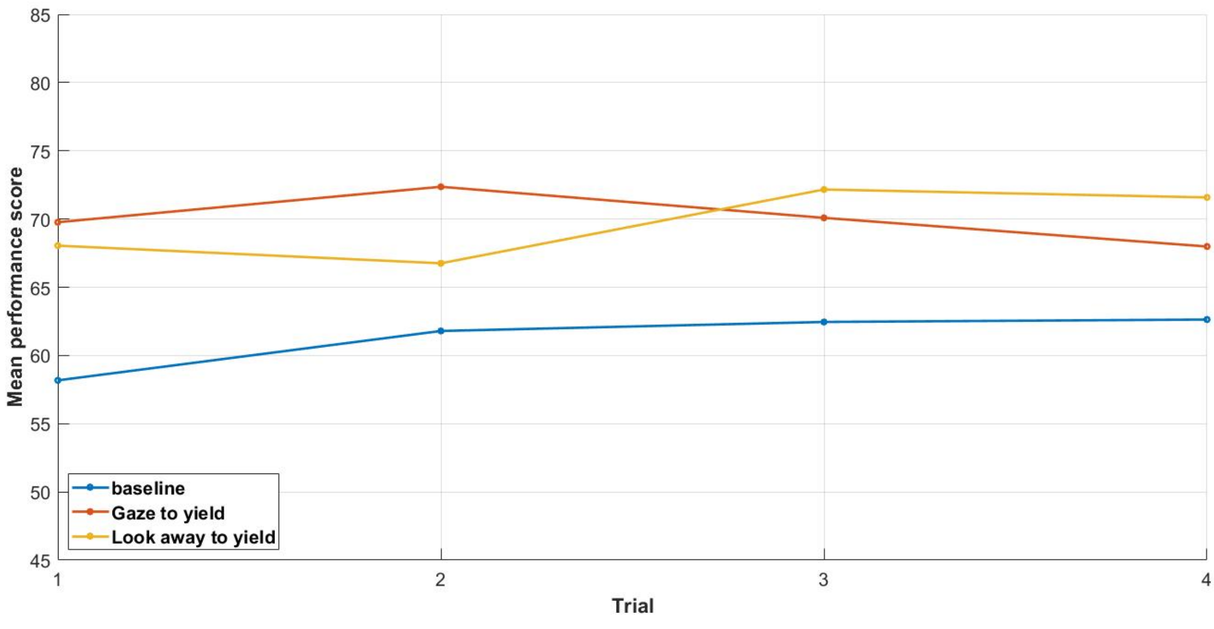


Figure A2:Learning effect of the pedestrian over the trials per mapping. Trial 1 consists of the mean of the first trial of every condition. Trial 2 consists of the mean of the second trial of every condition. Etc.

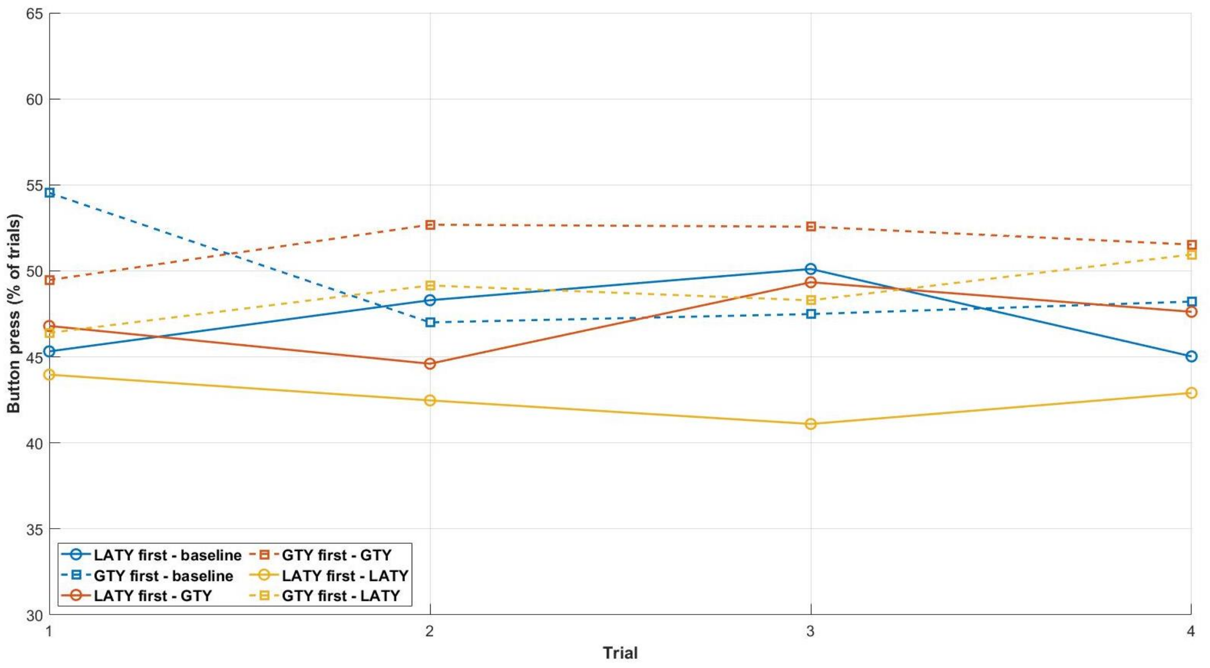


Figure A3: Learning effect of the pedestrian over the trials per mapping with the pedestrians divided per block order sequence. The circle represents the block order: baseline, LATY, GTY. The square represents the block order: baseline, GTY, LATY. Trial 1 consists of the mean of the first trial of every condition. Trial 2 consists of the mean of the second trial of every condition. Etc.

Distraction vehicle and AV position

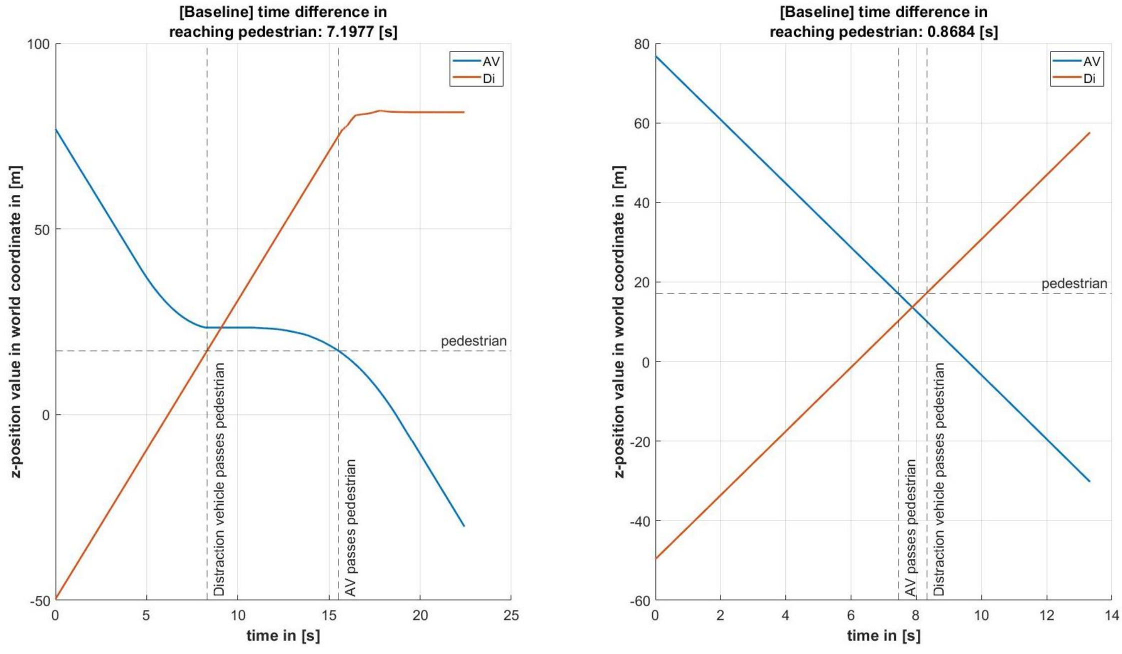
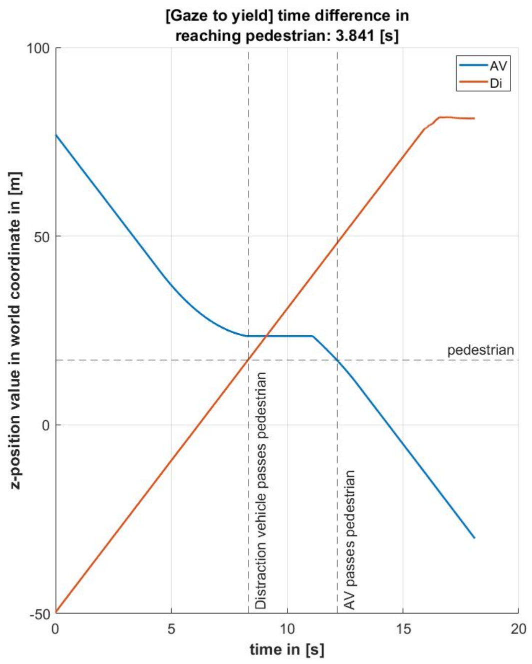


Figure A4: Distraction vehicle and AV position as function of the time in the baseline mapping. Left subfigure for the yielding condition and right subfigure for the non-yielding condition.



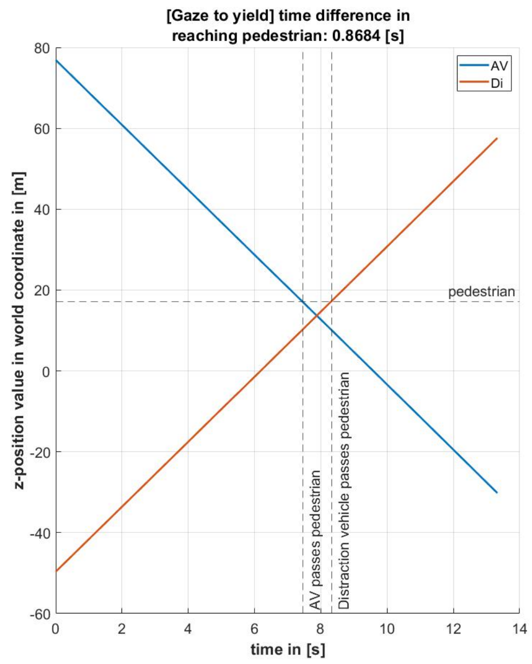
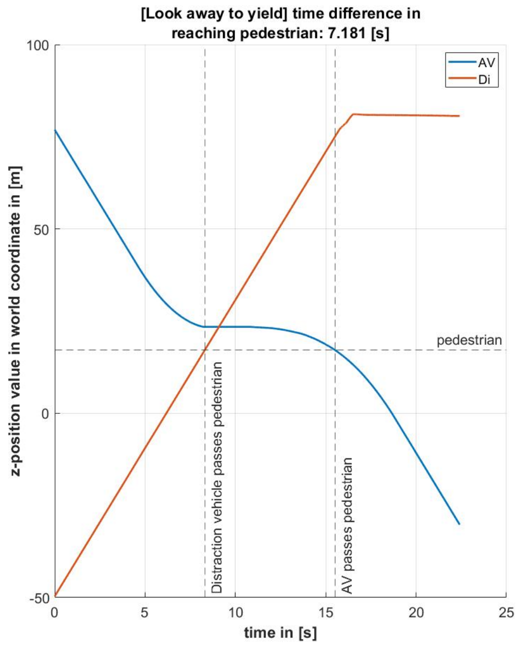


Figure A5: Distraction vehicle and AV position as function of the time in the gaze to yield mapping. Left subfigure for the yielding condition and right subfigure for the non-yielding condition. Note that this is just an example of one trial. The trajectory is dependent on the trajectory of the driver's gazing behaviour.



