Hand gestures as a form of communicating crossing intent from pedestrians to Automated Vehicles

Master of Science Thesis

By

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TU Delft

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Abstract

Communication between pedestrians and drivers partially relies on nonverbal communication methods such as eye-contact and gestures. With the transition from manually driven vehicles to automated vehicles (AVs), pedestrians could lose the ability to communicate their intention to the driver. This study investigated the use of hand gestures as a new form of communication from the pedestrian to the AV.

Twenty-six participants participated in a Virtual Reality (VR) experiment, in which they wore an Oculus Rift to interacted with AVs in a virtual environment. The movement of the participants was recorded and visualized through the use of a Xsens Link motion tracking suit, which provided the research with data about the hand gesture usage. The main independent variable of this study was the permission for the participant to use hand gestures to try to make the AV yield. The hand gesture increased the probability of the AV stopping for the participant. The second independent variable was the response of the AV through a message on an external-Human Machine Interface (eHMI). The participants went through four different scenarios. Therefore, both one-way communication and two-way communication were investigated in the same experiment.

The participants were given the freedom to decide if they wanted to use the hand gesture. Aside from the hand gesture, the participants were asked to perform a forward step at the moment they felt safe to cross the road in the virtual environment, without actual crossing. Alongside the gathered data on movement of the participants, the research also included data gathered from questionnaires in which the participants were asked about their feeling of safety, assurance of being seen by the AV, the effect that the lack of eye-contact had on their decision making, difficulty predicting the behaviour of the AV, and their trust in communication involving AVs and hand gestures.

The research found that the participants used hand gestures to communicate crossing intent to the AV around 80% of the time. The ability to use hand gestures did not improve the feeling of safety significantly, and made it more difficult for the participants to predict the behaviour of the AV. The results of the subjective measurements did show positive results for the hand gesture in combination with responses from the AV by the eHMI, as well as for the eHMI alone. It is concluded that participants were willing to use the hand gesture, and that the hand gesture only increased the subjective feeling of safety if the AV responds to the hand gesture via an eHMI.

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1. Introduction

1.1 Transitioning from manually driven vehicles to automated driving technology

With each improvement in automated driving technology, a future in which automated vehicles (AVs) participate in daily traffic alongside manually driven vehicles and pedestrians comes closer to reality. Because the transition from manually driven traffic to fully automated traffic will not happen instantly, the 'transition phase' will lead not only lead to improvements in safety (Bengler et al., 2014) but could also lead to more dangerous situations for pedestrians (Litman, 2018).

AVs might not always be clearly recognisable, and their behaviour could differ from that of manually driven vehicles. Therefore, pedestrians might not know how to interact with an AV and therefore could become involved in dangerous traffic situations (Müller et al., 2016). As Habibovic et al. (2014) argued: *"obtaining a successful interaction in such a mixed traffic environment requires that all road users understand each other and that they behave in an expected way."*

Pedestrians and drivers of manually driven vehicles often rely on nonverbal communication such as eye-contact, gestures or technical means such as headlamp flashes to communicate information, acknowledge, draw attention, or to clarify situations (Keferböck & Riener, 2015; Matthews et al., 2017; Rasouli et al., 2017). It has been argued that established forms of nonverbal communication will no longer be relevant when AVs take over the driving tasks from human drivers (Rothenbücher et al., 2016). Therefore, the communication needs of the pedestrians will change, and new communication methods will be needed (Malmsten Lundgren et al., 2017).

Moreover, the unfamiliarity with the behaviour of AVs could lead to confusion of the participant, which could lead to the participant trying to use nonverbal communication methods which are not possible with AVs (Dey & Terken, 2016). If pedestrians do not have the ability to communicate nonverbally with AVs, they become reliant on the AVs' motion and behaviour, when making the decision to cross. Thus, the decision making and perceived safety of the pedestrians will rely more on the vehicle's motion pattern and external interfaces (Habibovic et al., 2016).

Furthermore, the change in nonverbal communication and technical limitations of the AV's artificial intelligence or camera/sensor systems could also lead to problems for the AV. In their research, Dong et al. (1998) stated that "*it is necessary that interactions could be implemented in the manner similar to human's natural communication preferences (i.e., voice or gesture)"*. However, implementing interactions in a similar manner to human's natural communication preferences could be difficult because recognising hand gestures, gazing directions and voice commands could be complicated due to environmental properties and systems requirements. Variations in lighting conditions, noise, or dynamic backgrounds make it difficult for the camera and sensor systems to obtain information about pedestrians that want to cross the road.

1.2 Research on the change in nonverbal communication

Multiple studies (Chang et al., 2017; De Clercq et al., 2019; Fridman et al., 2017; Clamann et al., 2017) have investigated methods of non-verbal communication to substitute or enhance AV-pedestrian communication. Rodríguez Palmeiro et al. (2018) articulate the importance of external signs stating that the vehicle in question is 'self-driving', because these signs would aid the pedestrians to identify the vehicle as an AV (Rodríguez Palmeiro et al., 2018). However, the signs used in that study were not interactive, and thus not suitable for dynamic communication. Rodríguez Palmeiro et al. (2018) argued that the recognisability of AVs is important because pedestrian crossing behaviour is dependent on how other road users behave in accordance with what is expected from them. However, when interacting with an AV, pedestrians might not know what to expect or how to react.

The notion that eHMIs can influence or determine the crossing behaviour of pedestrians is also shown in a study by Kooijman et al. (2019). They concluded that *"eHMIs can influence pedestrians' actual crossing behavior, compared to a baseline condition."* The results of Kooijman et al. (2019) are in line with a previous study by de Clercq et al. (2019) who found that pedestrians feel safer to cross when interacting with an AV with an eHMI, than without an eHMI. Furthermore, Ackermann et al. (2019) also found that eHMIs *"would replace the role of the driver in negotiation situations".* The use of eHMIs however, only substitutes the driver side of the nonverbal communication. The one-way communication from pedestrian to AV, and two-way communication remain to be investigated.

1.3 Two-way communication

In their literature review, Keferböck and Riener (2015) elaborated on the importance of signs and gestures of pedestrians in pedestrian-AV communication. They discussed that human-to-human contact relies on gestures such as hand or head movements to clarify intentions and situations. Such gestures are not possible in AV-to-pedestrian communication. Studies by Núñez Velasco et al. (2016) and Ren et al. (2016) also concluded that eye contact is important for pedestrians to extract intentions and confirm the attention of the driver. These studies reinforce the notion that non-verbal communication methods such as eye-contact are important, and that the lack of two-way communication could result in problems in the future.

The literature on the communication between pedestrians and AVs has mostly focused on the change that will come with AVs and the possible solutions for the AV to communicate to the pedestrians. Some suggestions were made to how pedestrians' decision making could be adapted to the new situation; however, no studies were found in which new communication methods were discussed for the pedestrian. Concluding, the literature researched did not provide insight into how pedestrians can communicate with the AV; only the communication from the AV to the pedestrian was investigated. Therefore, research had to be done on two-way communication between pedestrians and AVs.

The goals of this research were, therefore, to investigate whether pedestrians are willing to use a hand gesture to communicate their crossing intention to an approaching AV, and how a response from the AV via an eHMI would affect the participants crossing behaviour. The choice to focus only on hand gestures was based on research found in the field of robotics (Gleeson et al., 2013), driver-driver communication (Kitazaki & Myhre, 2015) and pedestrian-driver communication (Zhuang & Wu, 2014).

The experiment tested control conditions with two different one-way communication methods, as well as two-way communication. Therefore, the experiment investigated not only how the pedestrians communicate with an AV, but also how the AV communicates with the pedestrians, and how the communication was affected if there was a response to the pedestrian.

The following research questions were composed:

- Research question 1: Are pedestrians inclined to use a hand gesture to communicate with approaching AVs, if they are informed that the use of the hand gesture increases the probability of the AV stopping for them?
- Research question 2: How is the participants' crossing decision and self-reported experience affected by the use of a hand gesture to communicate crossing intent to approaching AVs.

The following hypotheses were expected to answer the research questions:

- Hypothesis 1: If the use of a hand gesture to communicate with AVs increases the probability of the AV stopping for the pedestrian, then the pedestrian will raise his/her hand more frequently. This will be reflected by:
    - On average, the participants will use hand gestures significantly more than half of the possible times.
    - After the experiment, the participants will have a higher self-reported rating of trust that hand gestures can be used to communicate with AVs after the experiment.

- Hypothesis 2: The participant will feel safer to cross after having given the hand gesture, in comparison to not having given the hand gesture. This will be reflected by:
    - Earlier initiation of the crossing by the pedestrian.
    - Increased self-reported feeling of safety to cross.

2. Methods

2.1. Participants

Twenty-six participants (6 females, 20 males) were recruited among students and PhD candidates at the TU Delft. They had a mean age of 26.0 years (*SD* = 3.7 years). All participants were living in the Netherlands at the time of the study but had nationalities from different parts of the world (i.e., Europe, Asia, North America, South America, and Africa). The participants were offered a compensation of €10 for participating in the study and signed a written informed consent form before starting the experiment.

2.2. Materials

The experiment environment was developed on a laptop from the brand Lenovo, with Intel(R) Core(TM) i5-6200U CPU @ 2.30GHz Processor, NVIDIA GeForce 940MX 2Gb Graphics Card, 4GB of RAM. The experiment ran on a desktop computer running Windows 10, from the brand Alienware, with Intel(R) Core(TM) i7-9700K CPU @ 3.60GHz Processor, NVIDIA GeForce RTX 2080 8GB Graphics Card, 16GB of RAM.

The virtual environment used in the experiment was developed and run using UNITY version 2018.4.6f1 on a Windows 10 64-bit platform. The scripts and environment were adapted from earlier experiments performed by Kooijman et al. (2019) and De Clercq et al. (2019). The participants wore an Oculus Rift to experience the virtual environment. To provide the participants with enough freedom of movement, the Oculus Rift was worn over the eyes of the participant, while the cables were hung from a support above the participant by extending the HDMI and USB cables with additional 1-meter HDMI and USB cables.

To track and record the motion of the participant during the experiment, the Xsens Link was used, as can be seen in Figure 1, with sensors (MVN Link MTx) on 17 different locations on the participant's body. The sensors were connected via a cable to a transmitter called the Body Pack, from which the data was sent to an ASUS RT-AC68U connected by a LAN cable and MVN Link USB Ethernet Adapter to the desktop computer.

Data received from the Xsens Link was handled by the motion tracking software Xsens MVN Analyse Version 2019.0.0 build 1627, which was configured to stream the data with a skip factor of 4 through UDP protocol.

Figure 1: Participant wearing Xsens Link and Oculus Rift

2.3 Design

The experiment was of a within-subjects design in which each participant experienced a virtual environment and interactions with a virtual AV (Figure 2). For each participant, the experiment consisted of a series of 40 randomised interactions, divided over four randomised scenarios.

The four scenarios were designed to test two different independent variables. The first independent variable was the permission to use a hand gesture to yield or communicate to the AV. The response through an eHMI from the AV was chosen to be the second independent variable in this study. The combination of independent variables led to the following conclusion: two Hand gesture conditions and two eHMI response conditions combined to create four scenarios (2 x 2). The scenarios were thus named: “Baseline”, “eHMI”, “Hand” and “Combination”.

Figure 2: VR environment with AV displaying the message "I SEE YOU".

The scenarios were constructed as follows:

- Scenario 1 named "Baseline", in which no hand gesture was allowed to be used by the participant, and the vehicle would not respond via the eHMI. Even if the participant did use a hand gesture, the AV would not respond via the eHMI or yield.
- Scenario 2 named "eHMI", which was identical to Scenario 1, with the exception that the AV would respond by displaying the message "I SEE YOU" on its eHMI when it yielded for the participant. Hand gesture usage would not result in any change to the pre-programmed behaviour of the AV. Thus, the AV would behave as programmed, regardless of the unauthorised hand gesture of the participant.
- Scenario 3 named "Hand", in which a hand gesture was allowed to be used by the participant. The use of the hand gesture would only result in yielding of the AV if the AV was pre-programmed to yield during that specific interaction. If the hand gesture was used during an interaction in which the AV was not pre-programmed to yield, the AV would continue without yielding. If the AV was pre-programmed to yield, but the participant did not use a hand gesture during this interaction, the AV would also continue without yielding. The AV would not respond via the eHMI in any of the interactions.
- Scenario 4 named "Combination", in which a hand gesture was allowed to be used by the participant, and the AV would respond by displaying the message "I SEE YOU" on its eHMI when it yielded for the participant. Similar to scenario 3, the AV would not yield or display the message, if the participant used the hand gesture during interaction in which the AV was not pre-programmed to yield. The same

would happen if the participant did not use a hand gesture during the interactions in which the AV was pre-programmed to yield.

Regarding permission to use a hand gesture, the choice was given to each participant during two out of four scenarios, respectively ("Hand" and "Combination"). Hand gesture usage was not made obligatory in order to test if the participants were willing to try and adopt this method of communication instead of forcing them to use a method of communication with which they did not feel comfortable. An example of a participant using a hand gesture is shown in Figure 3.

Figure 3: VR Avatar raising the right hand to yield the approaching AV

For the second independent variable, two out of four scenarios ("eHMI" and "Combination"), involved an AV displaying a message of "I SEE YOU" on the front of the AV, as can be seen in Figure 2. The response of the AV would only occur if the AV yielded to the participant; in the cases it would not yield no message was shown.

In all four scenarios, the AV had one of two fixed behaviours. It would either yield or continue, based on a predefined randomised order which differed per participant. However, as discussed above, in the two scenarios in which a hand gesture was allowed, the AV's behaviour also depended on the hand gesture. Specifically, in the "Hand" and "Combination" scenarios, the AV would only yield if the participant used a hand gesture during the interactions that the AV was pre-programmed to yield, as can be seen in Figure 4.

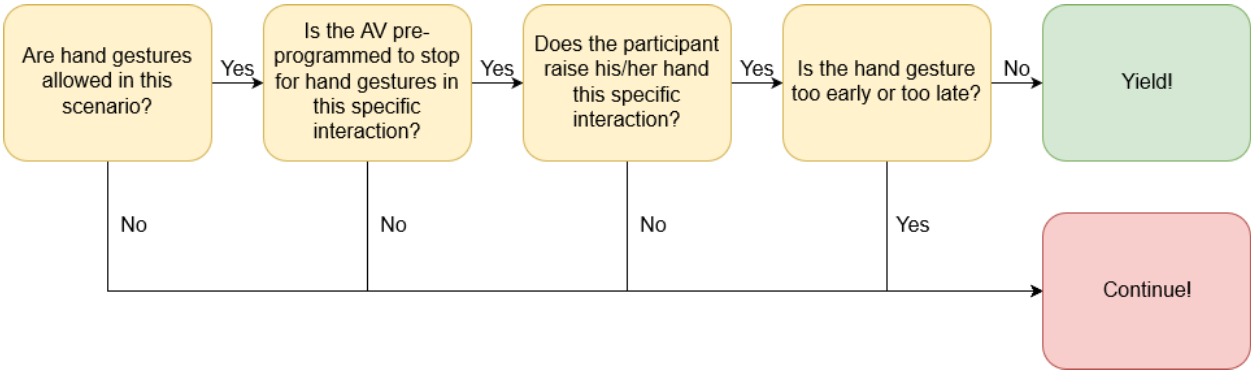

Figure 4: Diagram showing when the AV will yield or continue regarding the use of a hand gesture

If the AV would yield, it did so with a deceleration depending on the distance in X direction between the center of the pedestrian crossing and the center of the AV. The deceleration was calculated using the formula $a = \frac{v^2}{2s} * \frac{1}{2}$, where v was the constant approach speed of 13.89 m/s (i.e. the AV had a constant approach speed of 50 km/h during all scenarios and interactions) and s was the distance between the center of the AV and the center of the pedestrian crossing in X direction at the moment of initiating the deceleration. The AV would come to a full halt at a distance in the X direction of 6.9 meters between the center of the AV and the center of the pedestrian crossing.

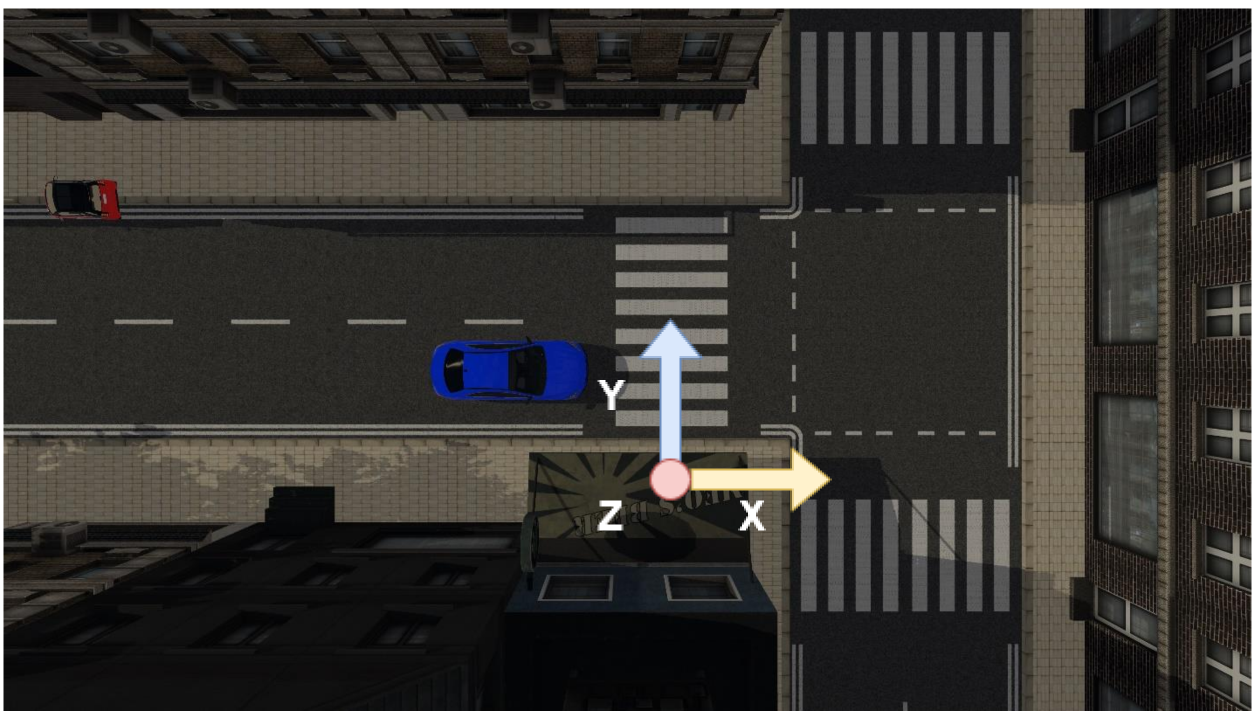

Figure 5: Coordinate system in the VR environment

Figure 5 shows the coordinate system used throughout the experiment. Where X means along the road with the left being negative and the right being positive. Y means across the road with forward being positive and backwards being negative. Z means upwards from the ground with up being positive and down being negative.

The pre-programmed yield order for all four scenarios was fixed on yielding in 50% of the interactions; however, as mentioned before for the “Hand” and “Combination” scenarios the yield rate also depended on the hand usage of the participants. As shown in Figure 4, the AV would not yield if the hand gesture was too early or too late.

The distance thresholds for the hand gesture were fixed at 30 and 50 meters in the X direction from the center of the pedestrian crossing. A hand gesture used while the AV was before the 50 meters threshold or after the 30 meters threshold would mean the hand gesture was used too early or too late respectively. Moreover, the AV would start the deceleration immediately when the hand gesture was used while the AV was between the thresholds. A random example of how the experiment was performed by a random participant is shown in Figure 6.

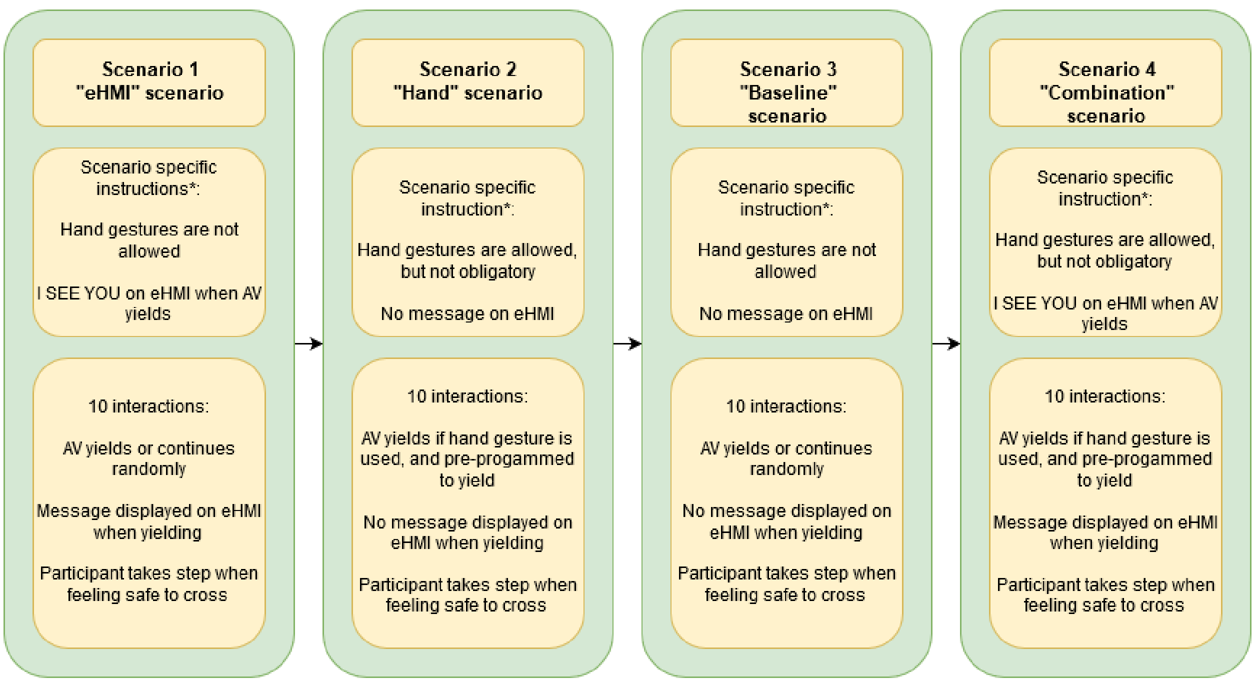

Figure 6: Scheme displaying an example proceedings of an experiment from a random participant (i.e. the order of scenarios was randomised for each participant)

2.4 Procedure

Before the start of the experiment, all participants completed a digital pre-experiment questionnaire consisting of questions related to demographics, crossing behaviour, walking preferences, and their feeling towards AVs and hand gestures as a form of communication.

After the pre-experiment questionnaire, the participants started the experiment on the corner of a virtual T-shaped junction, facing a pedestrian crossing. The participants were instructed to not cross the road, but only to make one step forward when they felt safe to cross the road, as shown in Figure 7. Furthermore, during the experiment, the participants were informed when they could use the hand gesture if they wanted. Informing the participant was done by the researcher standing in front of the participant and stating "*For the following ten interactions, you are allowed to use a hand gesture if you want to, but you do not have to*".

Figure 7: VR Avatar taking a step after the AV has yielded.

After each interaction, the participant was asked two questions related to the difficulty of interpreting the behaviour of the AV and the assurance of being seen by the AV. The two questions were: "*On a scale from 0 to 10, where 0 is Not difficult at all, and 10 is Very difficult, how difficult was it for you to predict the behaviour of the car?*" and "*On a scale from 0 to 10, where 0 is Not sure at all and 10 is Completely sure, how sure were you that* *the car would see you?*". A video showing one of the interactions can be found at https://drive.google.com/open?id=14H-W2YaP_53X2_gDjARarZdYnVfDCnko

The participants ended the experiment with a post-experiment questionnaire on their preferences between the four scenarios. Aside from their preferences, the post-experiment questionnaire included questions regarding their self-reported feeling of safety, assurance of being seen by the AV and the effect that the lack of eye contact had on their decision making.

The questions of the post-experiment questionnaire included a picture similar to Figure 2, and were formulated as follows: *"How safe do you feel to cross the road in this situation?", "How sure are you that the car has seen you in this situation?",* and *"How strongly does the fact that you cannot make eye contact with a driver affect your decision to cross the road in this situation?"* The participants provided their answers on a scale from 1 to 10, with 1 being *"Not safe at all", "Not sure at all",* and *"Not at all"* and 10 being *"Completely safe", "Completely sure",* and *"Very strongly"* for each respective question.

Furthermore, the post-experiment questionnaire required the participant to re-answering the questions from the pre-experiment questionnaire about their feeling towards AVs and hand gestures as a form of communication. The post-experiment questionnaire was included to investigate the effect of the experiment on the feeling of trust towards AVs and the use of hand gestures as a form of communication. After the experiment, the participants were given the compensation and asked to sign a sheet confirming to having received the compensation.

2.5 Dependent variables

For the experiment, the choice was made to focus on six dependent variables. The first dependent variable was the hand usage, which was gathered by recording the positions and angles of the wrists, elbows and the shoulders of the participants during the experiment. Recording of the positions and angles was done by using the Xsens Link and MVN Analyze. However, differentiation between the movement of the hand gesture and swaying of the arms of participants when making a step was needed. The hand gesture was only recognised when one of the positions or angles would change to above a threshold value predetermined during the development of the experiment. The thresholds were defined as 45° between the upper arm and the body, 60° between the forearm and the direction of the upperarm, and for the hand if its position was above that of the elbow.

Since the underlying goal of this research was to investigate if eye-contact with a driver could be replaced by a new form of communication such as hand gestures, the feeling of safety to cross the road was an important variable to analyse. The feeling of safety to cross the road was tested through the implementation of a step by the participant at the moment they felt safe to cross the road. The participants' step data was gathered by recording the participant's movement using the Xsens Link and MVN Analyze. Additional data on the feeling of safety to cross was gathered by analysing the answers regarding the feeling of safety from the post-experiment questionnaire.

The third dependent variable was the difficulty of predicting the behaviour of the AV. It was gathered for each interaction by repeatedly asking the participant the question: *"On a scale from 0 to 10, how difficult was it for you to predict the behaviour of the car?"* Finally, the fourth dependent variable was the assurance of being seen by the AV and it was gathered in the same way as the previous variable, by asking the question: *"On a scale from 0 to 10, how sure were you that the car would see you?"* These dependent variables were chosen to test how well the hand gesture and the eHMI replaced the eye-contact between the participant and the AV.

Furthermore, the results of the fifth and sixth dependent variables were collected with the post-experiment questionnaire. The fifth dependent variable was the preference of scenarios when interacting with an AV. The sixth dependent variable focused on how strongly the participants' decision was affected by the lack of eye contact for each scenario.

2.6 Data processing and statistics

The data gathered from the motion tracking software Xsens needed to be matched with the data gathered from the VR environment. Both datasets included the system time, which was used to match samples within the datasets. Following the data matching, the data needed to be filtered for the steps taken and hand gestures used. By matching the system time on the samples and filtering for steps and hand gestures, it was possible to create graphs of each interaction.

The samples that contained steps taken, were also assessed to find the system time at which the step was initiated. The system time matching the initiation of the step was then used to acquire the distance between the AV and the participant at the initiation of the step. Acquiring the distance was done by matching the system time at the initiation of the step from the Xsens software with the system time found in the UNITY software data.

For the questionnaires, the data was processed by analysing the excel files in which the answers were stored. Processing the questionnaire data was done by loading the excel files into the program Matlab R2018b and using the built-in function ttest. The *ttest* function was used to perform paired samples *t*-tests to analyse "trust" in the use of hand gestures regarding AVs, the feeling of safety, assurance of being seen by the AV and the effect that the lack of eye-contact had on decision making of the participants. The *t*-tests used a significance level of 0.05.

Furthermore, the post-experiment questionnaire provided data on the ranking that participants gave to the scenarios. The rankings were based on four questions related to feeling of safety to cross the road, assurance of being seen by the AV, how strongly the lack of eye-contact affected decision making and also the preference of scenario when interacting with an AV. These rankings were also processed by analysing the excel files in which the answers were stored. The combined data for each participant was then used in a stacked bar graph for each of the four questions.

3. Results

3.1. Main findings

The graphs created from the matched samples depicted an interaction between a participant and AV. The graphs included the hand gesture made by the participant, the distance between the AV and the participant over time, and the step taken by the participant. These graphs gave insight into the interaction moment by moment. An example of one of these graphs can be seen in Figure 8.

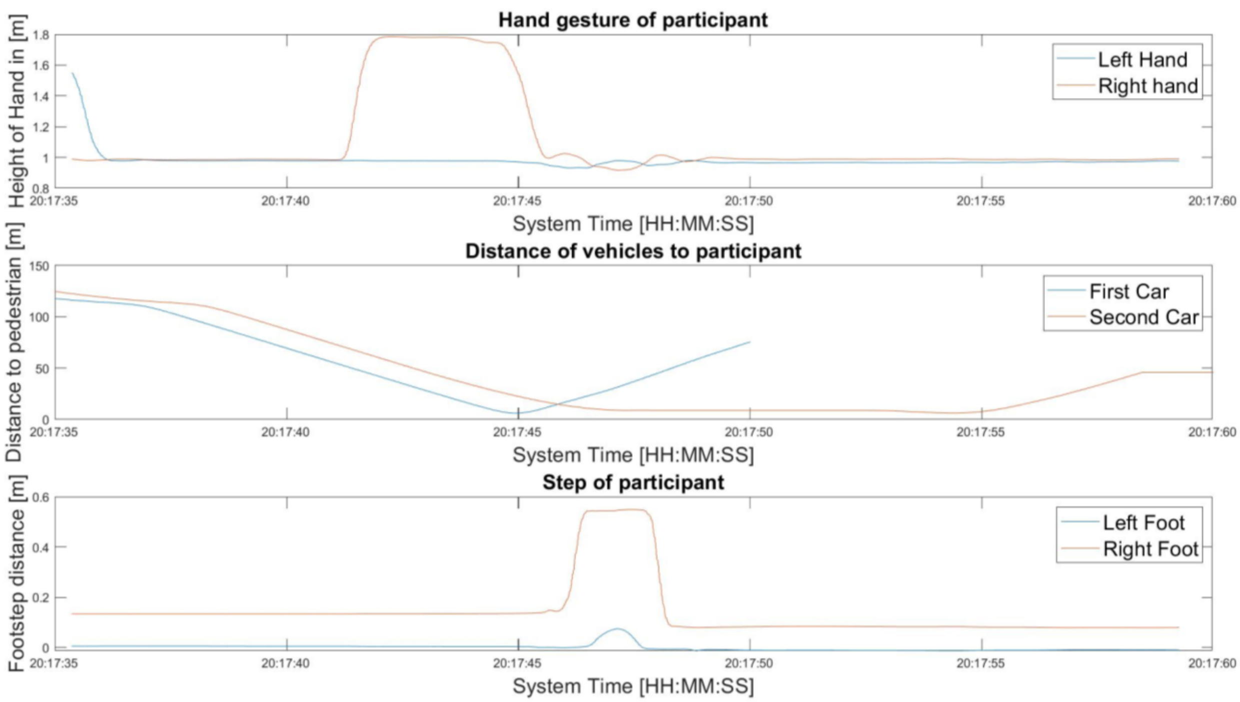

Figure 8: Specific interaction of one participant. Includes the hand gesture, distance between the AV and participant, and the step taken. Gathered from the experiment (UNITY and MVN Xsens).

The top graph of Figure 7 shows that during this specific interaction, the participant raised his/her right hand approximately 0.8 meters from its initial position alongside the participants body at 1 meter from above the ground. The middle graph shows that the hand was raised while the AV was at a distance of approximately 70 meters from the participant. The distance for these middle graph was taken in the horizontal XY plane by applying the Pythagorean distance formula to the distances in X and Y direction, however, the Pythagorean distance was only used for these graphs. For the VR environment in UNITY and the remaining results either the X, Y or Z directions were used. Furthermore, the bottom graph shows that after the hand was lowered and the AV had almost come to a halt, the participant took a right footstep of approximately 0.4 meters to the front.

3.2. Rate of hand gesture usage

Table 1 shows the average of hand gestures that were done throughout the entire experiment, as well as the division of these hand gestures over each of the two scenarios in which participants were allowed to use a hand gesture. It is shown that, on average, the participants used a hand gesture 15.92 times (SD = 3.99 times) out of the 20 possible times. Further analysis shows that when looking separately at the scenarios in which a hand gesture was allowed (“Hand” and “Combination”), the participants used a hand gesture on average 8.12 times (SD = 2.07 times) and 7.81 times (SD = 2.25 times) out of 10 possible times respectively. The percentages of hand gesture usage per scenario are shown in Figure 9.

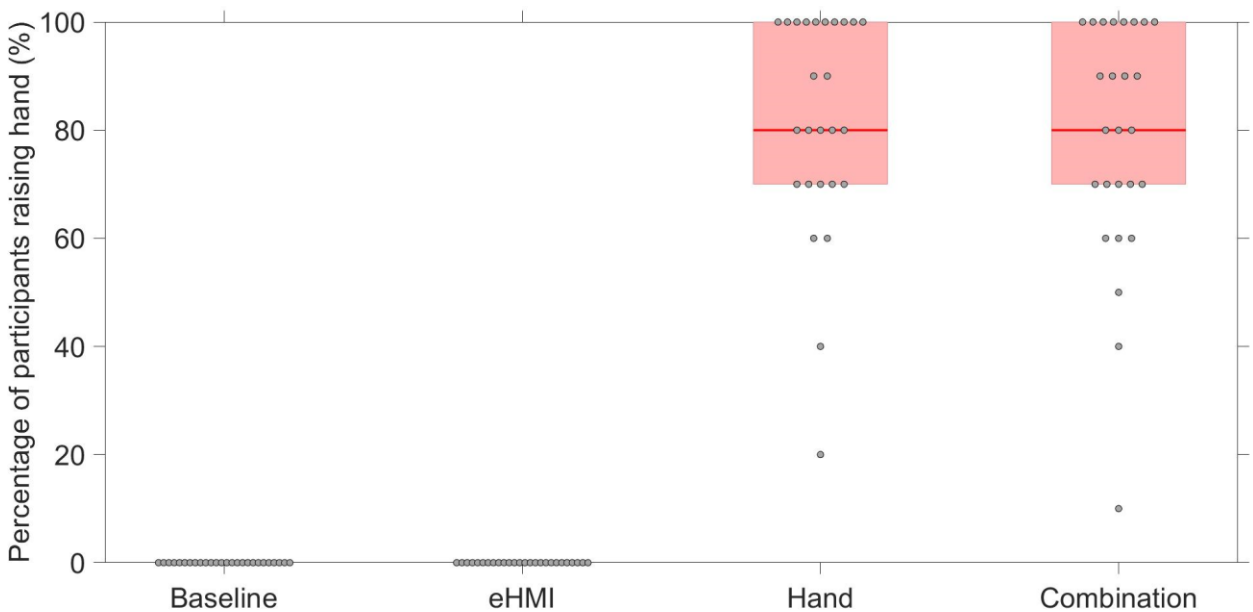

Figure 9: Percentage of hand gesture usage per scenario. Gathered from the experiment (UNITY and MVN Xsens).

The action of a hand gesture could result in two different responses of the AV, either continue or yield (not yet considering the addition of an eHMI message). Which meant that the previously mentioned averages needed to be divided into two groups: hand gestures that resulted in the AV yielding and hand gestures that did not result in the AV yielding. The average times the AV yielded and continued are shown per scenario in Table 1.

These results need to be split up over the two scenarios “Hand” and “Combination”. Table 1 shows that for both scenarios, on average the AV continued more often than that it yielded when the participant used a hand gesture. The averages of hand gestures used too early or too late to result in the AV yielding are 0.31 times (SD = 0.62 times) out of 10 times for the "hand" scenario and 0.42 times (SD = 0.81 times) out of 10 times for the "combination" scenario. Thus the averages for the AV continuing are for the majority from participants using hand gestures during interaction in which the AV was not pre-programmed to yield.

The results in Table 1 also show that on average, for both "hand" and "combination" scenario, the participants tried again more often after the previous attempt did not result in the AV yielding, than when the previous attempt was successful. In general, the majority of attempts to yield the AV were followed with a second attempt (i.e. follow-up attempt) immediately after.

Table 1
Average and standard deviation of number of hand gestures, per scenario and per AV behaviour. Gathered from the experiment (UNITY and MVN Xsens). N = 26 participants.

	M (SD)
Total average of number of hand gestures from both scenarios, out of 20 possible times	15.92 (3.99)
Hand gestures used during "Hand" scenario out of 10 possible times	8.12 (2.07)
Resulted in yielding	3.85 (1.38)
Follow-up hand gestures used out of 9 possible times	2.73 (1.64)
Did not result in yielding	4.27 (1.40)
Follow-up hand gestures used out of 9 possible times	3.38 (1.58)
Hand gestures used during "Combination" scenario out of 10 possible times	7.81 (2.25)
Resulted in yielding	3.50 (1.50)
Follow-up hand gestures used out of 9 possible times	2.50 (1.61)
Did not result in yielding	4.31 (1.38)
Follow-up hand gestures used out of 9 possible times	3.31 (1.69)

3.3. Steps taken by the participants

Before the experiment, the participants were instructed to take a step forward at the moment they felt safe to cross the road. The instruction included that the step could be taken before, during or after the second AV had passed, but that the participants had to let the first AV pass in all interactions. On average, the participants took 31.58 steps (SD = 8.56 steps) out of 40 possible steps. These interactions are divided over the four scenarios (“Baseline”, “eHMI”, ”Hand” and “Combination”) as shown in Table 2.