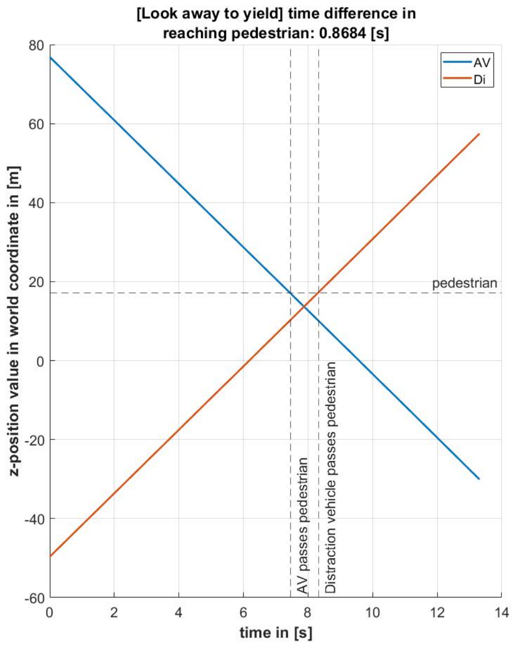


Figure A6: Distraction vehicle and AV position as function of the time in the look away to yield mapping. Left subfigure for the yielding condition and right subfigure for the non-yielding condition.

Mutual gazing and crossing performance score

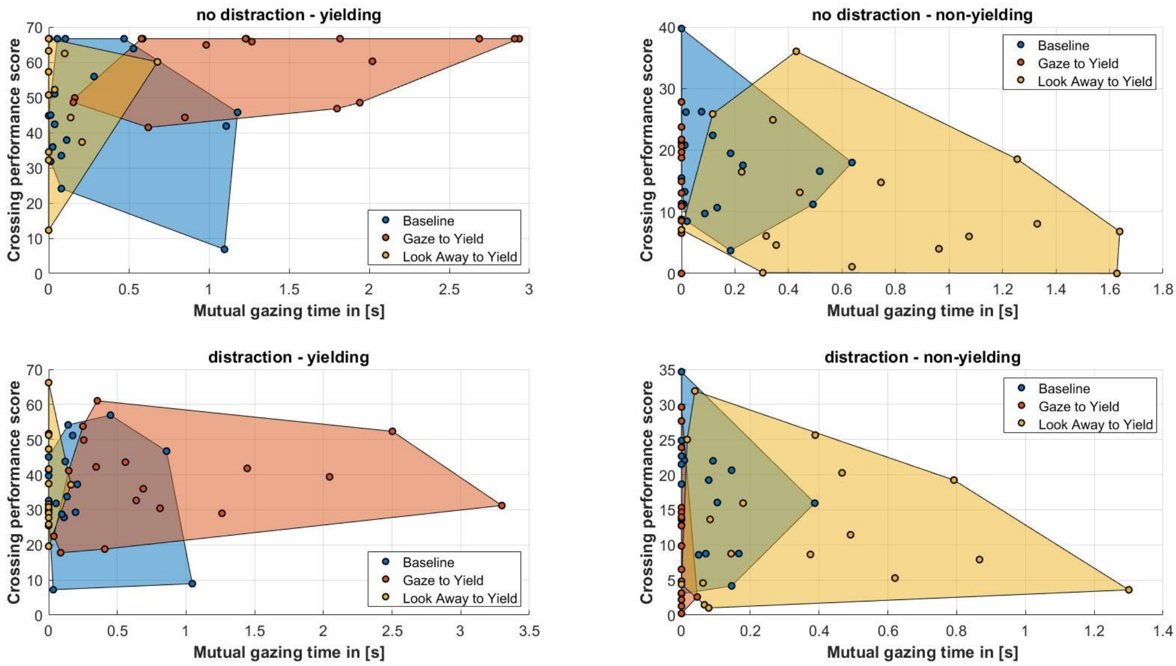


Figure A7: Mean crossing performance score per person as a function of the mean mutual gazing time per person.

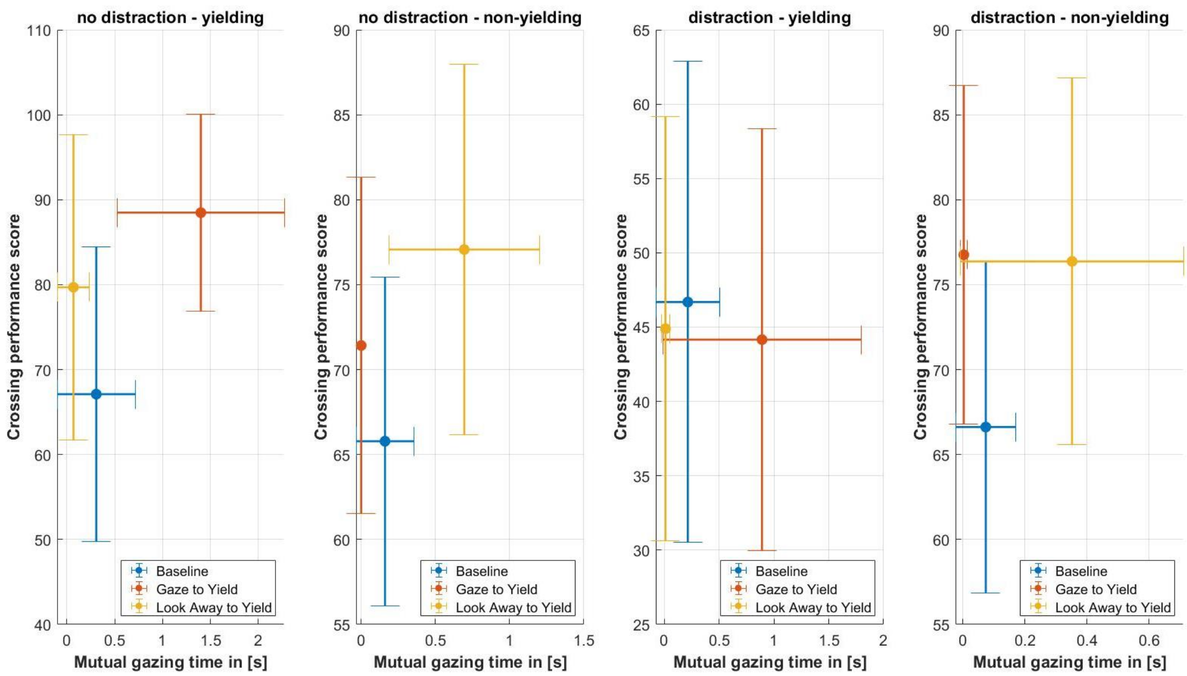


Figure A8: Mean crossing performance score as a function of the mean mutual gazing time.

Mean decision reversals per participant

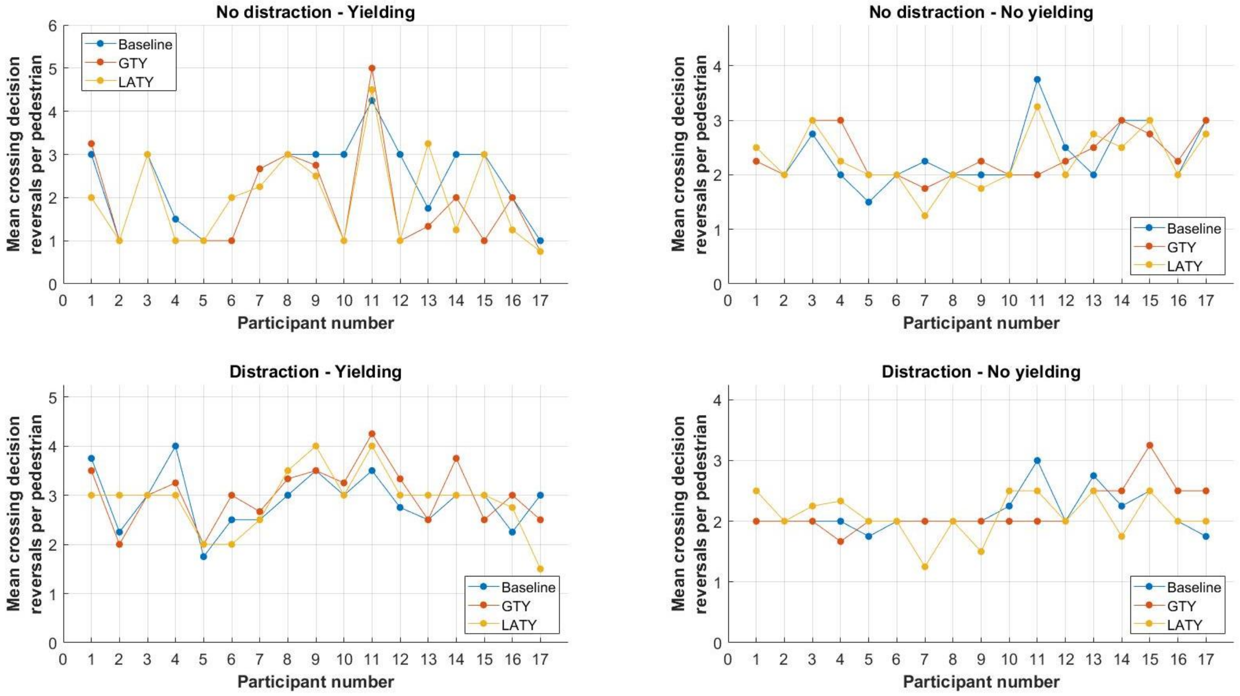


Figure A9: Mean crossing decision reversals per pedestrian for every condition and mapping.