Table 2

Average and standard deviation of steps taken by the participants, per scenario. Gathered from the experiment (UNITY and MVN Xsens). N = 24 participants.

Scenario	*M (SD)*
Total of all scenarios	31.58 steps (SD = 8.56 steps) out of 40 possible steps
Baseline scenario	7.83 steps (SD = 2.57 steps) out of 10 possible steps
eHMI scenario	8.33 steps (SD = 2.24 steps) out of 10 possible steps
Hand scenario	8.08 steps (SD = 2.24 steps) out of 10 possible steps
Combination scenario	7.33 steps (SD = 2.68 steps) out of 10 possible steps

On average, the “Combination” scenario resulted in the largest distance in X direction between the center of the AV and the center of the pedestrian crossing at the moment the participant took the step, as can be seen in Table 3. On average the distance between the AV and the participant was the smallest for the “Baseline” scenario. The average distance between the AV and the participant was slightly higher for the “Hand” and “eHMI” scenarios. However, the difference between the “Hand” and “eHMI” scenarios was not big as both have similar average distances in the X direction as can be seen in Table 3.

Table 3
Results of paired sample *t*-test of all four scenarios, regarding the distance in X direction when initiating the feeling of safety step, taken from the interactions in which the AV yielded. Gathered from the experiment (UNITY and MVN Xsens). N = 24 participants.

Scenario	*M (SD)*
Total of all scenarios	8.44 meters (SD = 21.04 meters)
Baseline scenario	6.93 meters (SD = 16.91 meters)
eHMI scenario	8.36 meters (SD = 15.97 meters)
Hand scenario	8.22 meters (SD = 22.12 meters)
Combination scenario	10.21 meters (SD = 27.84 meters)

Pair	*Test statistic, p-value*
Baseline – eHMI	$t(23) = 1.36$, $p = 0.189$
Baseline – Hand	$t(23) = 1.10$, $p = 0.283$
Baseline – Combination	$t(23) = 1.53$, $p = 0.141$
eHMI – Hand	$t(23) = -0.32$, $p = 0.750$
eHMI – Combination	$t(23) = 0.75$, $p = 0.459$
Hand – Combination	$t(23) = 1.09$, $p = 0.286$

The distances in the X direction for all four scenarios were also analysed by paired sample *t*-test. For this analysis, the average distances per scenario per participant were taken of the interactions for which the AV yielded, and the participant took a step. It was found that the scenarios did not result in statistically significant different distances in X direction between the AV and the participant as can be seen in Table 3.

3.4. Self-reported feeling of safety

In addition to the feeling of safety shown by the distance between the AV and the participants, the feeling of safety was also registered via questionnaire. Table 4 shows the mean responses of the participants' self-reported feeling of safety. The participants found that the pictures of the post-experiment questionnaire in which a message was displayed on the eHMI, gave them a significantly larger feeling of safety than when the eHMI message was left out, as can be seen in Table 4.

Table 4
Results of paired sample *t*-test of all four scenarios, regarding the self-reported feeling of safety. Gathered from the post-experiment questionnaire. N = 26 participants.

Scenario	*M (SD)*
Total of all scenarios	7.49 (SD = 2.79)
Baseline	5.69 (SD = 3.11)
eHMI	8.81 (SD = 1.96)
Hand	6.46 (SD = 2.53)
Combination	9.00 (SD = 1.85)
Pair	*Test statistic, p-value*
Baseline – eHMI	$t(25) = -5.75$, $\boldsymbol{p < 0.001}$
Baseline – Hand	$t(25) = -1.58$, $p = 0.127$
Baseline – Combination	$t(25) = -5.28$, $\boldsymbol{p < 0.001}$
eHMI – Hand	$t(25) = 4.07$, $\boldsymbol{p < 0.001}$
eHMI – Combination	$t(25) = -0.39$, $p = 0.700$
Hand – Combination	$t(25) = -5.46$, $\boldsymbol{p < 0.001}$

The pictures involving the use of hand gestures did not give the participants a significantly larger feeling of safety. However, Figure 10 shows that the "Combination" scenario did result in the highest feeling of safety of all scenarios. While this scenario did not significantly differ from the "eHMI" scenario, it did significantly differ from the "Baseline" and "Hand" scenarios, as can be seen in Table 4.

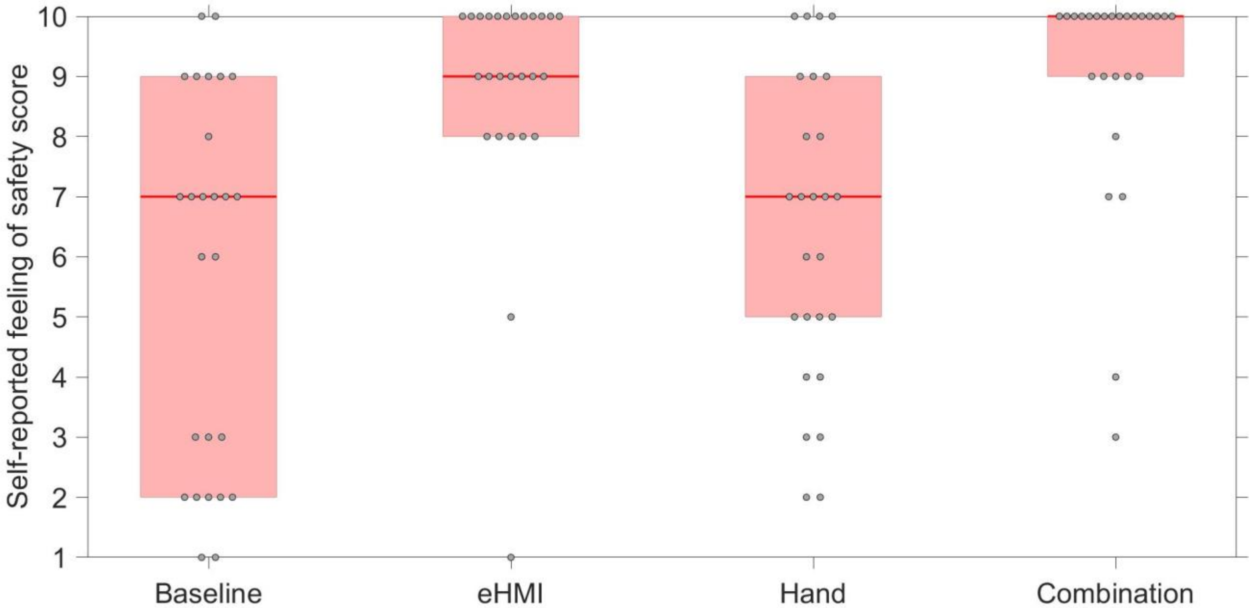

Figure 10: Self-reported feeling of safety, per scenario. Gathered from the post-experiment questionnaire. With 1 being "Not safe at all" and 10 being "Completely safe".

3.5. Self-reported assurance of being seen by the AV

In a similar way to the self-reported feeling of safety, the participants answered that the pictures depicting the AV with a message on the eHMI gave them a higher assurance that they were seen by the AV compared to the scenarios without an eHMI, as can be seen in Table 5 (gathered from the post-experiment questionnaire, not to be confused with the data gathered from the post-interaction questionnaire). The use of a hand gesture, however, did not increase their assurance significantly, except for the scenario in which both hand gesture and message on the eHMI were combined, as can be seen in Table 5.

Table 5
Results of paired sample *t*-test of all four scenarios, regarding the assurance of being seen by the AV. Gathered from the post-experiment questionnaire. N = 26 participants.

Scenario	*M (SD)*
Total of all scenarios	7.19 (SD = 2.77)
Baseline	5.54 (SD = 2.66)
eHMI	8.54 (SD = 2.44)
Hand	5.88 (SD = 2.66)
Combination	8.81 (SD = 1.55)
Pair	*Test statistic, p-value*
Baseline – eHMI	$t(25) = -5.64$, $\mathbf{p < 0.001}$
Baseline – Hand	$t(25) = -0.88$, $p = 0.386$
Baseline – Combination	$t(25) = -6.74$, $\mathbf{p < 0.001}$
eHMI – Hand	$t(25) = 5.16$, $\mathbf{p < 0.001}$
eHMI – Combination	$t(25) = -0.70$, $p = 0.493$
Hand – Combination	$t(25) = -6.64$, $\mathbf{p < 0.001}$

3.6. Self-reported effect of lack of eye-contact on decision making

Table 6 shows the average scores that participants gave to the effect that the lack of eye-contact had on their decision making. These results were comparable to the previously mentioned feeling of safety and assurance of being seen by the AV. The message on the eHMI resulted in a significant difference compared to the "baseline" scenario, while the hand gesture only resulted in a significant difference when combined with a message on the eHMI as can be seen in Table 6.

Table 6
Results of paired sample *t*-test of all four scenarios, regarding the effect that the lack of eye-contact had on decision making of the participants. Gathered from the post-experiment questionnaire. N = 26 participants.

Scenario	*M (SD)*
Total of all scenarios	5.05 (SD = 2.85)
Baseline	6.15 (SD = 2.63)
eHMI	4.27 (SD = 2.97)
Hand	5.73 (SD = 2.49)
Combination	4.04 (SD = 2.84)
Pair	*Test statistic, p-value*
Baseline – eHMI	$t(25) = 2.94$, $\mathbf{p = 0.007}$
Baseline – Hand	$t(25) = 1.00$, $p = 0.327$
Baseline – Combination	$t(25) = 3.97$, $\mathbf{p < 0.001}$
eHMI – Hand	$t(25) = -2.59$, $\mathbf{p = 0.016}$
eHMI – Combination	$t(25) = 0.48$ $p = 0.638$
Hand – Combination	$t(25) = 3.39$, $\mathbf{p = 0.002}$

3.7. Post-interaction questionnaire results

Table 7 and Table 8 show the mean responses of participants' difficulty to predict the behavior of the AV and the assurance of being seen by the AV (gathered from the post-experiment questionnaire). Together with Figure 11 they show that the participants found that the use of a hand gesture made it more difficult for them to predict the behaviour of the AV compared to the "baseline" scenario. On the contrary, the eHMI made it easier for them to predict the behaviour of the AV. Figure 11 and Table 8 also show the same pattern for the assurance of being seen by the AV. The participants were on average less sure of being seen by the AV in the scenario in which they were allowed to use a hand gesture compared to the scenario without hand gestures.

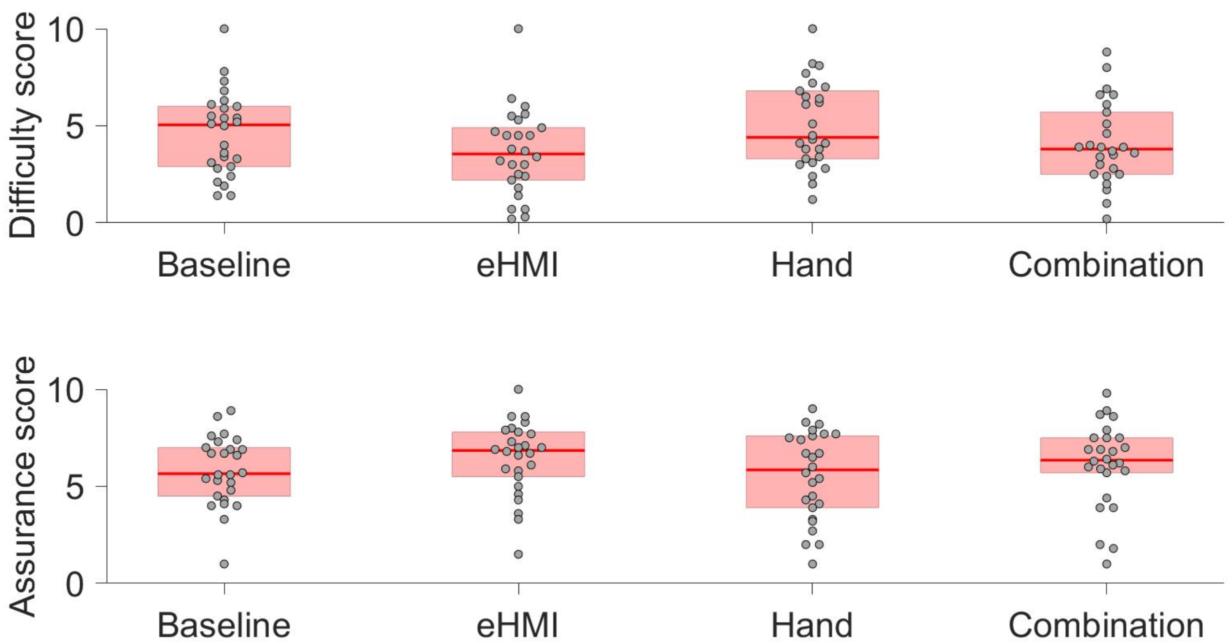

Figure 11: Difficulty predicting the behaviour of the AV and Assurance of being seen by the AV, per scenario. Gathered from the post-interaction questionnaire. With 0 being "Not difficult at all" and "Not sure at all" and 10 being "Very difficult" and "Completely sure" respectively.

The results from the post-interaction questions were also analysed by paired sample *t*-test, which found that there were statistically significant differences between some of the scenarios, as can be seen in Table 7 and Table 8. The tables show that while the hand gestures had a negative impact on the participants, the eHMI improved their interaction. Tables 7 and 8 show that the eHMI made it easier to predict the AV's behaviour and made the participants feel more sure about being seen by the AV.

Table 7

Results of paired sample *t*-test of all four scenarios, regarding the difficulty predicting the behaviour of the AV during the experiment. Gathered from the post-interaction questionnaire. N = 26 participants.

Scenario	*M (SD)*
Total of all scenarios	4.34 (SD = 2.99)
Baseline	4.62 (SD = 2.79)
eHMI	3.62 (SD = 3.01)
Hand	5.04 (SD = 2.92)
Combination	4.09 (SD = 3.06)
Pair	*Test statistic, p-value*
Baseline – eHMI	$t(25) = 2.37$, $\boldsymbol{p = 0.026}$
Baseline – Hand	$t(25) = -1.74$, $p = 0.095$
Baseline – Combination	$t(25) = 1.63$, $p = 0.115$
eHMI – Hand	$t(25) = -3.20$, $\boldsymbol{p = 0.004}$
eHMI – Combination	$t(25) = -1.06$, $p = 0.302$
Hand – Combination	$t(25) = 3.14$, $\boldsymbol{p = 0.004}$

Table 8

Results of paired sample *t*-test of all four scenarios, regarding the assurance of being seen by the AV during the experiment. Gathered from the post-interaction questionnaire. N = 26 participants.

Scenario	*M (SD)*
Total of all scenarios	5.99 (SD = 2.92)
Baseline	5.81 (SD = 2.68)
eHMI	6.46 (SD = 3.01)
Hand	5.56 (SD = 2.89)
Combination	6.13 (SD = 3.04)
Pair	*Test statistic, p-value*
Baseline – eHMI	$t(25) = -1.85$, $p = 0.077$
Baseline – Hand	$t(25) = 0.84$, $p = 0.407$
Baseline – Combination	$t(25) = -0.97$, $p = 0.343$
eHMI – Hand	$t(25) = 2.60$, $\boldsymbol{p = 0.015}$
eHMI – Combination	$t(25) = 1.28$, $p = 0.213$
Hand – Combination	$t(25) = -1.88$, $\boldsymbol{p = 0.071}$

3.8. Trust related to AVs and Hand gestures

Results of the *t*-tests on the data gathered both pre- and post-experiment are shown in Table 9. The paired sample *t*-tests in Table 9 were used to analyse the data that was gathered from the answers to the following questions: *"Q1; I have trust in self-driving vehicles", "Q2; I have trust that self-driving vehicles will notice me", "Q3; I have trust that self-driving vehicles will respond to hand gestures"* and *"Q4; I have trust that hand gestures can be used to communicate with a self-driving vehicle"*. The results in Table 9 show that on average after the experiment, the participants had a significantly higher trust on the questions related to hand gestures.

For the third question: *"I have trust that self-driving vehicles will respond to hand gestures"*, the participants answered significantly higher average scores for the post-experiment questionnaire, than for the pre-experiment questionnaire. For the fourth question: *"I have trust that hand gestures can be used to communicate with a self-driving vehicle"*, the participants also answered significantly higher average scores after the experiment compared to before the experiment. However, for the first two questions: *"I have trust in self-driving vehicles"* and *"I have trust that self-driving vehicles will notice me"* the results before and after did not differ significantly, as can be seen in Table 9.

Table 9
Mean, standard deviation, t-score and p-score per "Trust" question. Gathered from the pre-experiment and post-experiment questionnaires. N = 26 participants.

	M (SD)	
	Pre	Post
Question 1: I have trust in self-driving vehicles.	6.04 (1.95)	6.58 (1.72)
Question 2: I have trust that self-driving vehicles will notice me.	6.19 (1.86)	6.27 (1.71)
Question 3: I have trust that self-driving vehicles will respond to hand gestures.	5.15 (2.26)	6.77 (2.03)
Question 4: I have trust that hand gestures can be used to communicate with a self-driving vehicle.	6.04 (2.44)	7.62 (1.96)

	Test statistic, p-value
Question 1: I have trust in self-driving vehicles.	*t(25) = -1.59*, *p* = 0.124
Question 2: I have trust that self-driving vehicles will notice me.	*t*(25) = -0.19, *p* = 0.849
Question 3: I have trust that self-driving vehicles will respond to hand gestures.	*t*(25) = -2.87, ***p* = 0.008**
Question 4: I have trust that hand gestures can be used to communicate with a self-driving vehicle.	*t*(25) = -3.12, ***p* = 0.004**

3.9. Ranking of scenarios

In the post-experiment questionnaire, the participants were asked to rank the scenarios based on four different subjects. The subjects were: Feeling of safety to cross the road, Assurance of being seen by the AV, How strongly the lack of eye-contact affected decision making, and finally, preference of scenario when interacting with an AV. The data showed that participants ranked the “Combination” scenario as the safest to cross the road, highest assurance of being seen by the AV, and their first preference when interacting with an AV. It also showed that participants decision was the least affected by the lack of eye-contact in the “Combination” scenario.

Furthermore, the “eHMI” scenario and “Hand” scenario came in second and third place respectively for the topics safe to cross, assurance of being seen and preference of interacting with an AV. The “Baseline” scenario was, in general, chosen as the least preferred in all four topics. However, for the effect that the lack of eye contact had on decision making, the “eHMI” scenario and “Hand” scenario were ranked second and third without significant difference. The graphs representing the rankings can be found in the Appendix.

4. Discussion

4.1. The use of hand gestures

The averages of hand gestures including those that were done as follow-up by the participants throughout the entire experiment were sufficiently high (see Table 1). Thus it was assumed that the participants were willing to use a hand gesture to communicate to the AV that they wanted to cross. Moreover, the averages of the follow-up hand gestures (hand gestures used again during the next interaction) showed that the participants were not discouraged from using the hand gesture if it did not result in the AV yielding during the previous interaction. Because participants did use follow-up hand gestures during the next interactions, it can be argued that they saw the potential or were curious about the hand gestures, and thus were willing to use the hand gesture again.

Furthermore, significant increases between the answers to the pre-experiment questionnaire and the post-experiment questionnaire were found in participants' trust that AVs will respond to hand gestures and in their trust that hand gestures can be used to communicate with AVs. The questions related to trust did not focus on the usage of the hand gesture. The answers could, however, indicate a positive attitude towards the use of hand gestures in the future. As higher trust in a method could lead to acceptance and use of the method itself (Bahmanziari et al., 2003).

An explanation for the increase of trust could be found in the field of human-robot interaction. The study of Tsui et al. (2010) found that participants' trust in robots increased when the robots adhered to some degree of social protocol. Because hand gestures are already part of a social protocol in traffic (Gupta et al., 2016), participants would have a higher trust in the AV if it would adhere to the social protocol of yielding for the hand gesture.

However, further research needs to focus on the consequences of the use of hand gestures. Acceptance of hand gestures as a form of communication between pedestrians and AVs could lead to misuse of the hand gesture itself. Pedestrians could for example take the yielding effect of the hand gesture and cross the street without waiting for the AV to confirm or reply to the hand gesture.

Moreover, regulations would need to be developed around the yielding behaviour of the AVs. In order to prevent chaos and traffic jams due to AVs constantly yielding for pedestrians using hand gestures when there is no need for yielding. The AVs yielding policy needs to be such that a balance is found between yielding too often and too few. Furthermore, clear legislation on the use of hand gestures by the participant could also prevent the misuse of hand gestures in AV traffic.

Aside from regulations and legislations, there would be need for research into a globally accepted set of hand gestures. Hand gestures that would have the same definition in each country (Gupta et al., 2016), and would result in the same behaviour of the AV for each brand of AVs.

4.2. Improvement of the crossing for the pedestrian

The objective results of the feeling of safety gathered by the step analysis, show that none of the scenarios resulted in a significant increase in the feeling of safety compared to the baseline. However, the subjective results show a significant improvement for the combination of the hand gesture with the eHMI. Compared to the baseline, the eHMI by itself; but especially in combination with the hand gesture significantly improved the subjective feeling of safety, assurance of being seen by the AV and lowered the effect that the lack of eye contact had on decision making. The positive effect of the eHMI on the subjective feeling of safety was also found in the study of de Clercq et al. (2019), however, their study did not involve the combination of an eHMI with a hand gesture.

Differences between the subjective feeling of safety and objective feeling of safety could be related to the relationship between objective and subjective safety in traffic. A study by SWOV Institute for road safety. (2012) showed that *“half of the objectively hazardous situations were also subjectively considered to be hazardous.”* Perhaps the participants personally experienced the use of an eHMI with or without a hand gesture as unsafe during the experiment, while they subjectively considered that the hand gesture and/or eHMI could increase their feeling of safety. However, another explanation could be found in the sensitivity of the objective measurement. For the subjective results, the social desirability of the participant could have caused the difference.

The tendency for participants to show themselves in a positive way is called social desirable responding (van de Mortel, 2008) and it could lead to answers coming out more favourable than the actual response would be. In the case of the post-questionnaire questions regarding the feeling of safety, the participants might want to portray themselves as someone who is less afraid and therefore, rate a higher feeling of safety when they normally would not feel as safe.

Results of the post-interaction questionnaire showed that the use of a hand gesture made it significantly more difficult for the participants to predict the behaviour of the AV compared to the “baseline” scenario. Furthermore, the message via the eHMI did make it significantly easier for the participants to predict the behaviour, which was in line with the study of Kooijman et al. (2019), who also found that eHMIs lower the difficulty of predicting the behaviour of AVs. The negative impact that the hand gesture had on the difficulty of predicting the AV behaviour, could in part be due to the confusion caused by the AV’s behaviour. If participants expected the AV to yield to their hand gesture, they might have gotten confused when the AV did not always do what they expected.

Another possible explanation could be that during the “Hand” scenario the participants had to predict the AV behaviour based on their own input (i.e., hand usage) and the output of the AV (i.e., deceleration of the AV). During the “baseline” scenario the prediction could only be based on the output of the AV (i.e., deceleration of the AV). Furthermore, during the “eHMI” scenario, the prediction of the participant was aided by an extra output (i.e., the message via the eHMI).

The second explanation is substantiated further by the results that only the message via eHMI made the participants significantly more assured that the AV would see them. The assurance of being seen by the AV relates to the aid that the message via an eHMI gives to the participant in predicting the behaviour of the AV. Therefore, the result was comparable to the study of Mahadevan et al., (2018), who also found that an eHMI alone inspired more confidence about the vehicle's intent compared to the vehicle without an eHMI.

4.3. Two-way communication

Based on the subjective results and the percentage of hand gestures used, the notion is formed that two-way communication instead of one-way communication will likely be more effective in improving the crossing situation for the pedestrian, and perhapse also for the AV.

It should be considered that the two-way communication used in this experiment only consistented of a a single stage of two-way communication, with fixed outcome for the response via eHMI. As the participant initiated the two-way communication with the hand gesture, the AV ended the two-way communication with a response via eHMI. It is however, interesting to investigate what would happen if the AV would have varying responses. For example, adding the response that the AV has seen the participant but is not stopping would allow the participant to enter the second stage of the dialog by trying the hand gesture again.

Multi-stage two-way communication together with a globally accepted set of hand gestures, new regulations and legislation could lead to a more dynamic interaction between pedestrians and AVs. Moreover, it could perhapse even make traffic lights and pedestrian crossings less necessary, as pedestrians and AVs could negotiate right of way without constantly relying on infrastructure.

5. Conclusion

The goals of this research were, to investigate whether pedestrians are willing to use a hand gesture to communicate their crossing intention to an approaching AV, and how a response from the AV via an eHMI would affect the participants crossing behaviour. The research questions regarding these goals were answered with the results gathered from the motion recording and the questionnaires.

The first research question focused on the rate of using a hand gesture. It was formulated as: *“Are pedestrians inclined to use a hand gesture to communicate with approaching AVs, if this hand gesture increases the probability of the AV stopping for them?”*. To answer this question, hypothesis ***H1*** was formulated as: *“If the use of a hand gesture to communicate with AVs increases the possibility of the AV stopping for the pedestrian, the pedestrian will raise his/her hand more frequently.”* This hypothesis ***H1*** was expected to be reflected in the following two results: On average the participants will use hand gestures significantly more than half of the possible times. Furthermore, that after the experiment, the participants will have a higher self-reported rating of trust that hand gestures can be used to communicate with AVs after the experiment.

From the results of hand gestures used, together with the answers to the questions related to trust in hand gestures and AVs, it can be concluded that the participants indeed used it more frequently. However, the answers to the questions related to trust, did not specifically state that the participants would use or consider using the hand gesture more often. They did, however, indicate the positive attitude towards the use of hand gestures, which implies that participants would use or consider using the hand gesture more often in the future. Considering all the results it can be concluded that hypothesis ***H1*** was confirmed by the experiment.

The second research question was formulated as: *“How is the participants’ crossing decision and self-reported experience affected by the use of a hand gesture to communicate crossing intent to approaching AVs?”.* Hypothesis ***H2*** was formulated as: *“The participant will feel safer to cross after having given the hand gesture, in comparison to not having given the hand gesture.”* Which was expected to be reflected as earlier initiation of the crossing by the pedestrian, as well as increased self-reported feeling of safety to cross.

From the data gathered around the feeling of safety step, it was shown that participants did not feel safer to cross after having used a hand gesture to the AV. Neither did the message via an eHMI have a significant effect on the feeling of safety step. However, the self-reported feeling of safety disputes these results, as it was found that the hand gesture in combination with the eHMI did have a significant effect on the feeling of safety. Therefore, Hypothesis ***H2*** cannot be confirmed nor rejected, because the hand gesture did not significantly increase objective results regarding feeling of safety, but the subjective results did show a significant increase in the feeling of safety for the use of a hand gesture in combination with a response through an eHMI from the AV.

6. Recommendations

As mentioned in the discussion, further research should be done on the consequences of the use of hand gestures. As well as multi-stage two-way communication together, a globally accepted set of hand gestures, new regulations and legislation regarding the use of hand gestures to communicate with AVs.

A long-term study is required to investigate the learning effects on the feeling of safety. It is possible that long-term usage of the hand gesture could result in a positive increase of the objectively measured feeling of safety.

Verbally repeating the questions after each interaction confused some of the participants. Therefore, it would be recommended to use a different method of acquiring the data gathered through these questions. For example, one could automate the questions by formulating the questions more clearly and recording the questions digitally to be played to the participant through the built-in headphones of the Oculus Rift. Another example could be to display the questions with their scales in the virtual environment.

This experiment required the participants to perform a step at the moment they felt safe to cross. The problem, however, was that some participants did not do the step in every interaction. Some participants forgot or thought that the step was only needed in the interactions where the AV yielded. Therefore, the sample size of steps taken was not equal for all four scenarios and participants. Therefore, it is recommended to instruct the participants clearly on the importance of the step. Another solution would be to replace the step with a button-press, in which the participant presses a button instead of taking a step. This could make it easier for the participant to remember the task.

The implementation of the button-press instead of the step would also aid the analysis of the respective data. As for the step, the data was saturated with movements of the feet that were not steps and therefore the data had to be filtered before use.

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APPENDIX A: Informed consent form

Informed consent form

Communication between pedestrians and automated vehicles

Researcher: Michael Ray Epke

Supervisors: Dr. Ir. J.C.F. de Winter

Dr. P. Bazilinskyy

Ir. L. Kooijman

Contact details: m.r.epke@student.tudelft.nl

Please take the time to read the following information carefully

You are about to participate in a study about the communication between a pedestrian (you) and an automated vehicle in virtual reality. The experiment is designed to investigate the effect that hand gestures have on your crossing behaviour. You will experience a virtual reality representation of a city, in which you are placed next to a virtual pedestrian crossing.

There will be a total of 40 scenarios divided into blocks of 10, for you to go through. In each scenario you will see two automated vehicles driving towards the pedestrian crossing. Your task is to let the first car pass by and to make only one step forward as a sign to cross the road when you think is a good time to cross. This can be both before and after the second car. During some parts of this experiment, the researcher will inform you that you are allowed to use hand gestures if you want to communicate to the automated vehicle that you want to cross (i.e. raising your hand to make a stop sign).

You will be wearing a motion tracking suit and a pair of virtual reality glasses. This allows you to see and move your virtual body in the virtual world, just as you would in the real world. After manually measuring the lengths/heights of your body you will be asked to put on a shirt and some Velcro straps onto which some sensors will be placed. After attaching the sensors, the researcher will instruct you to stand still followed by a walk to calibrate the sensors. After the calibration the researcher will instruct you again on what your task is during the experiment.

It can happen that you might experience motion sickness, because you're wearing virtual reality glasses. If at any point you begin to experience any discomfort, disorientation, or nausea, please notify the experimenter and the experiment will be paused or ceased entirely. Please do not engage in potentially hazardous activities (e.g., driving, cycling) in case you continue to feel nauseous. There is also a possibility that unsafe crossing decisions may be experienced as genuinely stressful or frightening, due to the high level of visual immersion.

Performing the experiment will take around 60 minutes, and you may stop the study at any time before or during the experiment. If you want to stop the experiment, please notify the researcher immediately. The participant (you) will not receive any benefit from participating.

All data obtained through this experiment will be anonymised. The gathered data may be used for statistical analysis and an MSc thesis, and stored in a public repository in an anonymous form.

After participating in the experiment you will receive your 10€ compensation for helping out in the study.

By signing this form, you state that you have read the informed consent form, and agree with the conditions on this form of consent. You are free to stop the experiment at any time, and if you have any questions concerning this experiment please ask or contact the researcher Michael Ray Epke.

Name:

……………………………………………………………………………………………..

Signature:

……………………………………………………………………………………………..

Date:

……… / …….. / ………

APPENDIX B: recruitment posters

PARTICIPANTS NEEDED

MSC THESIS RESEARCH

PEDESTRIAN-AUTOMATED VEHICLE COMMUNICATION

Are you interested in participating in a MSc thesis experiment about **Automated Vehicles, Virtual Reality and Communication between pedestrians and automated vehicles?** Do you have 1 hour of your time **and you would like to get a gift of 10€ while helping a MSc student finish his MSc thesis experiment?** Then this might be interesting for you!

The experiment consists of a Virtual Reality Environment in which you will be interacting with Automated Vehicles. The goal of the research is to find out how pedestrians prefer to communicate with Automated Vehicles if there is no driver.

You will be using a pair of Virtual Reality Glasses and a Motion Tracking Suit to experience and interact with Automated Vehicles in a safe Laboratory Environment at the 3ME faculty. While wearing the VR glasses and Motion Tracking Suit you will be asked to perform some small tasks and answer a few questions about the experiment on a questionnaire. Your answers and data will be treated confidentially and anonymised so it cannot be traced back to individual persons.

The whole experiment will take around 1 hour. After which you will receive your 10€ reward and the experimenter's sincere gratitude!

IMPORTANT INFORMATION

When?: 3-10-2019 – 25-10-2019

How long?: 1 hour

Where?: CoR Lab at the faculty of 3Me, TU Delft

What do you get?: 10€ Cash

Who?: People between the age of 18 and 40

How to sign up? E-mail your name and date and time you would like to participate to: m.r.epke@student.tudelft.nl or Call/Whatsapp to +31631000430.

 

PARTICIPANTS NEEDED

MSC THESIS RESEARCH

PEDESTRIAN-AUTOMATED VEHICLE COMMUNICATION

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IMPORTANT INFORMATION

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How to sign up? **E-mail your name and date and time you would like to participate to: m.r.epke@student.tudelft.nl or Call/Whatsapp to +31631000430.**

APPENDIX C: Pre-experiment questionnaire

Pre-experiment questionnaire

Thank you for participating in this study. This questionnaire serves to provide us with information about your road crossing behaviour. It also provides us information about your feeling towards the use of hand gestures as a form of communicating crossing intent.
Please fill in the following questions. Your answers will remain anonymous and will only be used by the researchers of this study.

1. **What is your nationality?**

2. **What is your age**

3. **What is your gender?**
   Mark only one oval.
   - Female
   - Male
   - Prefer not to say
   - Other:

4. **How often did you commute to work or school by foot in the last 12 months on average?**
   Mark only one oval.
   - Daily
   - 4 to 6 days a week
   - 1 to 3 days a week
   - Once a month to once a week
   - Less than once a week
   - Less than once a month
   - Never

5. **Do you have computer gaming experience?**
   Mark only one oval.
   - Yes, I play several times a week
   - Yes, I play approximately once a month
   - Yes, but rarely / not anymore
   - No, I have never played computer games

6. **Have you worn Virtual Reality-glasses before?**
Mark only one oval.

- Yes, multiple times
- Yes, once
- No

7. **Do you have any experience encountering a vehicle with external Human-Machine Interface (eHMI) or participating in an experiment involving a vehicle with eHMI, before the start of this experiment?**
Mark only one oval.

- Yes
- No

Questions on daily crossing behaviour

Please read the questions carefully.

8. **On a scale from 1 to 5, how likely are you to make eye-contact with the driver when you want to cross the road?**
Mark only one oval.

	1	2	3	4	5	
Not likely at all						Very likely

9. **On a scale from 1 to 5, how likely are you to use hand gestures to communicate with the driver when you want to cross the road?**
Mark only one oval.

	1	2	3	4	5	
Not likely at all						Very likely

As a pedestrian, how much would you agree with each one of the following statements:

10. **I walk for the pleasure of it**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

11. **I walk because it is healthy**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

12. **In short trips I prefer walking over other modes of transportation**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

13. **Crossing roads is difficult**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

14. **Crossing roads outside designated locations increases the risk of an accident**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

15. **Crossing roads outside designated locations is wrong**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

16. **Crossing roads outside designated locations saves time**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

17. **Crossing roads outside designated locations is acceptable because other people do it**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

18. **I prefer routes with signalised crosswalks**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

19. **I try to make as few road crossings as possible**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

20. **I try to take the most direct route to my destination**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

21. **I try to take the route to my destination on which I encounter the least amount of traffic**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

22. **I am willing to make a detour to find a protected crossing**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

23. **I am willing to take any opportunity to cross**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

24. **I am willing to make dangerous actions as a pedestrian to save time**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

Compared to other pedestrians, how much do you agree that:

25. **I am less likely to be involved in a road crash than other pedestrians**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

26. **I am faster than other pedestrians**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

27. **I am more careful than other pedestrians**
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

Please indicate how much the following statements apply to you.

28. **I have trust in self-driving vehicles.**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	Strongly agree

29. **I have trust that self-driving vehicles will notice me.**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	Strongly agree

30. **I have trust that self-driving vehicles will respond to hand gestures.**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	Strongly agree

31. **I have trust that hand gestures can be used to communicate with a self-driving vehicle.**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly agree

APPENDIX D: Post-interaction interview

Post-interaction interview

1. **Participant number**

2. **Interaction number**

3. **Motion Sickness**
Check all that apply.

	Score
No Problems	☐
Slight discomfort but no specific symptoms	☐
Vague dizziness, warm, headache, stomach awareness, sweating	☐
Some dizziness, warm, headache, stomach awareness, sweating	☐
Medium dizziness, warm, headache, stomach awareness, sweating	☐
Severe dizziness, warm, headache, stomach awareness, sweating	☐
Some nausea	☐
Medium nausea	☐
Severe nausea	☐
Retching	☐
Vomiting	☐

4. **On a scale from 0 to 10, how difficult was it for you to predict the behaviors of the car?**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	10	
Not difficult at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very difficult

5. **On a scale from 0 to 10, how sure were you that the car would see you?**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	10	
Not sure at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Completely sure

APPENDIX E: Post-experiment questionnaire

Post-experiment questionnaire

Thank you for participating in this study. This questionnaire serves to provide us with information about your preference of crossing situations related to hand gestures and external Human-Machine Interfaces (eHMI).
The final part of this questionnaire will contain questions about your feelings of trust towards automated vehicles and hand gestures as a form of communication.

Please consider that the car in the following pictures has come to a full stop.

1. **How safe do you feel to cross the road in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not safe at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely safe

2. **How safe do you feel to cross the road in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not safe at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Completely safe

3. **How sure are you that the car has seen you in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not sure at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Completely sure

4. **How sure are you that the car has seen you in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not sure at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Completely sure

5. **How strongly does the fact that you cannot make eye contact with a driver affect your decision to cross the road in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very strongly

6. **How strongly does the fact that you cannot make eye contact with a driver affect your decision to cross the road in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very strongly

For the following six questions, consider that you have used a hand gesture to communicate to the car that you want to cross the road.