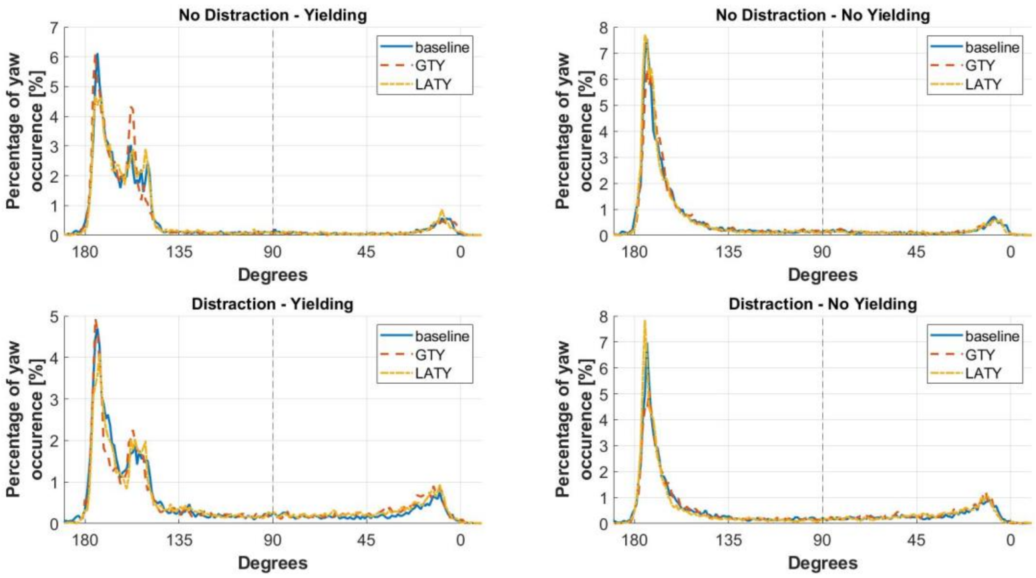


Figure A10: Pedestrian yaw. A gaze yaw of 90^0 represents the driver looking straight ahead at the zebra crossing. Gaze yaw smaller than 90^0 represent the right of the zebra crossing, where the pedestrian stands, and larger than 90^0 represent the left of the zebra crossing.

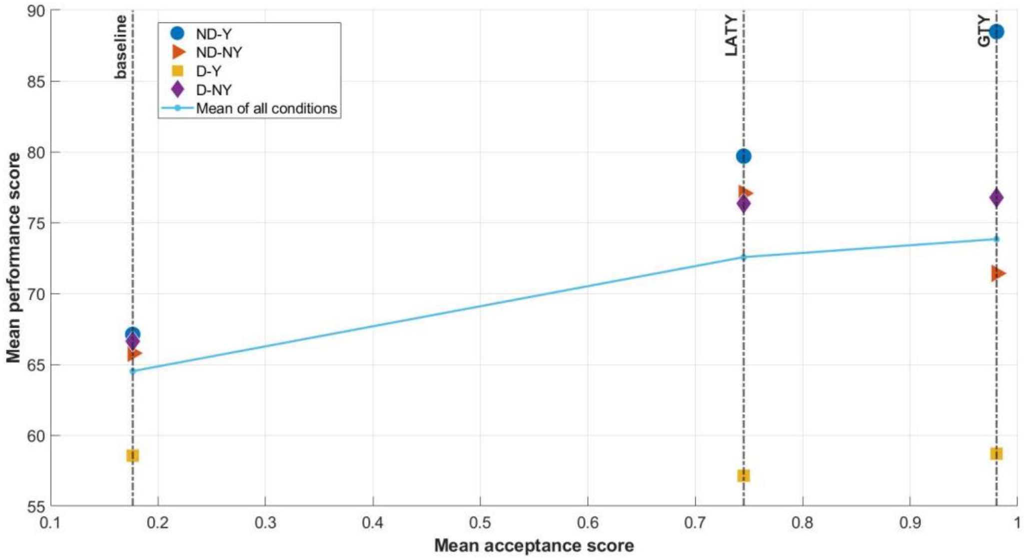


Figure A11: Mean crossing performance for all four conditions ((No) Distraction and (No) Yielding) versus the mean acceptance score. The acceptance score was calculated per mapping.

Appendix D Statistical analysis

Statistical analysis acceptance

The results of the statistical analysis for pedestrian and driver acceptance subscales: usefulness and satisfaction, are presented here. A two-tailed paired samples t-test is used to determine significant difference. Significant difference is found when the probability is smaller than 0.05. Cohen's D is used to determine the effect size. The effect size is small for a D of 0.2, medium for a D of 0.5, and large for a D of 0.8 (Cohen, 1992).

Table A1: Paired samples t-test results for pedestrian usefulness and satisfaction.

Mapping	**Pedestrian - Usefulness**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	**t(16) = -4.301, p < 0.001**	X	X
LATY	**t(16) = -3.618, p = 0.002**	t(16) = 2.063, p = 0.056	X
Mapping	**Pedestrian - Satisfaction**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	**t(16) = -4.790, p < 0.001**	X	X
LATY	**t(16) = -2.811, p = 0.013**	**t(16) = 3.917, p = 0.001**	X

Table A2: Paired samples t-test results for driver usefulness and satisfaction.

Mapping	**Driver - Usefulness**		
	Baseline	**GTY**	**LATY**
Baseline	X		
GTY	**t(16) = -5.828, p < 0.001**	X	
LATY	t(16) = -1.849, p = 0.083	**t(16) = 2.194, p = 0.043**	X
Mapping	**Driver - Satisfaction**		
	Baseline	**GTY**	**LATY**
Baseline	X		
GTY	t(16) = 0.199, p = 0.845	X	
LATY	t(16) = 1.141, p = 0.271	t(16) = 0.912, p = 0.375	X

Table A3: Cohen's D values for the satisfaction and usefulness score of pedestrians and drivers.

Mapping	**Cohen's D**			
	Pe – Usefulness	**Pe – Satisfaction**	**Pa – Usefulness**	**Pa – Satisfaction**
Baseline - GTY	-1.0432	-1.1616	-1.4136	0.0482
GTY - LATY	0.5003	0.9499	0.5320	0.2213
Baseline - LATY	-0.8774	-0.6818	-0.4485	0.2768

Statistical analysis crossing performance score

The results of the statistical analysis for the crossing performance, are presented here. A two-tailed paired samples t-test is used to determine significant difference. Significant difference is found when the probability is smaller than 0.05. Cohen's D is used to determine the effect size. The effect size is small for a D of 0.2, medium for a D of 0.5, and large for a D of 0.8 (Cohen, 1992).

Table A4: Paired samples t-test results for crossing performance score.

Mapping	**Distraction– No yielding**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	**t(16) = -3.531, p = 0.003**	X	X
LATY	**t(16) = -2.259, p = 0.038**	t(16) = 0.487, p = 0.633	X
Mapping	**Distraction - Yielding**		

	Baseline	GTY	LATY
Baseline	X	X	X
GTY	t(16) = -0.404, p = 0.692	X	X
LATY	t(16) = -0.529, p = 0.604	t(16) = 0.050, p = 0.961	X
Mapping	**No Distraction – No Yielding**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	t(16) = -1.677, p = 0.113	X	X
LATY	**t(16) = -2.825, p = 0.012**	t(16) = -1.493, p = 0.155	X
Mapping	**No Distraction - Yielding**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	**t(16) = -3.842, p = 0.001**	X	X
LATY	**t(16) = -3.406, p = 0.004**	t(16) = 1.412, p = 0.177	X

Table A5: Cohen's D values for the crossing performance score.

Mapping	**Cohen's D**			
	D – NY	**D – Y**	**ND – NY**	**ND - Y**
Baseline - GTY	**-0.8563**	-0.0980	-0.4067	**-0.9319**
GTY - LATY	0.1182	-0.0121	-0.3622	0.3425
Baseline - LATY	**-0.5479**	-0.1282	**-0.6852**	**-0.8261**

Statistical analysis decision certainty

The results of the statistical analysis for the decision certainty, are presented here. A two-tailed paired samples t-test is used to determine significant difference. Significant difference is found when the probability is smaller than 0.05. Cohen's D is used to determine the effect size. The effect size is small for a D of 0.2, medium for a D of 0.5, and large for a D of 0.8 (Cohen, 1992). Pearson's correlation coefficient, r, is calculated to determine the correlation between the crossing performance score and the decision certainty. A positive r refers to a positive correlation and a negative r refers to a negative correlation. The strength of association is divided into three categories: small for $0.1 < r < 0.3$, medium for $0.3 < r < 0.5$, and large for $0.5 < r < 1.0$.

Table A6: Paired samples t-test results for decision certainty

Mapping	**Distraction – No Yielding**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	t(16) = -0.771, p = 0.452	X	X
LATY	t(16) = -0.068, p = 0.947	t(16) = 0.682, p = 0.504	X
Mapping	**Distraction – Yielding**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	t(16) = -1.084, p = 0.294	X	X
LATY	t(16) = -4.397E-16, p = 1.000	t(16) = 0.930, p = 0.366	X
Mapping	**No Distraction – No Yielding**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	t(16) = 0.107, p = 0.917	X	X
LATY	t(16) = 0.735, p = 0.473	t(16) = 0.543, p = 0.595	X
Mapping	**No Distraction - Yielding**		
	Baseline	**GTY**	**LATY**
Baseline	X	X	X
GTY	**t(16) = 2.281, p = 0.037**	X	X
LATY	t(16) = 1.912, p = 0.074	t(16) = -0.283, p = 0.781	X

Table A7: Cohen's D values for the decision certainty

Mapping	Cohen's D			
	D – NY	**D – Y**	**ND – NY**	**ND - Y**
Baseline - GTY	-0.1869	-0.2630	0.0258	**0.5531**
GTY - LATY	0.1656	0.2255	0.1317	-0.0685
Baseline - LATY	-0.0164	-1.0665E-16	0.1783	0.4637

Table A8: Correlation matrix between crossing performance score and decision certainty.

Mapping	Pearson Correlation Coefficient r (p-value)			
	D – NY	**D – Y**	**ND – NY**	**ND - Y**
Baseline	0.20 (0.43)	-0.46 (0.06)	0.36 (0.16)	-0.65 (4.70E-3)
GTY	-0.16 (0.53)	-0.62 (7.50E-3)	-0.38 (0.13)	-0.75 (5.52E-4)
LATY	0.08 (0.77)	-0.34 (0.17)	-0.05 (0.85)	-0.40 (0.11)
All	0.05 (0.71)	-0.46 (5.58E-4)	-6.4E-3 (0.96)	-0.57 (1.14E-5)

Appendix E Results pre-experiment questionnaire

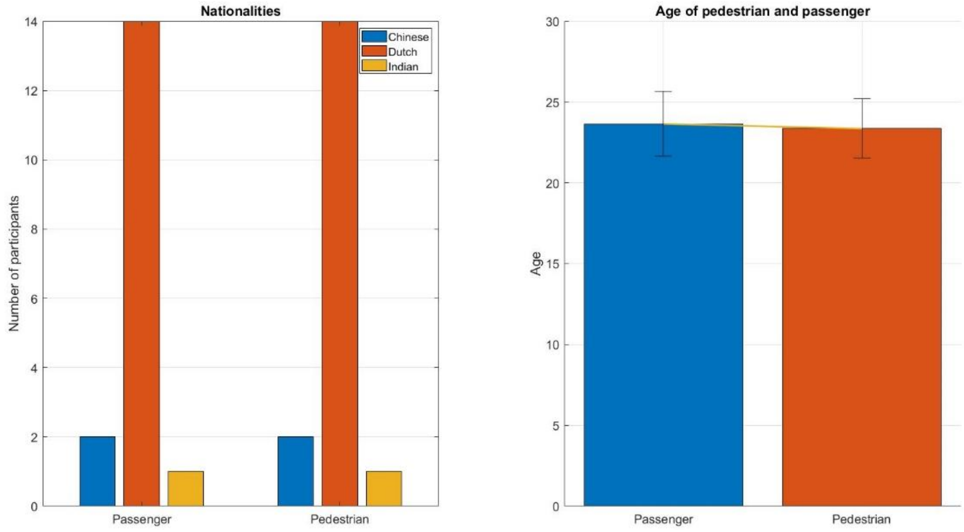


Figure A12: Nationality and mean age with standard deviation of the age as error bar of the participants.