7. **Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How safe do you feel to cross the road in this situation?**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	10	
Not safe at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely safe

8. **Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How safe do you feel to cross the road in this situation?**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	10	
Not safe at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Completely safe

9. **Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How sure are you that the car has seen you in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not sure at all											Completely sure

10. **Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How sure are you that the car has seen you in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not sure at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely sure

11. **Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How strongly does the fact that you cannot make eye contact with a driver affect your decision to cross the road in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very strongly

12. **Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How strongly does the fact that you cannot make eye contact with a driver affect your decision to cross the road in this situation?**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very strongly

Comparison of situations

13. **Rank the following situations on your feeling of safety to cross the road.**

Communication via eHMI

No communication

Communication via eHMI after hand gesture

No communication after hand gesture

Mark only one oval per row.

	First choice (most safe to cross)	Second Choice	Third choice	Fourth choice (least safe to cross)
Communication via eHMI	◯	◯	◯	◯
No communication	◯	◯	◯	◯
Communication via eHMI after hand gesture is used	◯	◯	◯	◯
No communication after hand gesture is used	◯	◯	◯	◯

14. **Rank the following situations on how sure you would be that the car has seen you.**

Communication via eHMI

No communication

Communication via eHMI after hand gesture

No communication after hand gesture

Mark only one oval per row.

	First choice (Surest that the car sees me)	Second Choice	Third choice	Fourth choice (least sure that the car sees me)
Communication via eHMI	◯	◯	◯	◯
No communication	◯	◯	◯	◯
Communication via eHMI after hand gesture is used	◯	◯	◯	◯
No communication after hand gesture is used	◯	◯	◯	◯

15. **Rank the following situations on how strongly your decision is affected by the fact that you cannot make eye contact with the driver.**

Communication via eHMI

No communication

Communication via eHMI after hand gesture

No communication after hand gesture

Mark only one oval per row.

	First choice (Most affected)	Second Choice	Third choice	Fourth choice (least affected)
Communication via eHMI				
No communication				
Communication via eHMI after hand gesture is used				
No communication after hand gesture is used				

16. **Which of the following situations do you prefer when interacting with an automated vehicle?**

Communication via eHMI

No communication

Communication via eHMI after hand gesture

No communication after hand gesture

Mark only one oval per row.

	First choice (most preferred)	Second Choice	Third choice	Fourth choice (least preferred)
Communication via eHMI				
No communication				
Communication via eHMI after hand gesture is used				
No communication after hand gesture is used				

Please indicate how much the following statements apply to you.

17. **I have trust in self-driving vehicles.**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree											Strongly agree

18. **I have trust that self-driving vehicles will notice me.**

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree											Strongly agree

19. **I have trust that self-driving vehicles will respond to hand gestures.**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree	○	○	○	○	○	○	○	○	○	○	Strongly agree

20. **I have trust that hand gestures can be used to communicate with a self-driving vehicle.**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree	○	○	○	○	○	○	○	○	○	○	Strongly agree

APPENDIX F: Scenario checklist per participant

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
1	1	eHMI	Yield	No	No				1
1	2	eHMI	Yield	No	No				2
1	3	eHMI	Continue	No	No				3
1	4	eHMI	Yield	No	No				4
1	5	eHMI	Yield	No	No				5
1	6	eHMI	Continue	No	No				6
1	7	eHMI	Yield	No	No				7
1	8	eHMI	Continue	No	No				8
1	9	eHMI	Continue	No	No				9
1	10	eHMI	Continue	Break?	Nausea?				10
1	11	Base	Continue	No	No				11
1	12	Base	Continue	No	No				12
1	13	Base	Yield	No	No				13
1	14	Base	Continue	No	No				14
1	15	Base	Continue	No	No				15
1	16	Base	Yield	No	No				16
1	17	Base	Yield	No	No				17
1	18	Base	Continue	No	No				18
1	19	Base	Yield	No	No				19
1	20	Base	Yield	Break?	Nausea?				20
1	21	Hand	Yield	No	No				21
1	22	Hand	Yield	No	No				22
1	23	Hand	Continue	No	No				23
1	24	Hand	Continue	No	No				24
1	25	Hand	Continue	No	No				25
1	26	Hand	Continue	No	No				26
1	27	Hand	Continue	No	No				27
1	28	Hand	Yield	No	No				28
1	29	Hand	Yield	No	No				29
1	30	Hand	Yield	Break?	Nausea?				30
1	31	Comb	Continue	No	No				31
1	32	Comb	Yield	No	No				32
1	33	Comb	Continue	No	No				33
1	34	Comb	Continue	No	No				34
1	35	Comb	Continue	No	No				35
1	36	Comb	Continue	No	No				36
1	37	Comb	Yield	No	No				37
1	38	Comb	Yield	No	No				38
1	39	Comb	Yield	No	No				39
1	40	Comb	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
2	1	**Base**	Continue	No	No				11
2	2	**Base**	Yield	No	No				12
2	3	**Base**	Continue	No	No				13
2	4	**Base**	Continue	No	No				14
2	5	**Base**	Continue	No	No				15
2	6	**Base**	Yield	No	No				16
2	7	**Base**	Yield	No	No				17
2	8	**Base**	Continue	No	No				18
2	9	**Base**	Yield	No	No				19
2	10	**Base**	Yield	Break?	Nausea?				20
2	11	**Comb**	Yield	No	No				31
2	12	**Comb**	Continue	No	No				32
2	13	**Comb**	Continue	No	No				33
2	14	**Comb**	Yield	No	No				34
2	15	**Comb**	Yield	No	No				35
2	16	**Comb**	Yield	No	No				36
2	17	**Comb**	Continue	No	No				37
2	18	**Comb**	Continue	No	No				38
2	19	**Comb**	Continue	No	No				39
2	20	**Comb**	Yield	No	No				40
2	21	**eHMI**	Yield	No	No				1
2	22	**eHMI**	Continue	No	No				2
2	23	**eHMI**	Continue	No	No				3
2	24	**eHMI**	Continue	No	No				4
2	25	**eHMI**	Yield	No	No				5
2	26	**eHMI**	Yield	No	No				6
2	27	**eHMI**	Continue	No	No				7
2	28	**eHMI**	Yield	No	No				8
2	29	**eHMI**	Continue	No	No				9
2	30	**eHMI**	Yield	Break?	Nausea?				10
2	31	**Hand**	Yield	No	No				21
2	32	**Hand**	Continue	No	No				22
2	33	**Hand**	Yield	No	No				23
2	34	**Hand**	Yield	No	No				24
2	35	**Hand**	Yield	No	No				25
2	36	**Hand**	Continue	No	No				26
2	37	**Hand**	Continue	No	No				27
2	38	**Hand**	Continue	No	No				28
2	39	**Hand**	Yield	No	No				29
2	40	**Hand**	Continue	Break?	Nausea?				30

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
3	1	Comb	Continue	No	No				1
3	2	Comb	Yield	No	No				2
3	3	Comb	Yield	No	No				3
3	4	Comb	Continue	No	No				4
3	5	Comb	Yield	No	No				5
3	6	Comb	Continue	No	No				6
3	7	Comb	Continue	No	No				7
3	8	Comb	Yield	No	No				8
3	9	Comb	Yield	No	No				9
3	10	Comb	Continue	Break?	Nausea?				10
3	11	Hand	Continue	No	No				11
3	12	Hand	Continue	No	No				12
3	13	Hand	Yield	No	No				13
3	14	Hand	Continue	No	No				14
3	15	Hand	Yield	No	No				15
3	16	Hand	Continue	No	No				16
3	17	Hand	Yield	No	No				17
3	18	Hand	Continue	No	No				18
3	19	Hand	Yield	No	No				19
3	20	Hand	Yield	Break?	Nausea?				20
3	21	Base	Continue	No	No				21
3	22	Base	Yield	No	No				22
3	23	Base	Continue	No	No				23
3	24	Base	Yield	No	No				24
3	25	Base	Yield	No	No				25
3	26	Base	Yield	No	No				26
3	27	Base	Continue	No	No				27
3	28	Base	Continue	No	No				28
3	29	Base	Continue	No	No				29
3	30	Base	Yield	Break?	Nausea?				30
3	31	eHMI	Continue	No	No				31
3	32	eHMI	Yield	No	No				32
3	33	eHMI	Continue	No	No				33
3	34	eHMI	Yield	No	No				34
3	35	eHMI	Continue	No	No				35
3	36	eHMI	Yield	No	No				36
3	37	eHMI	Yield	No	No				37
3	38	eHMI	Yield	No	No				38
3	39	eHMI	Continue	No	No				39
3	40	eHMI	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
4	1	eHMI	Yield	No	No				1
4	2	eHMI	Yield	No	No				2
4	3	eHMI	Yield	No	No				3
4	4	eHMI	Continue	No	No				4
4	5	eHMI	Continue	No	No				5
4	6	eHMI	Continue	No	No				6
4	7	eHMI	Yield	No	No				7
4	8	eHMI	Continue	No	No				8
4	9	eHMI	Yield	No	No				9
4	10	eHMI	Continue	Break?	Nausea?				10
4	11	Hand	Continue	No	No				11
4	12	Hand	Continue	No	No				12
4	13	Hand	Yield	No	No				13
4	14	Hand	Continue	No	No				14
4	15	Hand	Continue	No	No				15
4	16	Hand	Yield	No	No				16
4	17	Hand	Continue	No	No				17
4	18	Hand	Yield	No	No				18
4	19	Hand	Yield	No	No				19
4	20	Hand	Yield	Break?	Nausea?				20
4	21	Comb	Yield	No	No				21
4	22	Comb	Yield	No	No				22
4	23	Comb	Yield	No	No				23
4	24	Comb	Continue	No	No				24
4	25	Comb	Yield	No	No				25
4	26	Comb	Continue	No	No				26
4	27	Comb	Continue	No	No				27
4	28	Comb	Continue	No	No				28
4	29	Comb	Yield	No	No				29
4	30	Comb	Continue	Break?	Nausea?				30
4	31	Base	Yield	No	No				31
4	32	Base	Continue	No	No				32
4	33	Base	Continue	No	No				33
4	34	Base	Continue	No	No				34
4	35	Base	Continue	No	No				35
4	36	Base	Yield	No	No				36
4	37	Base	Yield	No	No				37
4	38	Base	Yield	No	No				38
4	39	Base	Continue	No	No				39
4	40	Base	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
5	1	Base	Continue	No	No				1
5	2	Base	Yield	No	No				2
5	3	Base	Yield	No	No				3
5	4	Base	Yield	No	No				4
5	5	Base	Continue	No	No				5
5	6	Base	Continue	No	No				6
5	7	Base	Yield	No	No				7
5	8	Base	Continue	No	No				8
5	9	Base	Continue	No	No				9
5	10	Base	Yield	Break?	Nausea?				10
5	11	Hand	Yield	No	No				11
5	12	Hand	Continue	No	No				12
5	13	Hand	Continue	No	No				13
5	14	Hand	Yield	No	No				14
5	15	Hand	Yield	No	No				15
5	16	Hand	Continue	No	No				16
5	17	Hand	Continue	No	No				17
5	18	Hand	Continue	No	No				18
5	19	Hand	Yield	No	No				19
5	20	Hand	Yield	Break?	Nausea?				20
5	21	eHMI	Yield	No	No				21
5	22	eHMI	Continue	No	No				22
5	23	eHMI	Yield	No	No				23
5	24	eHMI	Yield	No	No				24
5	25	eHMI	Continue	No	No				25
5	26	eHMI	Yield	No	No				26
5	27	eHMI	Continue	No	No				27
5	28	eHMI	Continue	No	No				28
5	29	eHMI	Yield	No	No				29
5	30	eHMI	Continue	Break?	Nausea?				30
5	31	Comb	Yield	No	No				31
5	32	Comb	Continue	No	No				32
5	33	Comb	Continue	No	No				33
5	34	Comb	Yield	No	No				34
5	35	Comb	Yield	No	No				35
5	36	Comb	Yield	No	No				36
5	37	Comb	Continue	No	No				37
5	38	Comb	Continue	No	No				38
5	39	Comb	Continue	No	No				39
5	40	Comb	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
6	1	Base	Continue	No	No				1
6	2	Base	Continue	No	No				2
6	3	Base	Continue	No	No				3
6	4	Base	Yield	No	No				4
6	5	Base	Yield	No	No				5
6	6	Base	Continue	No	No				6
6	7	Base	Yield	No	No				7
6	8	Base	Yield	No	No				8
6	9	Base	Yield	No	No				9
6	10	Base	Continue	Break?	Nausea?				10
6	11	eHMI	Yield	No	No				11
6	12	eHMI	Continue	No	No				12
6	13	eHMI	Continue	No	No				13
6	14	eHMI	Continue	No	No				14
6	15	eHMI	Continue	No	No				15
6	16	eHMI	Continue	No	No				16
6	17	eHMI	Yield	No	No				17
6	18	eHMI	Yield	No	No				18
6	19	eHMI	Yield	No	No				19
6	20	eHMI	Yield	Break?	Nausea?				20
6	21	Comb	Yield	No	No				21
6	22	Comb	Continue	No	No				22
6	23	Comb	Continue	No	No				23
6	24	Comb	Yield	No	No				24
6	25	Comb	Yield	No	No				25
6	26	Comb	Yield	No	No				26
6	27	Comb	Yield	No	No				27
6	28	Comb	Continue	No	No				28
6	29	Comb	Continue	No	No				29
6	30	Comb	Continue	Break?	Nausea?				30
6	31	Hand	Yield	No	No				31
6	32	Hand	Yield	No	No				32
6	33	Hand	Continue	No	No				33
6	34	Hand	Yield	No	No				34
6	35	Hand	Continue	No	No				35
6	36	Hand	Yield	No	No				36
6	37	Hand	Continue	No	No				37
6	38	Hand	Yield	No	No				38
6	39	Hand	Continue	No	No				39
6	40	Hand	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
7	1	eHMI	Yield	No	No				1
7	2	eHMI	Continue	No	No				2
7	3	eHMI	Continue	No	No				3
7	4	eHMI	Continue	No	No				4
7	5	eHMI	Yield	No	No				5
7	6	eHMI	Yield	No	No				6
7	7	eHMI	Yield	No	No				7
7	8	eHMI	Continue	No	No				8
7	9	eHMI	Yield	No	No				9
7	10	eHMI	Continue	Break?	Nausea?				10
7	11	Comb	Yield	No	No				11
7	12	Comb	Yield	No	No				12
7	13	Comb	Continue	No	No				13
7	14	Comb	Yield	No	No				14
7	15	Comb	Continue	No	No				15
7	16	Comb	Yield	No	No				16
7	17	Comb	Yield	No	No				17
7	18	Comb	Continue	No	No				18
7	19	Comb	Continue	No	No				19
7	20	Comb	Continue	Break?	Nausea?				20
7	21	Base	Yield	No	No				21
7	22	Base	Yield	No	No				22
7	23	Base	Yield	No	No				23
7	24	Base	Continue	No	No				24
7	25	Base	Continue	No	No				25
7	26	Base	Continue	No	No				26
7	27	Base	Continue	No	No				27
7	28	Base	Yield	No	No				28
7	29	Base	Continue	No	No				29
7	30	Base	Yield	Break?	Nausea?				30
7	31	Hand	Yield	No	No				31
7	32	Hand	Continue	No	No				32
7	33	Hand	Yield	No	No				33
7	34	Hand	Continue	No	No				34
7	35	Hand	Yield	No	No				35
7	36	Hand	Continue	No	No				36
7	37	Hand	Continue	No	No				37
7	38	Hand	Yield	No	No				38
7	39	Hand	Yield	No	No				39
7	40	Hand	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
8	1	Base	Continue	No	No				1
8	2	Base	Continue	No	No				2
8	3	Base	Yield	No	No				3
8	4	Base	Continue	No	No				4
8	5	Base	Yield	No	No				5
8	6	Base	Continue	No	No				6
8	7	Base	Yield	No	No				7
8	8	Base	Continue	No	No				8
8	9	Base	Yield	No	No				9
8	10	Base	Yield	Break?	Nausea?				10
8	11	Hand	Yield	No	No				11
8	12	Hand	Continue	No	No				12
8	13	Hand	Continue	No	No				13
8	14	Hand	Yield	No	No				14
8	15	Hand	Yield	No	No				15
8	16	Hand	Continue	No	No				16
8	17	Hand	Continue	No	No				17
8	18	Hand	Continue	No	No				18
8	19	Hand	Yield	No	No				19
8	20	Hand	Yield	Break?	Nausea?				20
8	21	eHMI	Continue	No	No				21
8	22	eHMI	Continue	No	No				22
8	23	eHMI	Yield	No	No				23
8	24	eHMI	Yield	No	No				24
8	25	eHMI	Yield	No	No				25
8	26	eHMI	Continue	No	No				26
8	27	eHMI	Yield	No	No				27
8	28	eHMI	Yield	No	No				28
8	29	eHMI	Continue	No	No				29
8	30	eHMI	Continue	Break?	Nausea?				30
8	31	Comb	Yield	No	No				31
8	32	Comb	Continue	No	No				32
8	33	Comb	Continue	No	No				33
8	34	Comb	Continue	No	No				34
8	35	Comb	Continue	No	No				35
8	36	Comb	Yield	No	No				36
8	37	Comb	Yield	No	No				37
8	38	Comb	Yield	No	No				38
8	39	Comb	Continue	No	No				39
8	40	Comb	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
9	1	eHMI	Continue	No	No				1
9	2	eHMI	Yield	No	No				2
9	3	eHMI	Yield	No	No				3
9	4	eHMI	Yield	No	No				4
9	5	eHMI	Yield	No	No				5
9	6	eHMI	Continue	No	No				6
9	7	eHMI	Continue	No	No				7
9	8	eHMI	Continue	No	No				8
9	9	eHMI	Yield	No	No				9
9	10	eHMI	Continue	Break?	Nausea?				10
9	11	Hand	Continue	No	No				11
9	12	Hand	Continue	No	No				12
9	13	Hand	Yield	No	No				13
9	14	Hand	Continue	No	No				14
9	15	Hand	Yield	No	No				15
9	16	Hand	Continue	No	No				16
9	17	Hand	Yield	No	No				17
9	18	Hand	Continue	No	No				18
9	19	Hand	Yield	No	No				19
9	20	Hand	Yield	Break?	Nausea?				20
9	21	Comb	Continue	No	No				21
9	22	Comb	Yield	No	No				22
9	23	Comb	Yield	No	No				23
9	24	Comb	Yield	No	No				24
9	25	Comb	Yield	No	No				25
9	26	Comb	Continue	No	No				26
9	27	Comb	Yield	No	No				27
9	28	Comb	Continue	No	No				28
9	29	Comb	Continue	No	No				29
9	30	Comb	Continue	Break?	Nausea?				30
9	31	Base	Yield	No	No				31
9	32	Base	Continue	No	No				32
9	33	Base	Continue	No	No				33
9	34	Base	Yield	No	No				34
9	35	Base	Continue	No	No				35
9	36	Base	Yield	No	No				36
9	37	Base	Continue	No	No				37
9	38	Base	Continue	No	No				38
9	39	Base	Yield	No	No				39
9	40	Base	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
10	1	eHMI	Continue	No	No				1
10	2	eHMI	Yield	No	No				2
10	3	eHMI	Yield	No	No				3
10	4	eHMI	Yield	No	No				4
10	5	eHMI	Yield	No	No				5
10	6	eHMI	Continue	No	No				6
10	7	eHMI	Continue	No	No				7
10	8	eHMI	Continue	No	No				8
10	9	eHMI	Yield	No	No				9
10	10	eHMI	Continue	Break?	Nausea?				10
10	11	Comb	Continue	No	No				11
10	12	Comb	Yield	No	No				12
10	13	Comb	Yield	No	No				13
10	14	Comb	Yield	No	No				14
10	15	Comb	Yield	No	No				15
10	16	Comb	Continue	No	No				16
10	17	Comb	Continue	No	No				17
10	18	Comb	Continue	No	No				18
10	19	Comb	Yield	No	No				19
10	20	Comb	Continue	Break?	Nausea?				20
10	21	Base	Yield	No	No				21
10	22	Base	Continue	No	No				22
10	23	Base	Yield	No	No				23
10	24	Base	Continue	No	No				24
10	25	Base	Yield	No	No				25
10	26	Base	Continue	No	No				26
10	27	Base	Continue	No	No				27
10	28	Base	Yield	No	No				28
10	29	Base	Continue	No	No				29
10	30	Base	Yield	Break?	Nausea?				30
10	31	Hand	Yield	No	No				31
10	32	Hand	Continue	No	No				32
10	33	Hand	Yield	No	No				33
10	34	Hand	Continue	No	No				34
10	35	Hand	Yield	No	No				35
10	36	Hand	Yield	No	No				36
10	37	Hand	Yield	No	No				37
10	38	Hand	Continue	No	No				38
10	39	Hand	Continue	No	No				39
10	40	Hand	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
11	1	Comb	Continue	No	No				1
11	2	Comb	Continue	No	No				2
11	3	Comb	Yield	No	No				3
11	4	Comb	Continue	No	No				4
11	5	Comb	Yield	No	No				5
11	6	Comb	Continue	No	No				6
11	7	Comb	Yield	No	No				7
11	8	Comb	Yield	No	No				8
11	9	Comb	Yield	No	No				9
11	10	Comb	Continue	Break?	Nausea?				10
11	11	Base	Continue	No	No				11
11	12	Base	Yield	No	No				12
11	13	Base	Continue	No	No				13
11	14	Base	Yield	No	No				14
11	15	Base	Continue	No	No				15
11	16	Base	Continue	No	No				16
11	17	Base	Yield	No	No				17
11	18	Base	Yield	No	No				18
11	19	Base	Continue	No	No				19
11	20	Base	Yield	Break?	Nausea?				20
11	21	Hand	Continue	No	No				21
11	22	Hand	Yield	No	No				22
11	23	Hand	Continue	No	No				23
11	24	Hand	Yield	No	No				24
11	25	Hand	Yield	No	No				25
11	26	Hand	Continue	No	No				26
11	27	Hand	Yield	No	No				27
11	28	Hand	Continue	No	No				28
11	29	Hand	Yield	No	No				29
11	30	Hand	Continue	Break?	Nausea?				30
11	31	eHMI	Yield	No	No				31
11	32	eHMI	Continue	No	No				32
11	33	eHMI	Yield	No	No				33
11	34	eHMI	Continue	No	No				34
11	35	eHMI	Continue	No	No				35
11	36	eHMI	Yield	No	No				36
11	37	eHMI	Continue	No	No				37
11	38	eHMI	Yield	No	No				38
11	39	eHMI	Continue	No	No				39
11	40	eHMI	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
12	1	eHMI	Yield	No	No				1
12	2	eHMI	Continue	No	No				2
12	3	eHMI	Continue	No	No				3
12	4	eHMI	Continue	No	No				4
12	5	eHMI	Continue	No	No				5
12	6	eHMI	Yield	No	No				6
12	7	eHMI	Yield	No	No				7
12	8	eHMI	Yield	No	No				8
12	9	eHMI	Continue	No	No				9
12	10	eHMI	Yield	Break?	Nausea?				10
12	11	Comb	Continue	No	No				11
12	12	Comb	Continue	No	No				12
12	13	Comb	Continue	No	No				13
12	14	Comb	Yield	No	No				14
12	15	Comb	Yield	No	No				15
12	16	Comb	Yield	No	No				16
12	17	Comb	Yield	No	No				17
12	18	Comb	Yield	No	No				18
12	19	Comb	Continue	No	No				19
12	20	Comb	Continue	Break?	Nausea?				20
12	21	Base	Yield	No	No				21
12	22	Base	Continue	No	No				22
12	23	Base	Yield	No	No				23
12	24	Base	Yield	No	No				24
12	25	Base	Continue	No	No				25
12	26	Base	Continue	No	No				26
12	27	Base	Yield	No	No				27
12	28	Base	Yield	No	No				28
12	29	Base	Continue	No	No				29
12	30	Base	Continue	Break?	Nausea?				30
12	31	Hand	Yield	No	No				31
12	32	Hand	Continue	No	No				32
12	33	Hand	Yield	No	No				33
12	34	Hand	Yield	No	No				34
12	35	Hand	Continue	No	No				35
12	36	Hand	Continue	No	No				36
12	37	Hand	Continue	No	No				37
12	38	Hand	Continue	No	No				38
12	39	Hand	Yield	No	No				39
12	40	Hand	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
13	1	Comb	Yield	No	No				1
13	2	Comb	Yield	No	No				2
13	3	Comb	Continue	No	No				3
13	4	Comb	Yield	No	No				4
13	5	Comb	Yield	No	No				5
13	6	Comb	Continue	No	No				6
13	7	Comb	Continue	No	No				7
13	8	Comb	Continue	No	No				8
13	9	Comb	Continue	No	No				9
13	10	Comb	Yield	Break?	Nausea?				10
13	11	Base	Continue	No	No				11
13	12	Base	Continue	No	No				12
13	13	Base	Yield	No	No				13
13	14	Base	Yield	No	No				14
13	15	Base	Continue	No	No				15
13	16	Base	Yield	No	No				16
13	17	Base	Continue	No	No				17
13	18	Base	Yield	No	No				18
13	19	Base	Continue	No	No				19
13	20	Base	Yield	Break?	Nausea?				20
13	21	Hand	Yield	No	No				21
13	22	Hand	Yield	No	No				22
13	23	Hand	Continue	No	No				23
13	24	Hand	Yield	No	No				24
13	25	Hand	Continue	No	No				25
13	26	Hand	Continue	No	No				26
13	27	Hand	Yield	No	No				27
13	28	Hand	Continue	No	No				28
13	29	Hand	Continue	No	No				29
13	30	Hand	Yield	Break?	Nausea?				30
13	31	eHMI	Yield	No	No				31
13	32	eHMI	Yield	No	No				32
13	33	eHMI	Continue	No	No				33
13	34	eHMI	Yield	No	No				34
13	35	eHMI	Yield	No	No				35
13	36	eHMI	Continue	No	No				36
13	37	eHMI	Continue	No	No				37
13	38	eHMI	Yield	No	No				38
13	39	eHMI	Continue	No	No				39
13	40	eHMI	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
14	1	Base	Continue	No	No				1
14	2	Base	Yield	No	No				2
14	3	Base	Yield	No	No				3
14	4	Base	Yield	No	No				4
14	5	Base	Continue	No	No				5
14	6	Base	Yield	No	No				6
14	7	Base	Continue	No	No				7
14	8	Base	Continue	No	No				8
14	9	Base	Yield	No	No				9
14	10	Base	Continue	Break?	Nausea?				10
14	11	Hand	Yield	No	No				11
14	12	Hand	Continue	No	No				12
14	13	Hand	Yield	No	No				13
14	14	Hand	Yield	No	No				14
14	15	Hand	Yield	No	No				15
14	16	Hand	Continue	No	No				16
14	17	Hand	Yield	No	No				17
14	18	Hand	Continue	No	No				18
14	19	Hand	Continue	No	No				19
14	20	Hand	Continue	Break?	Nausea?				20
14	21	eHMI	Continue	No	No				21
14	22	eHMI	Yield	No	No				22
14	23	eHMI	Continue	No	No				23
14	24	eHMI	Yield	No	No				24
14	25	eHMI	Continue	No	No				25
14	26	eHMI	Yield	No	No				26
14	27	eHMI	Yield	No	No				27
14	28	eHMI	Continue	No	No				28
14	29	eHMI	Yield	No	No				29
14	30	eHMI	Continue	Break?	Nausea?				30
14	31	Comb	Yield	No	No				31
14	32	Comb	Yield	No	No				32
14	33	Comb	Yield	No	No				33
14	34	Comb	Continue	No	No				34
14	35	Comb	Yield	No	No				35
14	36	Comb	Continue	No	No				36
14	37	Comb	Continue	No	No				37
14	38	Comb	Yield	No	No				38
14	39	Comb	Continue	No	No				39
14	40	Comb	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
15	1	Comb	Continue	No	No				1
15	2	Comb	Continue	No	No				2
15	3	Comb	Yield	No	No				3
15	4	Comb	Continue	No	No				4
15	5	Comb	Yield	No	No				5
15	6	Comb	Continue	No	No				6
15	7	Comb	Continue	No	No				7
15	8	Comb	Yield	No	No				8
15	9	Comb	Yield	No	No				9
15	10	Comb	Yield	Break?	Nausea?				10
15	11	Hand	Yield	No	No				11
15	12	Hand	Yield	No	No				12
15	13	Hand	Yield	No	No				13
15	14	Hand	Continue	No	No				14
15	15	Hand	Continue	No	No				15
15	16	Hand	Continue	No	No				16
15	17	Hand	Continue	No	No				17
15	18	Hand	Continue	No	No				18
15	19	Hand	Yield	No	No				19
15	20	Hand	Yield	Break?	Nausea?				20
15	21	Base	Yield	No	No				21
15	22	Base	Yield	No	No				22
15	23	Base	Continue	No	No				23
15	24	Base	Continue	No	No				24
15	25	Base	Yield	No	No				25
15	26	Base	Yield	No	No				26
15	27	Base	Yield	No	No				27
15	28	Base	Continue	No	No				28
15	29	Base	Continue	No	No				29
15	30	Base	Continue	Break?	Nausea?				30
15	31	eHMI	Continue	No	No				31
15	32	eHMI	Continue	No	No				32
15	33	eHMI	Yield	No	No				33
15	34	eHMI	Continue	No	No				34
15	35	eHMI	Yield	No	No				35
15	36	eHMI	Continue	No	No				36
15	37	eHMI	Yield	No	No				37
15	38	eHMI	Yield	No	No				38
15	39	eHMI	Continue	No	No				39
15	40	eHMI	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
16	1	Base	Continue	No	No				1
16	2	Base	Yield	No	No				2
16	3	Base	Yield	No	No				3
16	4	Base	Continue	No	No				4
16	5	Base	Yield	No	No				5
16	6	Base	Continue	No	No				6
16	7	Base	Continue	No	No				7
16	8	Base	Continue	No	No				8
16	9	Base	Yield	No	No				9
16	10	Base	Yield	Break?	Nausea?				10
16	11	Comb	Yield	No	No				11
16	12	Comb	Yield	No	No				12
16	13	Comb	Continue	No	No				13
16	14	Comb	Yield	No	No				14
16	15	Comb	Yield	No	No				15
16	16	Comb	Continue	No	No				16
16	17	Comb	Continue	No	No				17
16	18	Comb	Continue	No	No				18
16	19	Comb	Yield	No	No				19
16	20	Comb	Continue	Break?	Nausea?				20
16	21	Hand	Continue	No	No				21
16	22	Hand	Yield	No	No				22
16	23	Hand	Yield	No	No				23
16	24	Hand	Yield	No	No				24
16	25	Hand	Yield	No	No				25
16	26	Hand	Continue	No	No				26
16	27	Hand	Continue	No	No				27
16	28	Hand	Yield	No	No				28
16	29	Hand	Continue	No	No				29
16	30	Hand	Continue	Break?	Nausea?				30
16	31	eHMI	Yield	No	No				31
16	32	eHMI	Continue	No	No				32
16	33	eHMI	Yield	No	No				33
16	34	eHMI	Yield	No	No				34
16	35	eHMI	Yield	No	No				35
16	36	eHMI	Continue	No	No				36
16	37	eHMI	Continue	No	No				37
16	38	eHMI	Continue	No	No				38
16	39	eHMI	Continue	No	No				39
16	40	eHMI	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
17	1	Comb	Continue	No	No				1
17	2	Comb	Continue	No	No				2
17	3	Comb	Yield	No	No				3
17	4	Comb	Yield	No	No				4
17	5	Comb	Continue	No	No				5
17	6	Comb	Continue	No	No				6
17	7	Comb	Yield	No	No				7
17	8	Comb	Yield	No	No				8
17	9	Comb	Continue	No	No				9
17	10	Comb	Yield	Break?	Nausea?				10
17	11	eHMI	Yield	No	No				11
17	12	eHMI	Yield	No	No				12
17	13	eHMI	Yield	No	No				13
17	14	eHMI	Continue	No	No				14
17	15	eHMI	Yield	No	No				15
17	16	eHMI	Continue	No	No				16
17	17	eHMI	Continue	No	No				17
17	18	eHMI	Continue	No	No				18
17	19	eHMI	Yield	No	No				19
17	20	eHMI	Continue	Break?	Nausea?				20
17	21	Hand	Yield	No	No				21
17	22	Hand	Yield	No	No				22
17	23	Hand	Continue	No	No				23
17	24	Hand	Continue	No	No				24
17	25	Hand	Continue	No	No				25
17	26	Hand	Yield	No	No				26
17	27	Hand	Continue	No	No				27
17	28	Hand	Yield	No	No				28
17	29	Hand	Yield	No	No				29
17	30	Hand	Continue	Break?	Nausea?				30
17	31	Base	Yield	No	No				31
17	32	Base	Continue	No	No				32
17	33	Base	Continue	No	No				33
17	34	Base	Yield	No	No				34
17	35	Base	Continue	No	No				35
17	36	Base	Yield	No	No				36
17	37	Base	Continue	No	No				37
17	38	Base	Yield	No	No				38
17	39	Base	Continue	No	No				39
17	40	Base	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
18	1	eHMI	Yield	No	No				1
18	2	eHMI	Continue	No	No				2
18	3	eHMI	Yield	No	No				3
18	4	eHMI	Yield	No	No				4
18	5	eHMI	Yield	No	No				5
18	6	eHMI	Continue	No	No				6
18	7	eHMI	Continue	No	No				7
18	8	eHMI	Continue	No	No				8
18	9	eHMI	Continue	No	No				9
18	10	eHMI	Yield	Break?	Nausea?				10
18	11	Comb	Continue	No	No				11
18	12	Comb	Continue	No	No				12
18	13	Comb	Yield	No	No				13
18	14	Comb	Yield	No	No				14
18	15	Comb	Yield	No	No				15
18	16	Comb	Yield	No	No				16
18	17	Comb	Continue	No	No				17
18	18	Comb	Yield	No	No				18
18	19	Comb	Continue	No	No				19
18	20	Comb	Continue	Break?	Nausea?				20
18	21	Hand	Continue	No	No				21
18	22	Hand	Continue	No	No				22
18	23	Hand	Yield	No	No				23
18	24	Hand	Continue	No	No				24
18	25	Hand	Yield	No	No				25
18	26	Hand	Yield	No	No				26
18	27	Hand	Yield	No	No				27
18	28	Hand	Continue	No	No				28
18	29	Hand	Yield	No	No				29
18	30	Hand	Continue	Break?	Nausea?				30
18	31	Base	Continue	No	No				31
18	32	Base	Yield	No	No				32
18	33	Base	Yield	No	No				33
18	34	Base	Continue	No	No				34
18	35	Base	Continue	No	No				35
18	36	Base	Continue	No	No				36
18	37	Base	Yield	No	No				37
18	38	Base	Yield	No	No				38
18	39	Base	Yield	No	No				39
18	40	Base	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
19	1	Hand	Yield	No	No				1
19	2	Hand	Continue	No	No				2
19	3	Hand	Continue	No	No				3
19	4	Hand	Continue	No	No				4
19	5	Hand	Yield	No	No				5
19	6	Hand	Yield	No	No				6
19	7	Hand	Yield	No	No				7
19	8	Hand	Continue	No	No				8
19	9	Hand	Continue	No	No				9
19	10	Hand	Yield	Break?	Nausea?				10
19	11	eHMI	Continue	No	No				11
19	12	eHMI	Yield	No	No				12
19	13	eHMI	Continue	No	No				13
19	14	eHMI	Continue	No	No				14
19	15	eHMI	Continue	No	No				15
19	16	eHMI	Yield	No	No				16
19	17	eHMI	Continue	No	No				17
19	18	eHMI	Yield	No	No				18
19	19	eHMI	Yield	No	No				19
19	20	eHMI	Yield	Break?	Nausea?				20
19	21	Base	Continue	No	No				21
19	22	Base	Yield	No	No				22
19	23	Base	Continue	No	No				23
19	24	Base	Yield	No	No				24
19	25	Base	Continue	No	No				25
19	26	Base	Yield	No	No				26
19	27	Base	Yield	No	No				27
19	28	Base	Continue	No	No				28
19	29	Base	Yield	No	No				29
19	30	Base	Continue	Break?	Nausea?				30
19	31	Comb	Continue	No	No				31
19	32	Comb	Yield	No	No				32
19	33	Comb	Continue	No	No				33
19	34	Comb	Yield	No	No				34
19	35	Comb	Continue	No	No				35
19	36	Comb	Yield	No	No				36
19	37	Comb	Yield	No	No				37
19	38	Comb	Continue	No	No				38
19	39	Comb	Continue	No	No				39
19	40	Comb	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
20	1	Base	Yield	No	No				1
20	2	Base	Yield	No	No				2
20	3	Base	Yield	No	No				3
20	4	Base	Yield	No	No				4
20	5	Base	Yield	No	No				5
20	6	Base	Continue	No	No				6
20	7	Base	Continue	No	No				7
20	8	Base	Continue	No	No				8
20	9	Base	Continue	No	No				9
20	10	Base	Continue	Break?	Nausea?				10
20	11	Comb	Yield	No	No				11
20	12	Comb	Yield	No	No				12
20	13	Comb	Continue	No	No				13
20	14	Comb	Yield	No	No				14
20	15	Comb	Continue	No	No				15
20	16	Comb	Continue	No	No				16
20	17	Comb	Continue	No	No				17
20	18	Comb	Continue	No	No				18
20	19	Comb	Yield	No	No				19
20	20	Comb	Yield	Break?	Nausea?				20
20	21	Hand	Yield	No	No				21
20	22	Hand	Continue	No	No				22
20	23	Hand	Continue	No	No				23
20	24	Hand	Continue	No	No				24
20	25	Hand	Continue	No	No				25
20	26	Hand	Yield	No	No				26
20	27	Hand	Yield	No	No				27
20	28	Hand	Yield	No	No				28
20	29	Hand	Continue	No	No				29
20	30	Hand	Yield	Break?	Nausea?				30
20	31	eHMI	Yield	No	No				31
20	32	eHMI	Continue	No	No				32
20	33	eHMI	Continue	No	No				33
20	34	eHMI	Yield	No	No				34
20	35	eHMI	Yield	No	No				35
20	36	eHMI	Continue	No	No				36
20	37	eHMI	Yield	No	No				37
20	38	eHMI	Continue	No	No				38
20	39	eHMI	Continue	No	No				39
20	40	eHMI	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
21	1	Base	Continue	No	No				1
21	2	Base	Continue	No	No				2
21	3	Base	Yield	No	No				3
21	4	Base	Yield	No	No				4
21	5	Base	Continue	No	No				5
21	6	Base	Continue	No	No				6
21	7	Base	Yield	No	No				7
21	8	Base	Yield	No	No				8
21	9	Base	Continue	No	No				9
21	10	Base	Yield	Break?	Nausea?				10
21	11	eHMI	Yield	No	No				11
21	12	eHMI	Continue	No	No				12
21	13	eHMI	Yield	No	No				13
21	14	eHMI	Continue	No	No				14
21	15	eHMI	Yield	No	No				15
21	16	eHMI	Yield	No	No				16
21	17	eHMI	Continue	No	No				17
21	18	eHMI	Yield	No	No				18
21	19	eHMI	Continue	No	No				19
21	20	eHMI	Continue	Break?	Nausea?				20
21	21	Comb	Continue	No	No				21
21	22	Comb	Continue	No	No				22
21	23	Comb	Yield	No	No				23
21	24	Comb	Continue	No	No				24
21	25	Comb	Continue	No	No				25
21	26	Comb	Continue	No	No				26
21	27	Comb	Yield	No	No				27
21	28	Comb	Yield	No	No				28
21	29	Comb	Yield	No	No				29
21	30	Comb	Yield	Break?	Nausea?				30
21	31	Hand	Yield	No	No				31
21	32	Hand	Yield	No	No				32
21	33	Hand	Continue	No	No				33
21	34	Hand	Continue	No	No				34
21	35	Hand	Continue	No	No				35
21	36	Hand	Yield	No	No				36
21	37	Hand	Continue	No	No				37
21	38	Hand	Continue	No	No				38
21	39	Hand	Yield	No	No				39
21	40	Hand	Yield	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
22	1	Hand	Yield	No	No				1
22	2	Hand	Yield	No	No				2
22	3	Hand	Continue	No	No				3
22	4	Hand	Yield	No	No				4
22	5	Hand	Continue	No	No				5
22	6	Hand	Yield	No	No				6
22	7	Hand	Continue	No	No				7
22	8	Hand	Continue	No	No				8
22	9	Hand	Continue	No	No				9
22	10	Hand	Yield	Break?	Nausea?				10
22	11	Comb	Yield	No	No				11
22	12	Comb	Continue	No	No				12
22	13	Comb	Yield	No	No				13
22	14	Comb	Continue	No	No				14
22	15	Comb	Continue	No	No				15
22	16	Comb	Yield	No	No				16
22	17	Comb	Yield	No	No				17
22	18	Comb	Yield	No	No				18
22	19	Comb	Continue	No	No				19
22	20	Comb	Continue	Break?	Nausea?				20
22	21	Base	Yield	No	No				21
22	22	Base	Continue	No	No				22
22	23	Base	Yield	No	No				23
22	24	Base	Continue	No	No				24
22	25	Base	Continue	No	No				25
22	26	Base	Yield	No	No				26
22	27	Base	Continue	No	No				27
22	28	Base	Continue	No	No				28
22	29	Base	Yield	No	No				29
22	30	Base	Yield	Break?	Nausea?				30
22	31	eHMI	Yield	No	No				31
22	32	eHMI	Yield	No	No				32
22	33	eHMI	Continue	No	No				33
22	34	eHMI	Yield	No	No				34
22	35	eHMI	Continue	No	No				35
22	36	eHMI	Yield	No	No				36
22	37	eHMI	Continue	No	No				37
22	38	eHMI	Continue	No	No				38
22	39	eHMI	Continue	No	No				39
22	40	eHMI	Yield	No	No				40