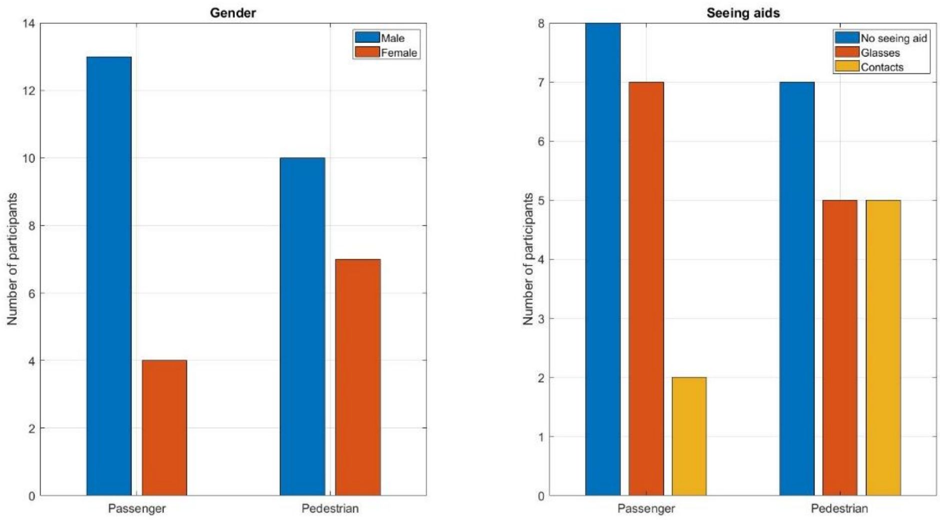


Figure A13: Gender and seeing aids of the participants.:

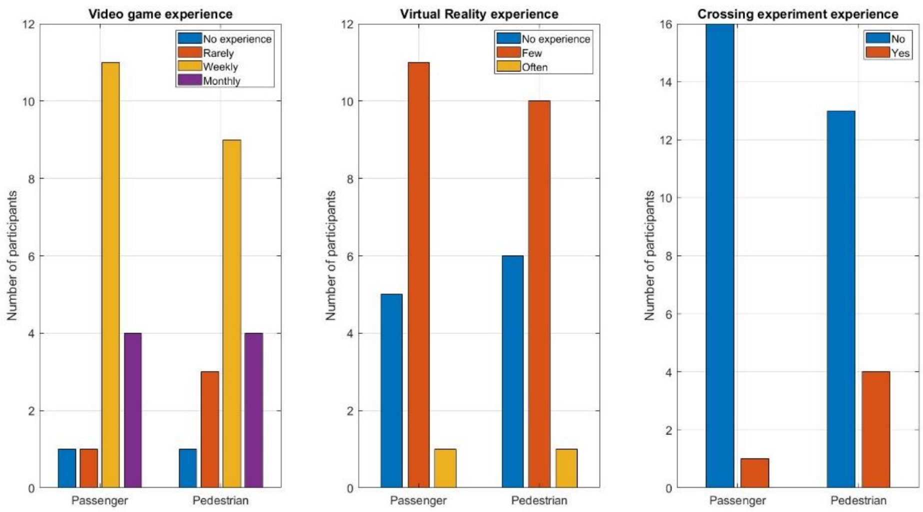


Figure A14: Participants' experience in video games, VR, and crossing experiments

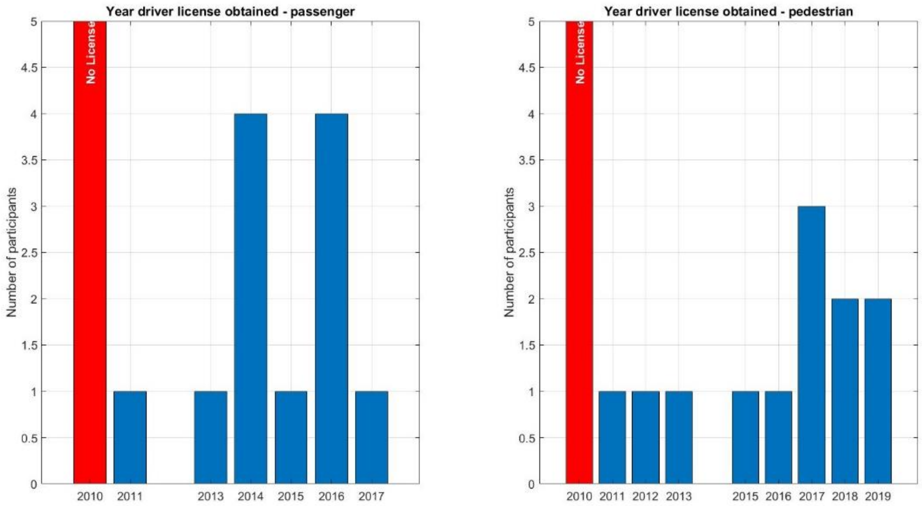


Figure A15: The year in which the participants' obtained their drivers license. The red bar indicates the number of participants without a driver's license.

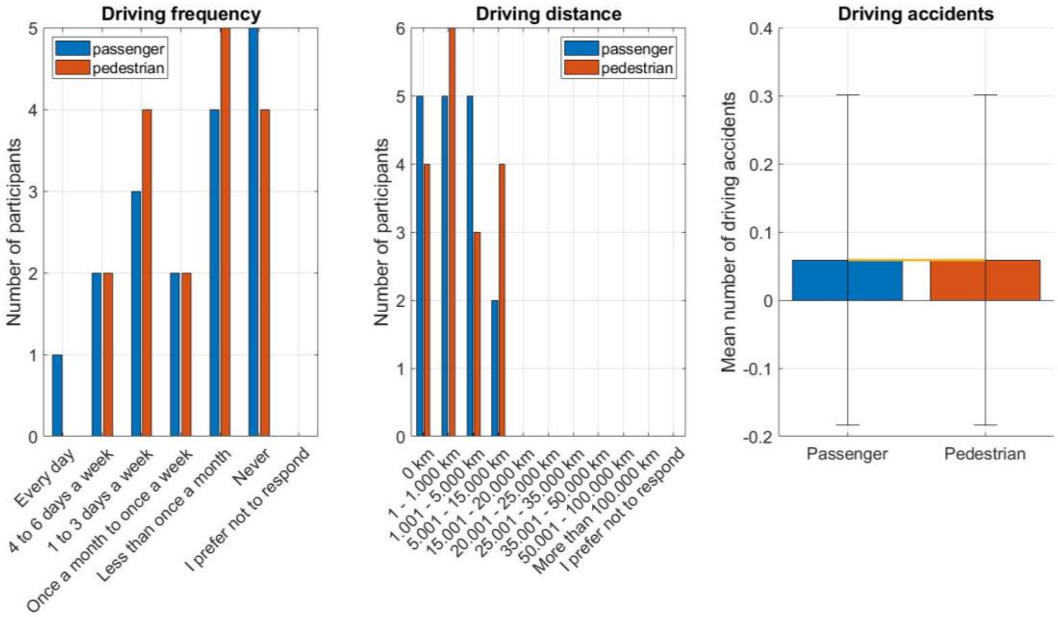


Figure A16: Participants' driving behaviour indicated via driving frequency, driving distance, and driving accidents.

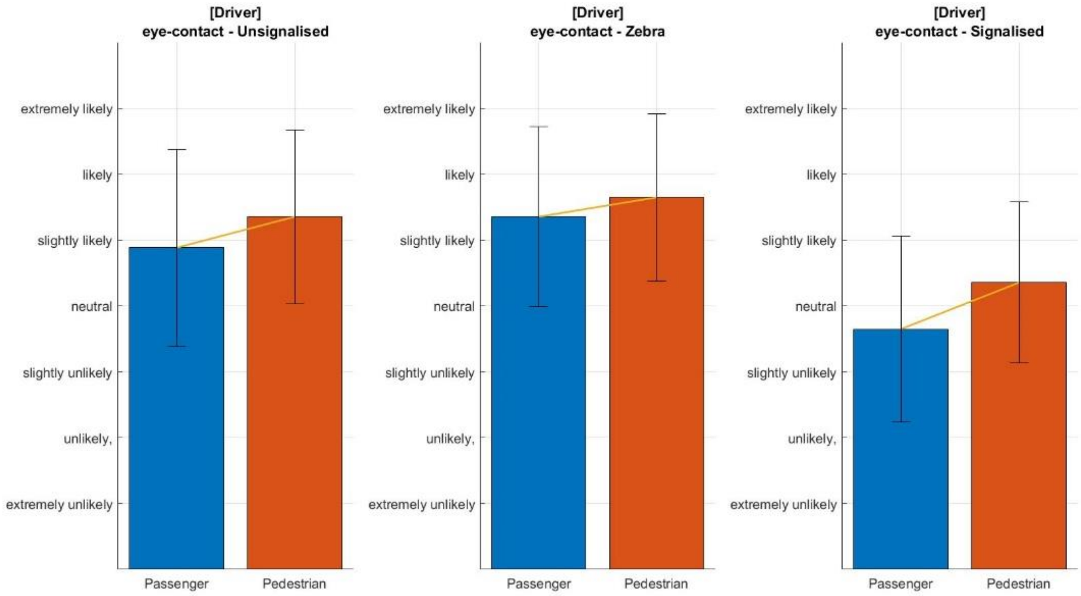


Figure A17: Participants' likelihood to make eye contact with the pedestrian as a driver at an unsignalized crossing, zebra crossing, and signalised crossing