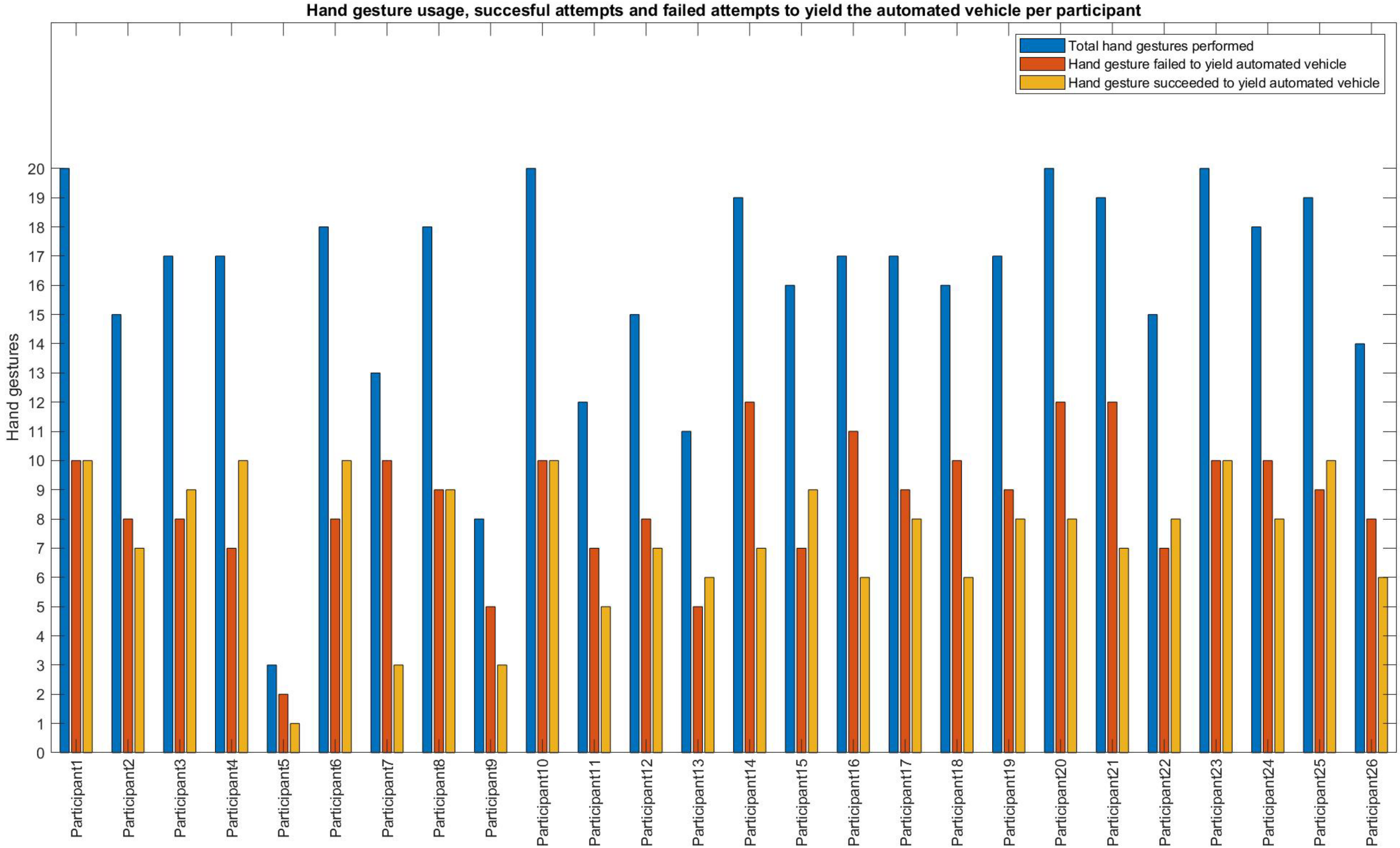
Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
23	1	eHMI	Yield	No	No				1
23	2	eHMI	Yield	No	No				2
23	3	eHMI	Yield	No	No				3
23	4	eHMI	Yield	No	No				4
23	5	eHMI	Yield	No	No				5
23	6	eHMI	Continue	No	No				6
23	7	eHMI	Continue	No	No				7
23	8	eHMI	Continue	No	No				8
23	9	eHMI	Continue	No	No				9
23	10	eHMI	Continue	Break?	Nausea?				10
23	11	Base	Yield	No	No				11
23	12	Base	Yield	No	No				12
23	13	Base	Yield	No	No				13
23	14	Base	Continue	No	No				14
23	15	Base	Yield	No	No				15
23	16	Base	Yield	No	No				16
23	17	Base	Continue	No	No				17
23	18	Base	Continue	No	No				18
23	19	Base	Continue	No	No				19
23	20	Base	Continue	Break?	Nausea?				20
23	21	Comb	Yield	No	No				21
23	22	Comb	Continue	No	No				22
23	23	Comb	Continue	No	No				23
23	24	Comb	Yield	No	No				24
23	25	Comb	Yield	No	No				25
23	26	Comb	Yield	No	No				26
23	27	Comb	Continue	No	No				27
23	28	Comb	Continue	No	No				28
23	29	Comb	Yield	No	No				29
23	30	Comb	Continue	Break?	Nausea?				30
23	31	Hand	Yield	No	No				31
23	32	Hand	Continue	No	No				32
23	33	Hand	Yield	No	No				33
23	34	Hand	Yield	No	No				34
23	35	Hand	Continue	No	No				35
23	36	Hand	Continue	No	No				36
23	37	Hand	Yield	No	No				37
23	38	Hand	Yield	No	No				38
23	39	Hand	Continue	No	No				39
23	40	Hand	Continue	No	No				40

Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
24	1	Hand	Yield	No	No				1
24	2	Hand	Yield	No	No				2
24	3	Hand	Continue	No	No				3
24	4	Hand	Yield	No	No				4
24	5	Hand	Yield	No	No				5
24	6	Hand	Continue	No	No				6
24	7	Hand	Continue	No	No				7
24	8	Hand	Continue	No	No				8
24	9	Hand	Yield	No	No				9
24	10	Hand	Continue	Break?	Nausea?				10
24	11	Comb	Yield	No	No				11
24	12	Comb	Yield	No	No				12
24	13	Comb	Continue	No	No				13
24	14	Comb	Yield	No	No				14
24	15	Comb	Continue	No	No				15
24	16	Comb	Continue	No	No				16
24	17	Comb	Continue	No	No				17
24	18	Comb	Continue	No	No				18
24	19	Comb	Yield	No	No				19
24	20	Comb	Yield	Break?	Nausea?				20
24	21	Base	Continue	No	No				21
24	22	Base	Yield	No	No				22
24	23	Base	Continue	No	No				23
24	24	Base	Continue	No	No				24
24	25	Base	Continue	No	No				25
24	26	Base	Yield	No	No				26
24	27	Base	Yield	No	No				27
24	28	Base	Yield	No	No				28
24	29	Base	Continue	No	No				29
24	30	Base	Yield	Break?	Nausea?				30
24	31	eHMI	Continue	No	No				31
24	32	eHMI	Yield	No	No				32
24	33	eHMI	Continue	No	No				33
24	34	eHMI	Continue	No	No				34
24	35	eHMI	Continue	No	No				35
24	36	eHMI	Yield	No	No				36
24	37	eHMI	Yield	No	No				37
24	38	eHMI	Yield	No	No				38
24	39	eHMI	Yield	No	No				39
24	40	eHMI	Continue	No	No				40

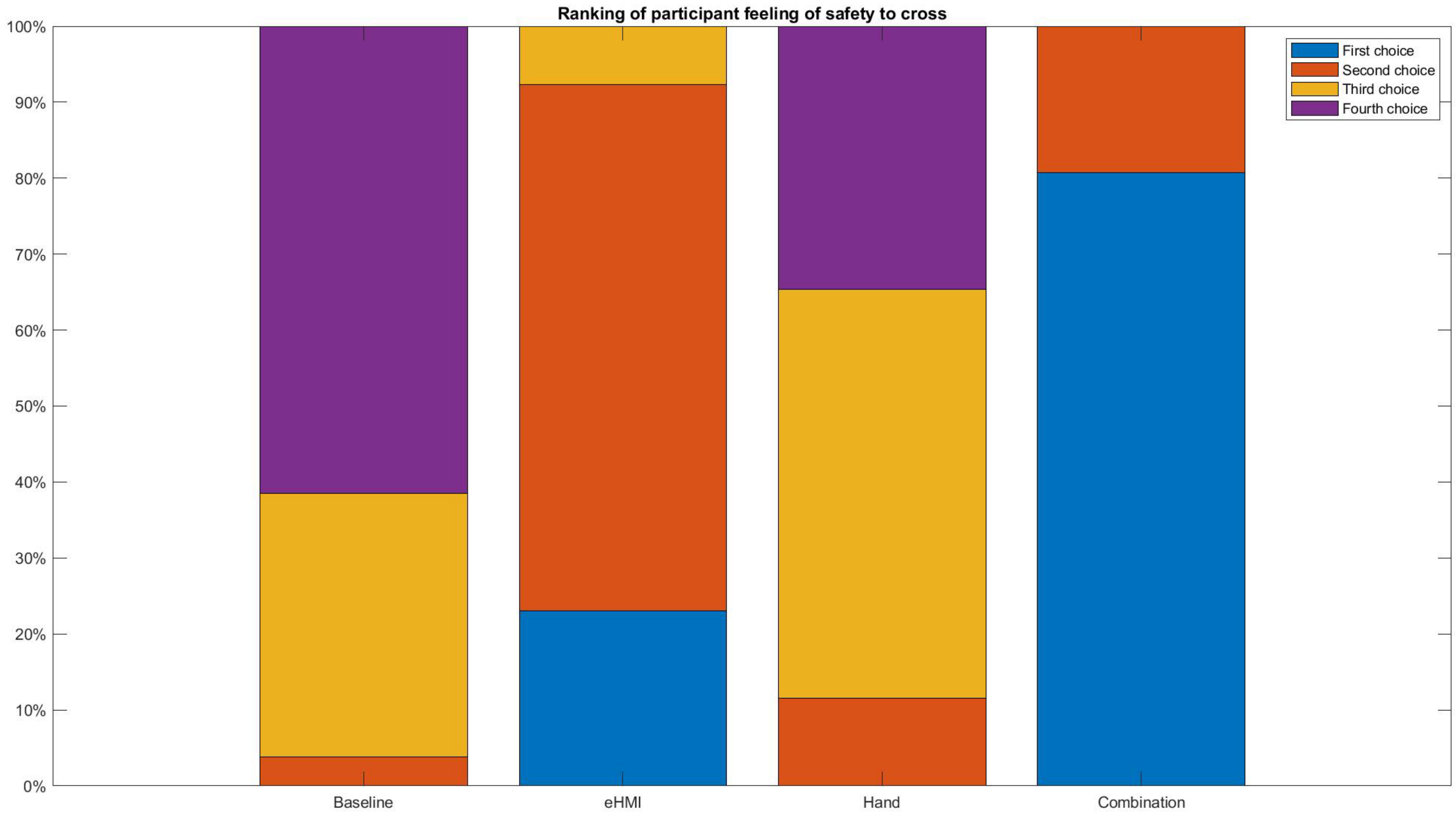
Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
25	1	eHMI	Yield	No	No				1
25	2	eHMI	Continue	No	No				2
25	3	eHMI	Continue	No	No				3
25	4	eHMI	Continue	No	No				4
25	5	eHMI	Yield	No	No				5
25	6	eHMI	Continue	No	No				6
25	7	eHMI	Yield	No	No				7
25	8	eHMI	Continue	No	No				8
25	9	eHMI	Yield	No	No				9
25	10	eHMI	Yield	Break?	Nausea?				10
25	11	Comb	Yield	No	No				11
25	12	Comb	Yield	No	No				12
25	13	Comb	Yield	No	No				13
25	14	Comb	Continue	No	No				14
25	15	Comb	Continue	No	No				15
25	16	Comb	Continue	No	No				16
25	17	Comb	Yield	No	No				17
25	18	Comb	Continue	No	No				18
25	19	Comb	Continue	No	No				19
25	20	Comb	Yield	Break?	Nausea?				20
25	21	Hand	Continue	No	No				21
25	22	Hand	Yield	No	No				22
25	23	Hand	Yield	No	No				23
25	24	Hand	Continue	No	No				24
25	25	Hand	Continue	No	No				25
25	26	Hand	Continue	No	No				26
25	27	Hand	Continue	No	No				27
25	28	Hand	Yield	No	No				28
25	29	Hand	Yield	No	No				29
25	30	Hand	Yield	Break?	Nausea?				30
25	31	Base	Continue	No	No				31
25	32	Base	Yield	No	No				32
25	33	Base	Yield	No	No				33
25	34	Base	Continue	No	No				34
25	35	Base	Continue	No	No				35
25	36	Base	Yield	No	No				36
25	37	Base	Yield	No	No				37
25	38	Base	Continue	No	No				38
25	39	Base	Yield	No	No				39
25	40	Base	Continue	No	No				40