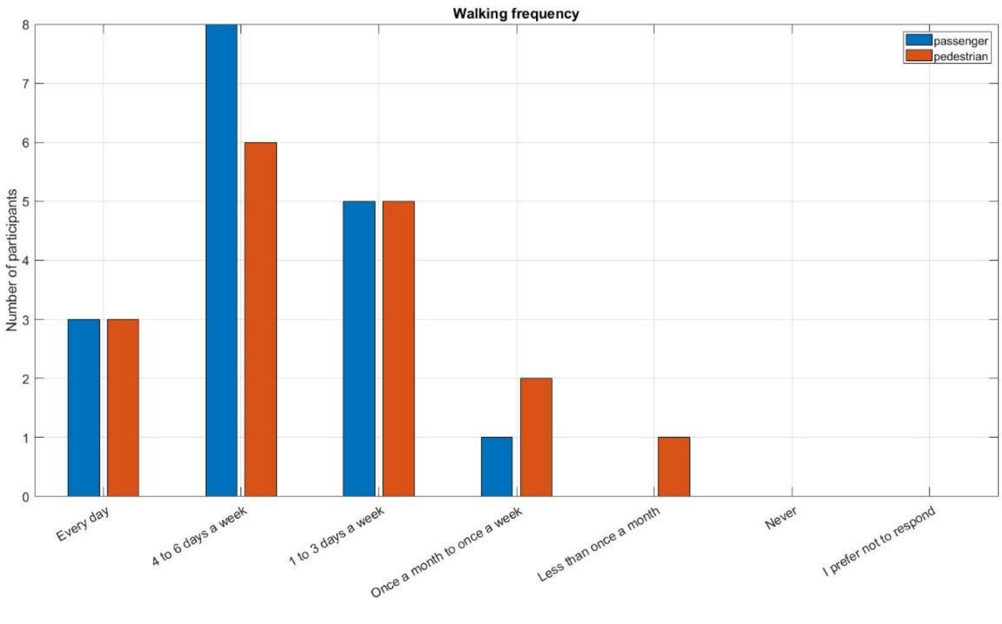


Figure A18: Participants' walking frequency

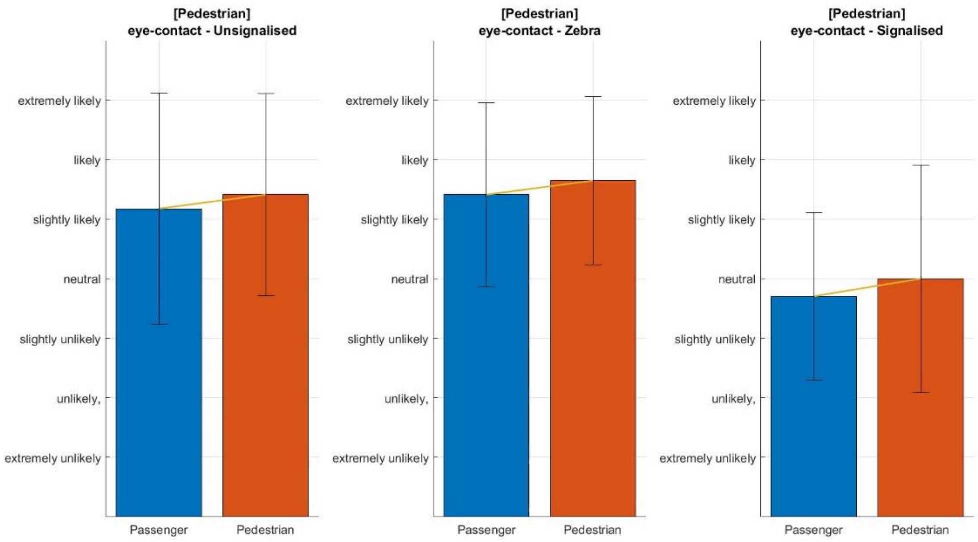


Figure A19: Participants' likelihood to make eye contact with the driver as a pedestrian at an unsignalized crossing, zebra crossing, and signalised crossing

Appendix F Results post-block questionnaire

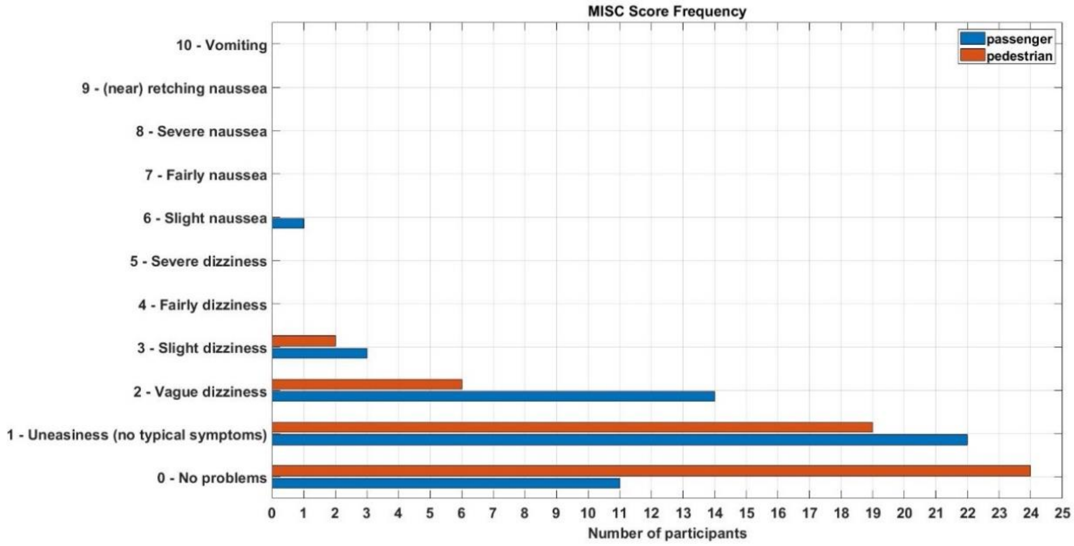


Figure A20: MISC score as rated by the participants.

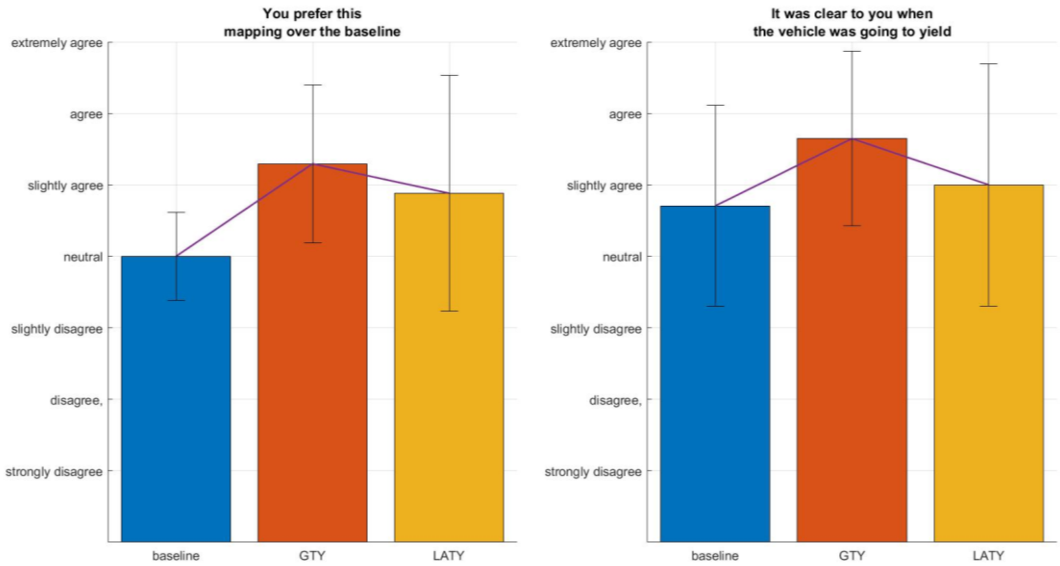


Figure A21: Pedestrian mean response to the questions "You prefer the mapping over the baseline" and "It was clear to you when the vehicle was going to yield"

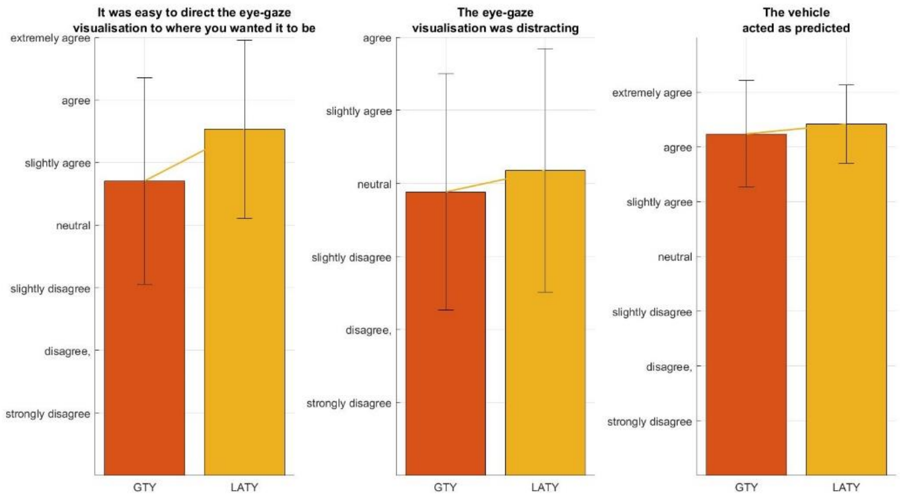


Figure A22: Drivers' mean response to the questions about the ease of eye gaze visualisation direction, eye gaze visualisation distraction, and vehicle behaviour.

Table A9: Mean scores and standard deviations in the parentheses for the acceptance rating and its subscales usefulness and satisfaction for each mapping per role. The scores range from -2 (unfavourable) to +2 (favourable).

Mapping	Pedestrian			Driver		
	Usefulness	Satisfaction	Acceptance	Usefulness	Satisfaction	Acceptance
Baseline	0.16 (0.63)	0.19 (0.42)	0.18 (0.20)	0.11 (0.25)	0.06 (0.29)	0.09 (0.20)
Gaze to Yield	1.00 (0.61)	0.96 (0.55)	0.98 (0.47)	0.93 (0.62)	0.01 (1.02)	0.52 (0.76)
Look Away to Yield	0.82 (0.73)	0.65 (0.62)	0.75 (0.56)	0.47 (0.85)	-0.18 (0.95)	0.18 (0.84)

Table A10: Drivers' answers to the question: Anything you would like to share regarding this mapping?

Driver
Question: Anything you would like to share regarding this mapping?
Baseline
'It was difficult not to look at the pedestrian in the condition "don't stop AV"'
Gaze to yield
'I think it's nicer than the baseline, but I might stop too much in a real world scenario. Now I actively try not to look at the person. But normally I automatically look at people.'
This felt easier than the 2nd mapping. I did not have to think about what to do when instructed to stop or not to stop
Look away to yield
'Counter-intuitive'
'I had to think hard about if I had to look away or not. It was not logical to me.'
'Felt unituitive: had to think what I had to do when instructed not to stop the vehicle'

Table A11: Pedestrians' answers to the question: Anything you would like to share regarding this mapping?

Pedestrian
Question: Anything you would like to share regarding this mapping?
Baseline
'Intermitted eye tracking laser confusing'
'quite heavy equipment with a tunnel view'

'Sometimes I didn't see the second car in time (because of the VR-view)'
Gaze to yield
'Compared to the baseline, the car starts to drive faster when it is done in the mapping. This made me think that I had more time to cross the road so I held the button longer to mark that I was safe.'
'The car accelerated real fast, so it was hard sometimes to release the button fast as well.'
'The laser light make it more clear when the vehicle is going to stop'
‘In this mapping, the car accelerated very fast. in the last mapping it didn't’
Look away to yield
'Seems the wrong way around. Dependent on execution of the passenger, so can give a false sense of security'
'This map was confusing me a bit. When the spotlights (the lasers) were on me. I was thinking that it was my turn to cross the road, while I actually should wait. '
‘It felt opposite and not really what I am used to’

Appendix G Results post-experiment questionnaire

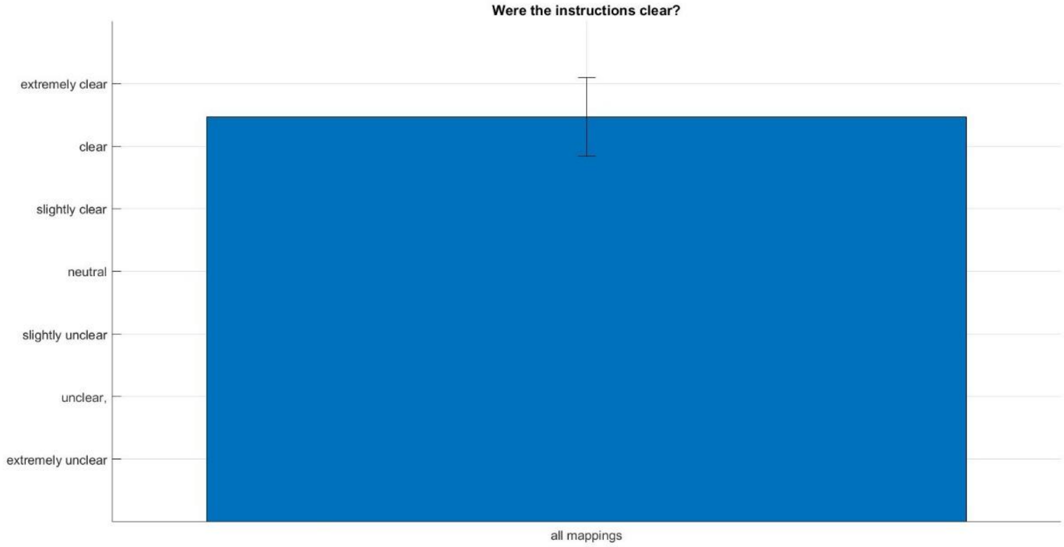


Figure A23: Clarity of instructions as perceived by the drivers.

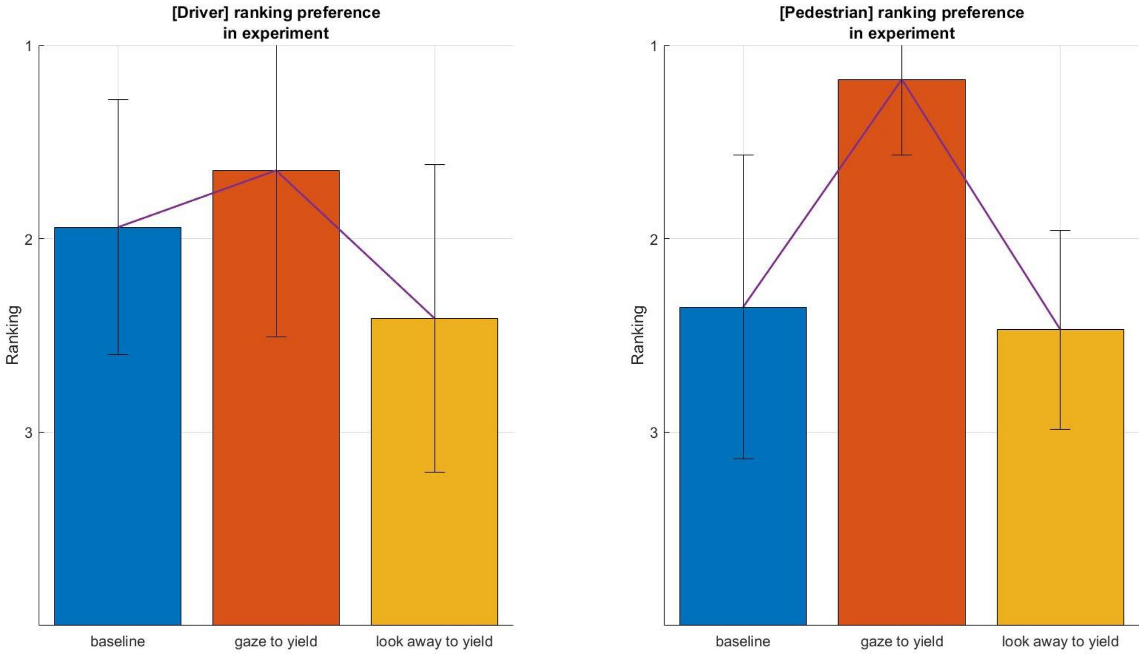


Figure A24: Mapping mean preference in VR as ranked by the drivers and pedestrians.

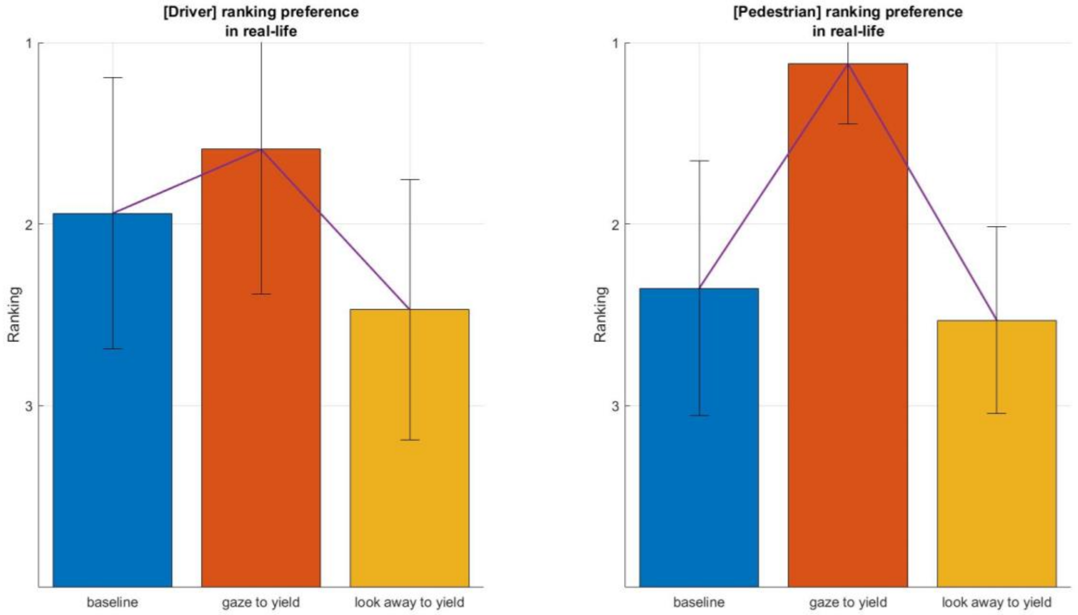


Figure A25: Mapping mean preference in real-life as ranked by the drivers and pedestrians.

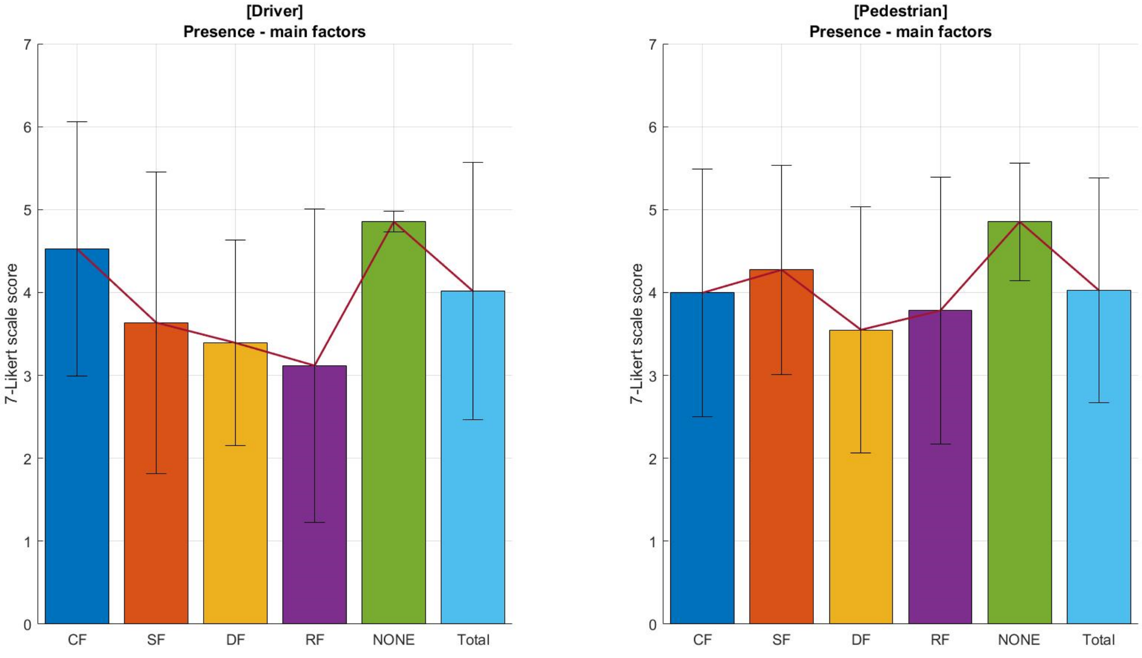


Figure A26: Mean presence score presented as the main factors: Control Factors (CF), Sensory Factors (SF), Distraction Factors (DF), Realism factors (RF), Not part of any of the factors (NONE). Total refers to all the factors combined.

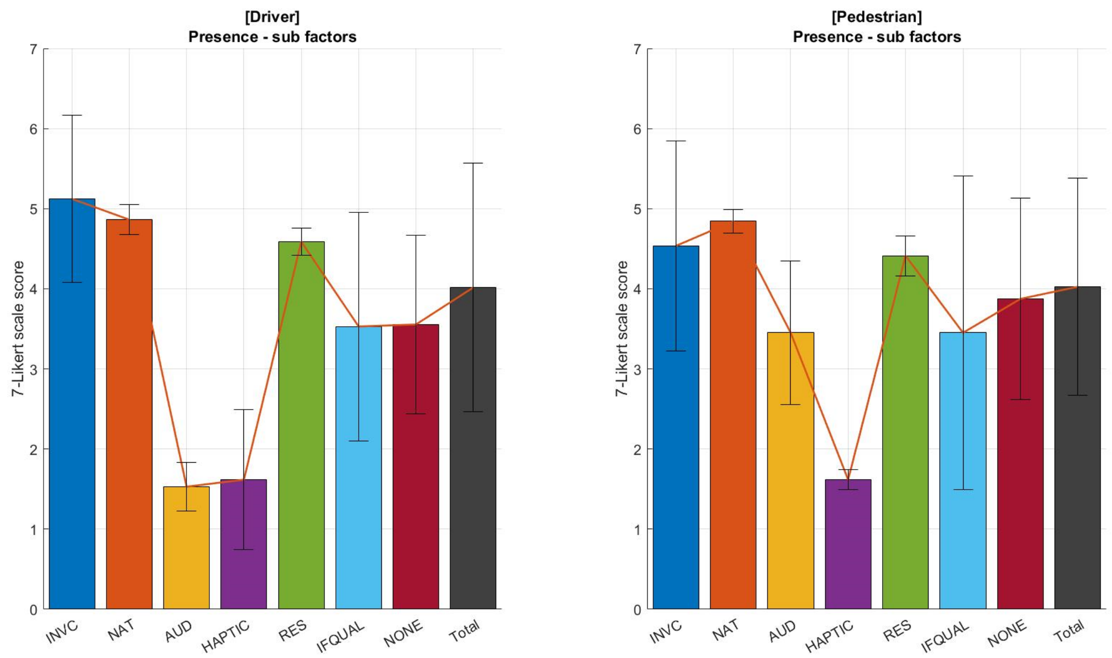


Figure A27: Mean presence score presented as the sub factors: Involvement/Control (INVC), Natural (NAT), Auditory (AUD), Haptic (HAPTIC), Resolution (RES), Interface Quality (IFQUAL), Not part of any of the factors (NONE). Total refers to all the factors combined.

Table A12: Drivers' answers to the open question: Do you think it would be helpful to visualize eye gaze in real traffic? Explain your answer.

Driver	
Question: Do you think it would be helpful to visualize eye gaze in real traffic? Explain your answer.	
Answer	**Positive/Neutral/Negative**
'No. I don't really see the benefit...'	Negative
'Not sure to what extend technology is reliable'	Negative
'Not really because it can be quite distracting when visualised for a long period of time.'	Negative
'Potentially yes. Though, visualising your own gaze does not seem useful. Visualising gazes of others may be useful when they are not as salient as in the current setup, such salient gazes can be very distracting.'	Positive
'Ja, voor extra voor controle'	Positive
'This would help long distance drivers when they are tired on the roads, the eye gaze could help them with concentrations.'	Positive
'It could but need to be very accurate. Maybe with extra feedback besides eye tracking could help improving.'	Positive
'Yes, cause then the pedestrians can get the information that if the vehicle will stop or not so that they can decide whether to cross the road or not'	Positive
'I think visualizing eye gaze could be distracting in a real world scenario. And I don't think it will be helpful enough to outweigh the distracting.'	Negative
'no because I normally don't make eye contact with people on the street that are crossing the road'	Negative

'For cars driven by people, I think it is helpful to visualize eye gaze, because then the interaction between driver and pedestrian is very important I think.'	Positive
'No, eye-gaze can be a little bit distracting passenger'	Negative
'Yes, but in condition of accurate and comfortable eye-gaze visualization technique.'	Positive
'Yes. As a pedestrian I think it would be nice (but not necessary, because you can also just look at the drivers face) to know exactly when a driver is looking at you'	Positive
'No, because while the eye-gaze may help you focus on an object in traffic that you already see, it may be distracting to the extent of missing other objects in the scene.'	Negative
'Not really helpful, because it could become a mess when there are a lot of vehicles.'	Negative
'Yes but only if not visible during driving itself. It would be useful to check what happened as in where did the driver look at during a crash. During the driving itself, it would be distracting the driver too much in my opinion.'	Positive

Table A13: Drivers' answers to the question: Do you think it would be helpful to visualize eye gaze in real traffic with future autonomous vehicles? Explain your answer.

Driver	
Question: Do you think it would be helpful to visualize eye gaze in real traffic with future autonomous vehicles? Explain your answer.	
Answer	**Positive/Neutral/Negative**
'No'	Negative
'if there were no malfunctions'	Positive
'It might be useful in urban traffic because it can ensure control over the car at pedestrian crossings.'	Positive
'Not so much, as the autonomous vehicle would be controlling the car? Not the passenger?'	Negative
'Ja, voor veiligheid'	Positive
'It would be more pleasant to have no eye gaze for the AV, however it would be helpful for the beginners who just started using the AV, it helps them to make the decision/actions.'	Positive
'Yes, it could as extra feedback if the vehicle couldn't track obstacles.'	Positive
'Yes, then the pedestrians can have the information of the vehicle as well, and can also rise the confidence or trust of people to the AV'	Positive
'Distracting in a fully autonomous world is not as bad as in a half autonomous one. So it might be helpful.'	Positive
'yes because you will be more alert when you see the eye gaze in real traffic'	Positive
'It would only be helpful if the passengers can control the autonomous car. So for example, it is only helpful if the passenger can stop the self-driving car.'	Positive
'Eye-gaze can be a little bit distracting for the passenger but it would be useful for the pedestrian '	Positive
'Yes, it's a good interaction between AV and pedestrians.'	Positive

'Yes. If you do indeed control the AV with your eye gaze, it would be very useful to be able to see that your vision is tracked correctly instead of trusting that it is'	Positive
'No, because that would subtract from the autonomous feature of autonomous vehicles. I feel that these vehicles would be more successful if they were completely autonomous instead of needing a passenger to make use of an eye-gaze future.'	Negative
'Not really helpful, because it could become a mess when there are a lot of vehicles. Maybe if the eye-gaze could differ from each other.'	Negative
'Yes but only if not visible during driving itself. It would be useful to check what happened as in where did the driver look at during a crash. During the driving itself, it would be distracting the driver too much in my opinion.'	Positive

Table A14: Drivers' answers to the question: Any other comments or advice?

Driver
Question: Any other comments or advice?
Answer
'It would be nice to have a clue of when the car will start again after it had stopped.'
'Locking the head in virtual space within the virtual environment decreases the immersiveness. The gaze visualisation is distracting for the passenger.'
'An update on the graphics of the test.'
'Eye-tracking is not very accurate for me (with glasses). A lot of calibrations were used and still, the laser is dancing and drifting very frequently.'

Table A15: Pedestrians' answers to the open question: Do you think it would be helpful to visualize eye gaze in real traffic? Explain your answer.

Pedestrian	
Question: Do you think it would be helpful to visualize eye gaze in real traffic? Explain your answer.	
Answer	**Positive/Neutral/Negative**
'Yes it would as you have an idea whether the passenger has noticed you in the car and therefore makes it easier for you to assess whether it is safe to cross or not. Thought it is useful, I think that many people might find it annoying as you can see many "laser beams" shooting everywhere.'	Positive
'Could be an extra tool in case of real cars and autonomous cars'	Positive
'Driver gaze visualization, shown to pedestrians via AR would lead them to make crossing decisions faster and more safely, but only if the gaze is accurately visualized and is followed by the expected behaviour (yielding/not yielding) every single time. Even one failure e.g. eye contact while yielding but the vehicle moves on suddenly anyway can severely harm trust in the gaze visualization.'	Positive
'Yes, because the eye gaze and vehicle actions are coupled.'	Positive
'Nee, want dan zijn er te veel manieren van remmen en dit kan verwarrend zijn voor veel mensen.'	Negative
'yes, in this case you can anticipate on the cars'	Positive

'No, you expect the car to operate fully autonomous'	Negative
'yes, when the driver doesn't look at the people, you will stop earlier. but when the driver looks at the people, you won't feel confident that you can go across the road since they are not believing the system.'	Positive
'I think it would. I am already looking at peoples faces when crossing the road and if those faces aren't driving anymore, then I would like the car to sign its intentions.'	Positive
'Yes could be. As a driver, I frequently look for eye contact to anticipate the pedestrian's behaviour.'	Positive
'Yes, because then it is more clear whether the driver see you or not'	Positive
'Yes, you have a better idea on what to expect from the driver '	Positive
'I think it would be useful. It is useful to make it safer on the road, but as a pedestrian it is difficult to be sure when the car would stop. There is not that much of a reference. The laser helped in that sense. But I prefer it if there is still human involvement as well. '	Positive
'Yes, because you can even know where the driver is looking at when you look to the other side.'	Positive
'it would assist the pedestrian but it you could not completely rely on it, some drivers may still continue to drive even if you have eye contact'	Positive
'Yes, then I would be able to see if the driver sees me and lets me cross the road'	Positive
'Yes. Now you don't know if you are actually making eye contact with the driver. I do feel safer when I know for sure they are looking at me/notice me at the zebra pad. '	Positive

Table A16: Pedestrians' answers to the question: Do you think it would be helpful to visualize eye gaze in real traffic with future autonomous vehicles? Explain your answer.

Pedestrian	
Question: Do you think it would be helpful to visualize eye gaze in real traffic with future autonomous vehicles? Explain your answer.	
Answer	**Positive/Neutral/Negative**
'Yes it would as you have an idea whether the passenger has noticed you in the car and therefore makes it easier for you to assess whether it is safe to cross or not. It adds an extra sense of security in traffic as you know that the vehicle is completely autonomous. '	Positive
'Definitely needed in case of only having autonomous cars'	Positive
'No, I think the goal of SAE level 5 automation should be to eliminate the need for human-like (anthropomorphic) communication and make the pedestrian process as little information as possible, while making the crossing as safe as possible.'	Negative
'No, because there can be a discrepancy between a passenger looking and the cars action. Resulting in dangerous situation where the pedestrian expects a certain outcome'	Negative
'Ja, want dan weten de meeste voetgangers en passagiers wel hoe ze moeten reageren.'	Positive

'no, since the driver is not involved in the driving task of the autonomous vehicle'	Negative
'No, you expect the car to operate fully autonomous'	Negative
'Yes. the laser can tell people when the car will stop.'	Positive
'Yes, same answer as in the previous questions.'	Positive
'Yes, as machines could be unpredictable, it would be more reassuring.'	Positive
'Yes, because it makes the movement of the car more predictable'	Positive
'yes, it will give an extra sense of security that someone will stop.'	Positive
'Yes I think so. Similar as above. However, I believe street users should get used to it first. '	Positive
'Yes, because communication is important, so this is an extra signal that can be used to cross or not to cross.'	Positive
'not really helpful, predictions made using eye gaze are not 100% reliable'	Negative
'Yes, then I would be able to see if the driver sees me and lets me cross the road'	Positive
'Yes; see answer above. '	Positive

Table A17: Pedestrians' answers to the question: Any other comments or advice?

Pedestrian
Question: Any other comments or advice?
Answer
'Maybe another sign would work even better. So in stead of the lasers and new pair of lights could do the same thing, without being so aanwezig'

Appendix H Data management plan

The effect of eye gaze vector visualization of the passenger of automated vehicles on pedestrians crossing behaviour.

General TU Delft data management questions

Name of data management support staff consulted during the preparation of this plan

Yasemin Türkyilmaz-van der Velden, the Data Steward of the faculty of Mechanical, Maritime and Materials Engineering.

Date of consultation with support staff [YYYY-MM-DD]

18-08-2020

1. Is TU Delft the lead institution for this project?

- Yes, the only institution involved

2. If you leave TU Delft (or are unavailable), who is going to be responsible for the data resulting from this project?

Dr.ir. J.C.F. (Joost) de Winter (J.C.F.deWinter@tudelft.nl)

3. Where will the data (and code, if applicable) be stored and backed-up during the project lifetime?

- SURFdrive
- Another storage system – please explain below, including provided safety measures

Departmental safe dropbox storage, which is password protected and backed up regularly.

4. How much data storage will you require during the project lifetime?

- < 250 GB

500-600KB per trial. 48 trials per participant. 28.8 MB per participant. Expect about 30 participants, thus 864 MB data logging. The simulation environment is about 6GB.

5. What data will be shared in a research data repository?

- Not all data can be publicly shared – please explain below which data and why cannot be publicly shared
- All data (and code) underlying published articles / reports / theses

- Personal information that can be traced back to the individual e.g. name and email will not be shared.
- Participants will be assigned a number.
- Personal data can be deleted when the project has finished.

6. How much of your data will be shared in a research data repository?

- < 100 GB

7. How will you share your research data (and code)?

- Data will be uploaded to the 4TU.Centre for Research Data

8. Does your research involve human subjects?

- Yes

9. Will you process any personal data? Tick all that apply

- Date of birth/age

- Gender
- E-mail addresses
- Name and addresses

TU Delft questions about management of personal research data

1. Please detail what type of personal data you will collect, for what purpose, how you will store and protect that data, and who has access to the data.

Please provide your answer in the table below. Add an extra row for every new type of data processed:

(delete data from online form and move it to a more secure place)

Type of data	How will the data be collected?	Purpose of processing	Storage location	Who will have access to the data
Name, Email-address	Through paper forms	Recruit participants for the experiments.	Stored in a locked closet from the supervisor.	Researcher and supervisor.
Gender and age	Through paper surveys.	To facilitate trend analysis and correlations.	Surfdrive, paper form stored in a locked closet from the supervisor.	Researcher and supervisor.
Signed consent forms	Through paper forms.	To record the consent of the participants who agreed for their data processing.	Stored in a locked closet from the supervisor.	Researcher and supervisor.

2. Will you be sharing personal data with individuals/organisations outside of the EEA (European Economic Area)?

- No

3. What is the legal ground for personal data processing?

- Informed consent - please describe the informed consent procedures you will follow

4. Will the personal data be shared with others after the end of the research project, and if so, how and for what purpose?

The personal data will not be shared with others after the end of the research project.

5. Does the processing of the personal data results in a high risk to the data subjects?

If the processing of the personal data results in a high risk to the data subjects, it is required to perform a Data Protection Impact Assessment (DPIA). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data during your research (check all that apply).
If two or more of the options listed below apply, you will have to complete the DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to receive support with DPIA. If only one of the options listed below applies, your project might need a DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to get advice as to whether DPIA is necessary.

If you have any additional comments, please add them in the box below.

- None of the above apply

Appendix I Informed consent form

Informed Consent Form in a Virtual Reality study

Researchers:
MSc. Student: C.S. Mok

Supervisor: Dr.ir. J.C.F. de Winter

Supervisor: P. Bazilinskyy

This document describes the purpose, procedures, benefits, risks and possible discomforts of this study. It also describes the right to withdraw from the study at any time in any case. Before agreeing to participate in this study, it is important that the information provided is fully read and understood.

Location of the experiment:

TU Delft, Faculty of Mechanical, Maritime and Material Engineering.
Department of Cognitive Robotics
Mekelweg 2, 2628 CD, Delft
F-0-220 CoR Lab

Prevention of the spread of COVID-19

You cannot take part in this study, if any of these statements apply to you:

- are over the age of 70.
- have underlying ailments that could be seen as a risk factor for COVID-19 infection.
- have any complaints or symptoms that could be indicative of a COVID-19 infection.
- Have been in contact with a COVID-19 patient within 14 days prior to today.
- Are not enabled to travel outside of rush hours to and from the research location.

Purpose of the research

The purpose of this research is to investigate a new communication method between autonomous vehicles and pedestrians. Subjective and objective measures will be taken to determine which communication method is preferred. The results will be statistically analysed and published in a Master thesis. This study should help the integration of autonomous vehicles in the real world.

Procedure

There are two roles in this experiment: pedestrian and passenger. You will be assigned to one of these roles.

For the pedestrian: You will need to stand on the cross in the room while wearing a virtual reality headset and holding a Vive controller. Your task is to hold the button when you feel safe to cross the road.

For the passenger: You will need to sit on a chair while wearing a virtual reality headset. Eye-tracking will be performed since you will have to use your eye gaze to brake the vehicle. You will get instructions at the start of a trial which either instructs you to stop the vehicle or to not stop the vehicle.

The experiment consists of an autonomous vehicle approaching a cross road while the pedestrian stands near it. The experiment is divided into three blocks. In the first block, there will be no communication between the autonomous vehicle and the pedestrian. At this stage, the passenger does not need to participate yet. In the second and third block, the eye gaze of the passenger will be visualized. The passenger will be able to see where the passenger is looking at. With the eye gaze visualization there will be two mappings.

Mapping 1:

- Passenger looks at the pedestrian -> vehicle stops.
- Passenger does **not** look at the pedestrian -> vehicle does **not** stop.

Mapping 2:

- Passenger looks at the pedestrian -> vehicle does **not** stops.
- Passenger does **not** look at the pedestrian -> vehicle stops.

This corresponding mapping to the block will be told before the start of a new block.

Duration: the complete experiment, including filling out questionnaires, will approximately take 60-80 minutes.

Benefits and risks of participating

Virtual environments and the use of virtual reality glasses can cause different types of sickness: visuomotor dysfunctions (eyestrain, blurred vision, difficulty focusing), nausea, drowsiness, fatigue, or headache. These symptoms are similar to motion sickness. You are advised to stop the experiment or rest for several minutes if you feel uncomfortable in any way. You can stop the experiment and withdraw at any time, without negative consequences. Please take sufficient rest before leaving the laboratory if you feel unwell.

Procedures for withdrawal from the study

Participation to the experiment is strictly voluntary and you may withdraw or stop the experiment at any time without negative comments.

Confidentiality

The collected data in this experiment is kept confidential and will be used for human factors research purposes only. Throughout the study you will only be identified by a subject number. You have the right to request access to and rectification or erasure of personal data.

Questions

If you have any questions regarding this experiment, feel free to contact C.S. Mok

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Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason. ○ ○

I understand that taking part in the study involves giving permission to process the data for the purpose described above. ○ ○

Risks associated with participating in the study

I understand that taking part in the study involves the following risks: visuomotor dysfunctions, nausea, drowsiness, fatigue, or headache. ○ ○

Use of the information in the study

I understand that information I provide will be used for a Master thesis and possibly for a scientific publication. ○ ○

I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team. ○ ○

I agree that my information can be quoted in research outputs ○ ○

COVID-19

I agree that none of the COVID-19 statements mentions above apply to me. ○ ○

Signatures

______________________ ______________________ ________

Name of participant Signature Date

Appendix J Participant recruitment poster

PARTICIPANTS NEEDED

MSC THESIS RESEARCH

AUTOMATED VEHICLE TO PEDESTRIAN COMMUNICATION

Do you want to experience the latest technology in the field of Virtual Reality? Are you willing to participate in a MSc thesis experiment about **Automated Vehicles, Virtual Reality and Eye-tracking?** Do you have approximately 1 hour and 15 minutes free time? Then this might be interesting for you!

Two participants are needed to perform one experiment. The experiment consists of a virtual reality environment in which one of the **participants is a pedestrian** and **the other is a passenger in the automated vehicle**. The purpose of this study is to investigate the effect of visualizing the passenger's gaze on your crossing behaviour.

You will both be using VR glasses (Varjo VR2-Pro) to immerse yourself in the virtual environment in a safe Laboratory Environment at the faculty of 3ME. While wearing the VR glasses, you will be asked to perform some small tasks and answer a few questions about the experiment afterwards. Your answers and data will be treated confidentially and will be anonymised, so that it cannot be traced back to individual persons. **Participation in this experiment is voluntary. Feel free to share!**

IMPORTANT INFORMATION

When: 7-12-2020 till 18-12-2020
Duration: +/- 1 hour and 15 minutes
Who: Healthy people between 18 and 60 years old
Where: CoR Lab at the faculty of 3Me, TU Delft, room number 34-F-0-220
How to sign up:
https://forms.gle/xH7aHLpttVaVMFTJ9

Appendix K Experiment roadmap

Before the arrival of the participant.

- Check connection HMDs.
- Check connection Vive controller on client PC.
- Start up Varjo Base.
- Check tracking HMDs and controller.
- Start up experiment unity execution file.
- Select the right settings for the experiment.
- Make sure only the following programs are active: Varjo Base, Unity, and SteamVR.
- Print informed consent.
- Clean mouse, keyboard, HMD, controller, and chair.

Arrival of participant

- Welcome participants and instruct them to clean their hands.
- Check if everyone is wearing masks and gloves.
- Provide the participants with the informed consent form and let them sign it.
- Assign a role to each of the participants.
- Participants fill-in the questionnaire: pre-experiment questionnaire.
- Provide the participants with the instructions.

Pre-experiment

- Explain where the participants have to stand/sit.
- Explain how to adjust the HMD.
- Provide the driver and pedestrian with HMDs, and provide the pedestrian with a headset and the controller.
- Repeat the mapping conditions.
- Repeat the driver and pedestrian task.
- Mention that the automated vehicle approaches from the pedestrian's left side.

Experiment

- *Record the view inside the virtual environment using Varjo Base.*
- *Manually initiate the driving of the vehicle.*
- *Introduce a break after every experiment block.*

Break

- Instruct the participants to take off the HMDs.
- Participants fill in the questionnaire: post-block questionnaire.
- Offer a snack to the participants.
- Move the logging files to a separate folder.
- Rename the video files.
- Wait till the participants are ready again, and repeat.

After completion of the experiment

- Instruct the participants to take off the HMDs.
- Participants fill in the questionnaire: post-experiment questionnaire.
- Check and convert the byte log files to csv log files.

Appendix L MISC

MISC table shown to the participants during the experiments.

MISC TABLE

Symptom		score
No problems		0
Uneasiness (no typical symptoms)		1
Dizziness, warmth, headache, stomach awareness, sweating, . . .	vague	2
	slight	3
	fairly	4
	severe	5
Nausea	slight	6
	fairly	7
	severe	8
	(near) retching	9
Vomiting		10

- **Score >= 4 -> Take a break**
- **Score >= 6 -> Stop**