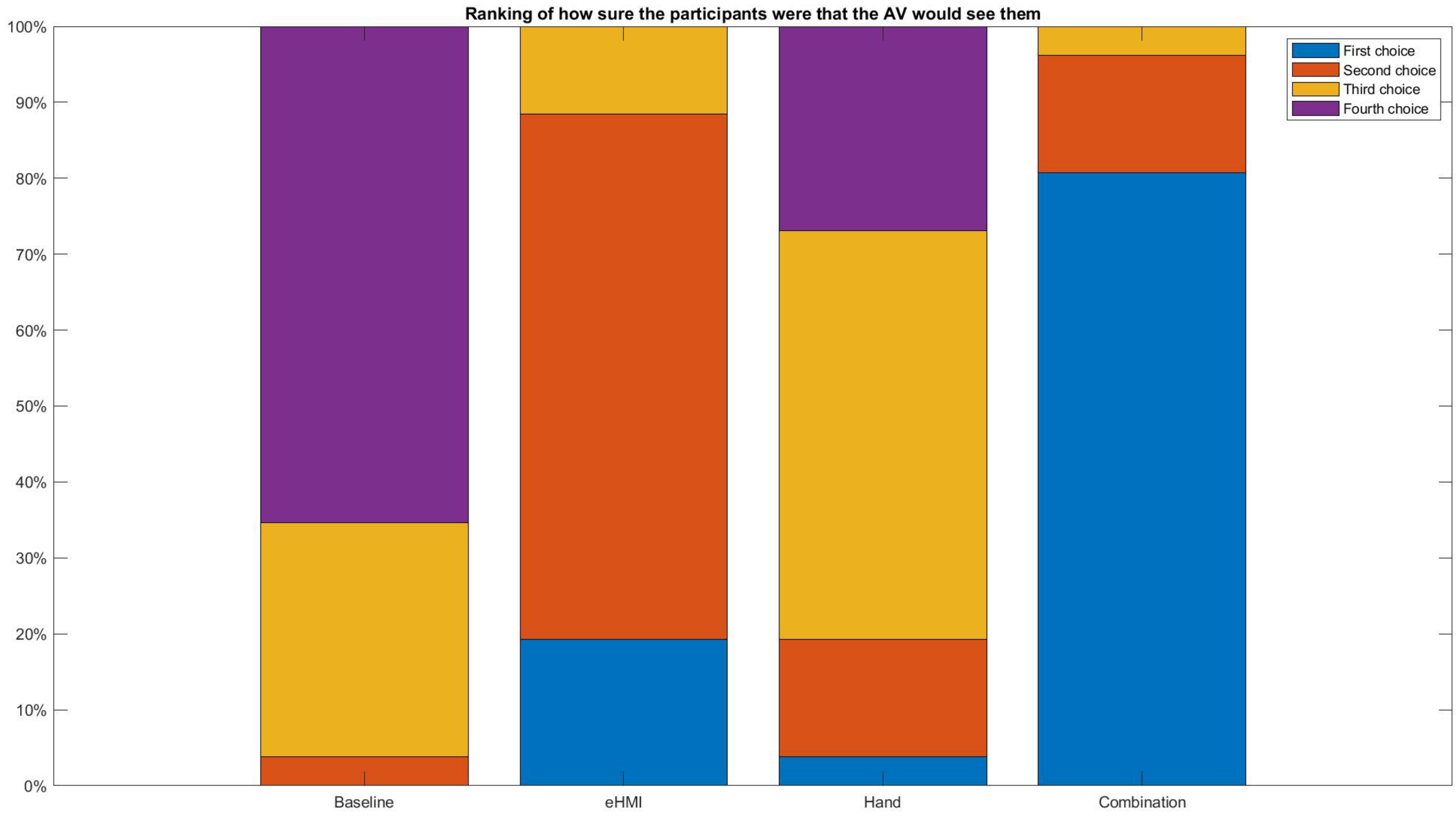
Participant Number	Trial Number	Scenario	Yield or Continue	Ask for break	Ask for Nausea	Unity Paused	MVN Paused	Questions Asked	Trial Number
26	1	Comb	Continue	No	No				1
26	2	Comb	Yield	No	No				2
26	3	Comb	Yield	No	No				3
26	4	Comb	Continue	No	No				4
26	5	Comb	Continue	No	No				5
26	6	Comb	Yield	No	No				6
26	7	Comb	Yield	No	No				7
26	8	Comb	Yield	No	No				8
26	9	Comb	Continue	No	No				9
26	10	Comb	Continue	Break?	Nausea?				10
26	11	Base	Continue	No	No				11
26	12	Base	Yield	No	No				12
26	13	Base	Continue	No	No				13
26	14	Base	Yield	No	No				14
26	15	Base	Continue	No	No				15
26	16	Base	Yield	No	No				16
26	17	Base	Yield	No	No				17
26	18	Base	Continue	No	No				18
26	19	Base	Yield	No	No				19
26	20	Base	Continue	Break?	Nausea?				20
26	21	eHMI	Continue	No	No				21
26	22	eHMI	Continue	No	No				22
26	23	eHMI	Yield	No	No				23
26	24	eHMI	Yield	No	No				24
26	25	eHMI	Yield	No	No				25
26	26	eHMI	Continue	No	No				26
26	27	eHMI	Continue	No	No				27
26	28	eHMI	Yield	No	No				28
26	29	eHMI	Continue	No	No				29
26	30	eHMI	Yield	Break?	Nausea?				30
26	31	Hand	Yield	No	No				31
26	32	Hand	Continue	No	No				32
26	33	Hand	Continue	No	No				33
26	34	Hand	Yield	No	No				34
26	35	Hand	Continue	No	No				35
26	36	Hand	Continue	No	No				36
26	37	Hand	Yield	No	No				37
26	38	Hand	Continue	No	No				38
26	39	Hand	Yield	No	No				39
26	40	Hand	Yield	No	No				40

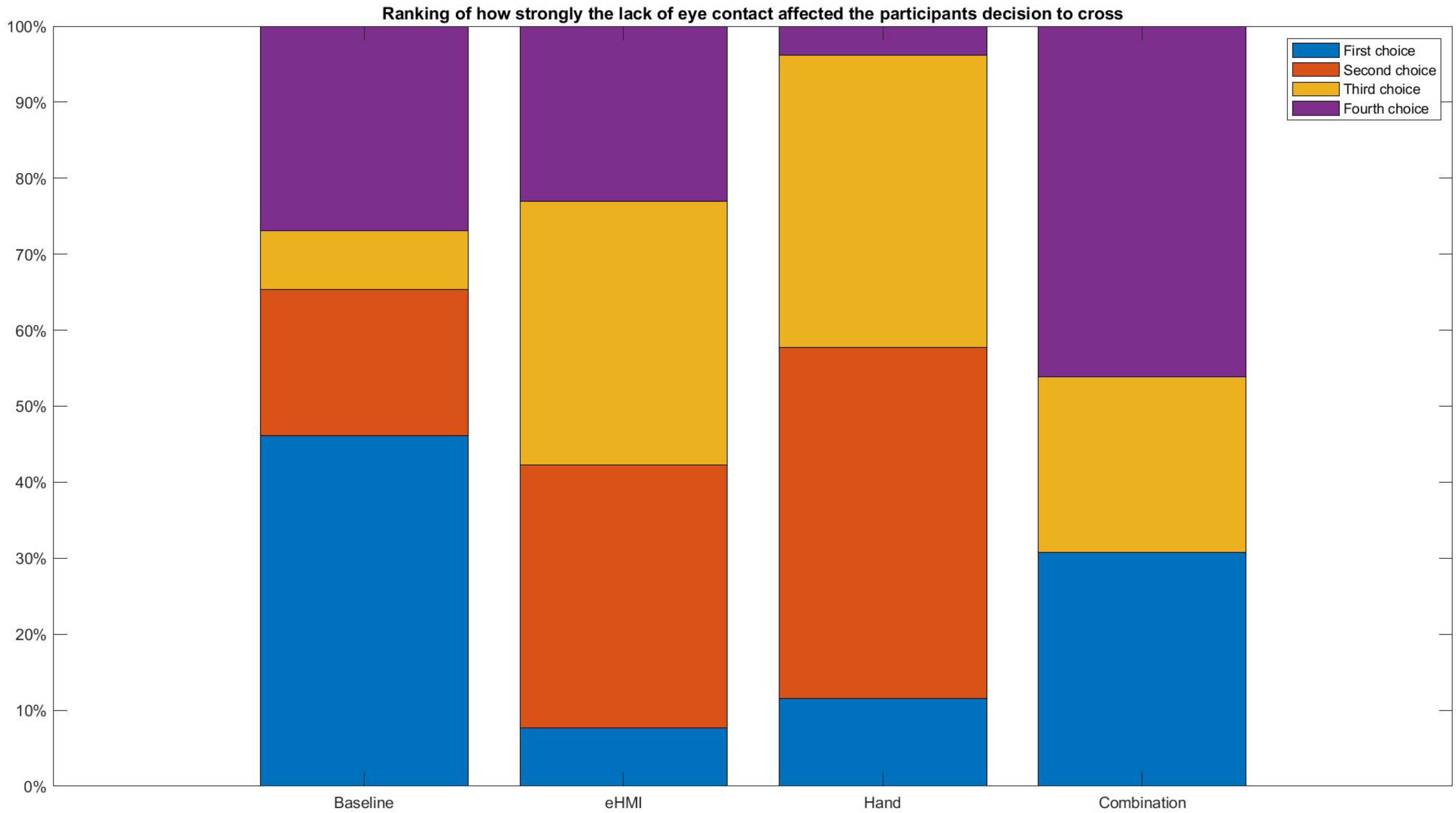
APPENDIX G: Hand usage per trial per participant

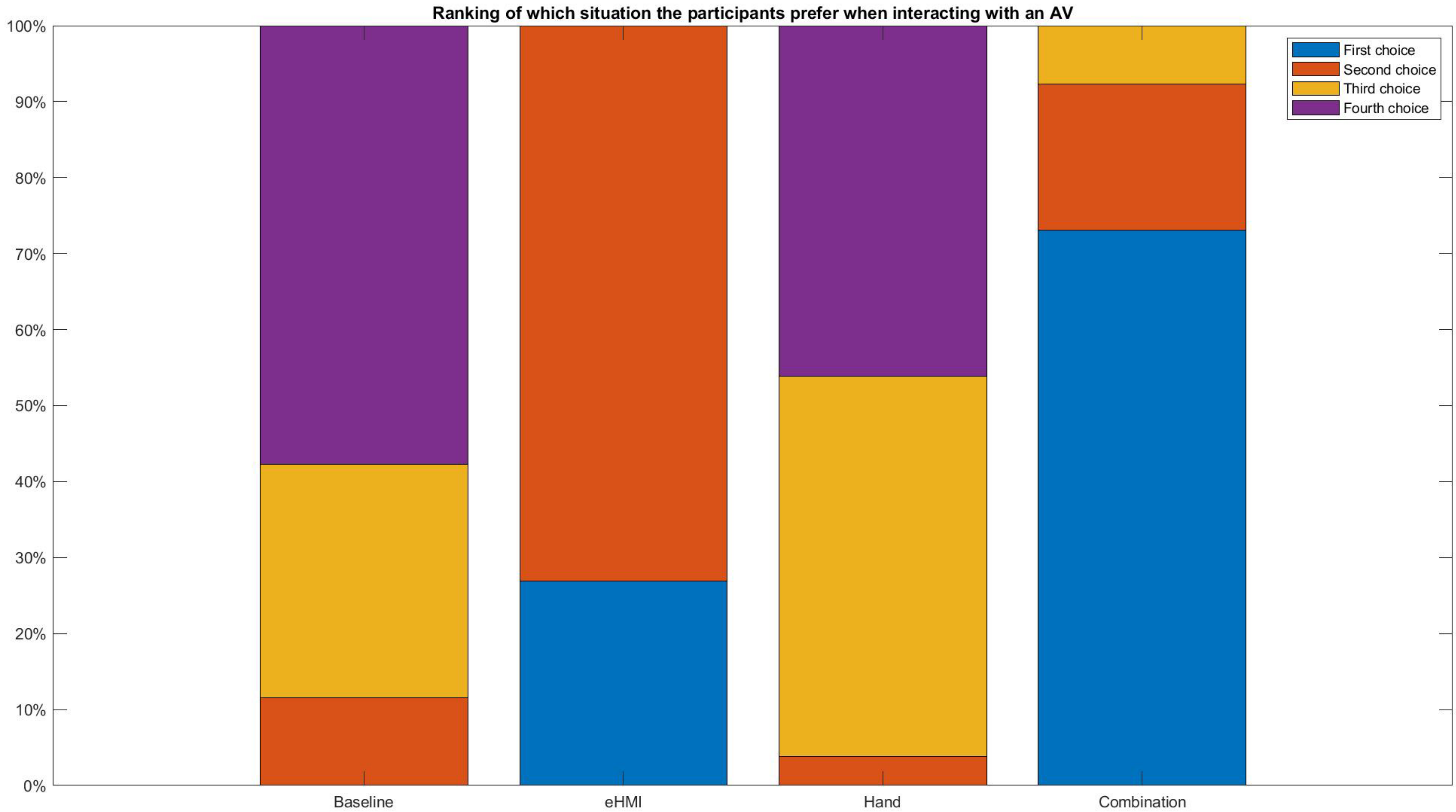


APPENDIX H: Ranking of scenarios by participants



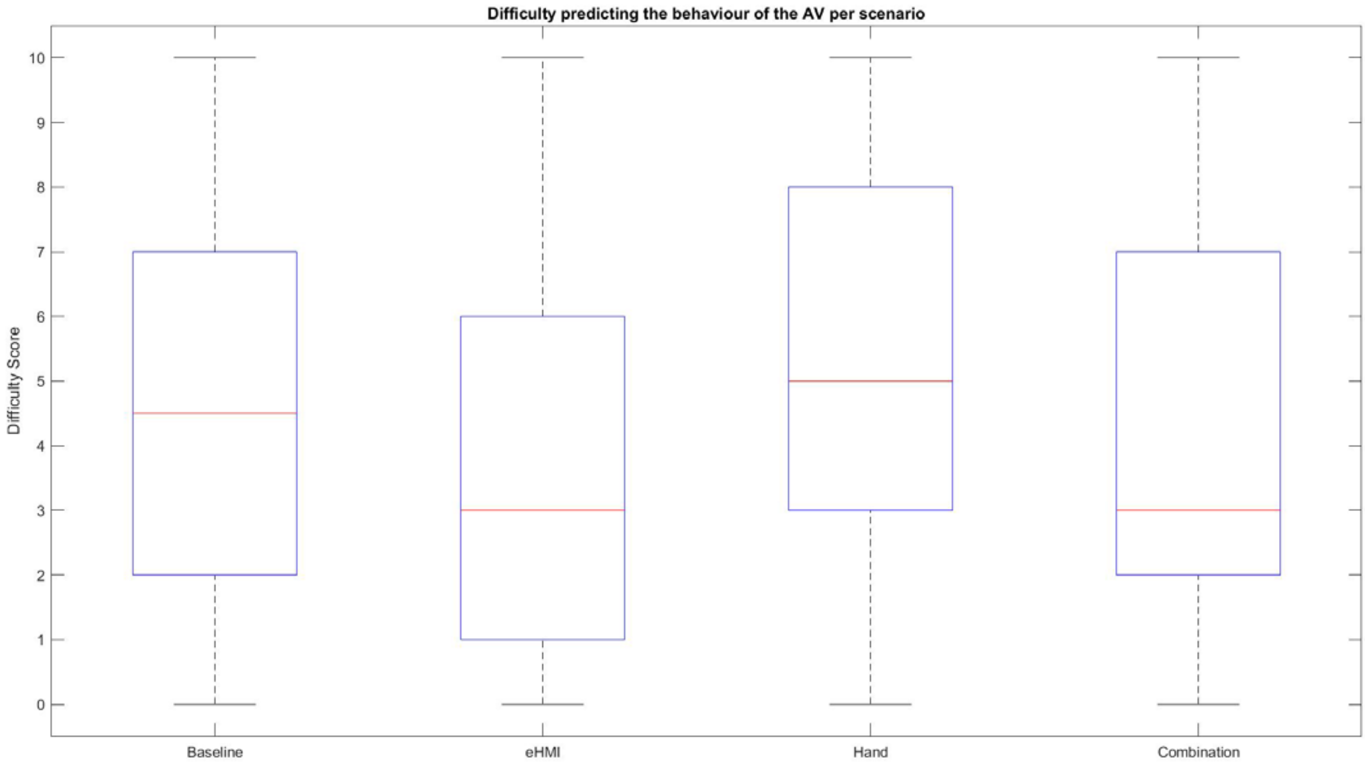

Ranking of how sure the participants were that the AV would see them
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Baseline
eHMI
Hand
Combination
First choice
Second choice
Third choice
Fourth choice

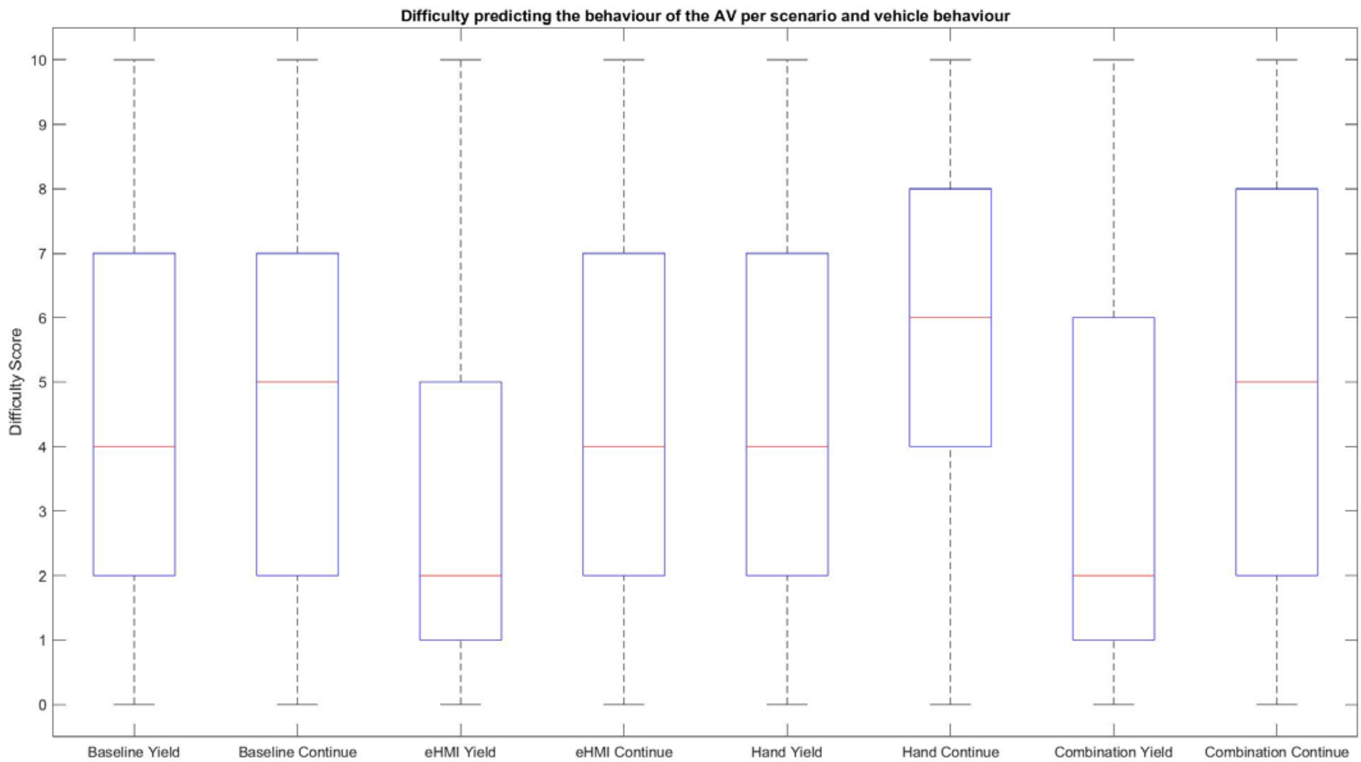

Ranking of how strongly the lack of eye contact affected the participants decision to cross
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Baseline
eHMI
Hand
Combination
First choice
Second choice
Third choice
Fourth choice

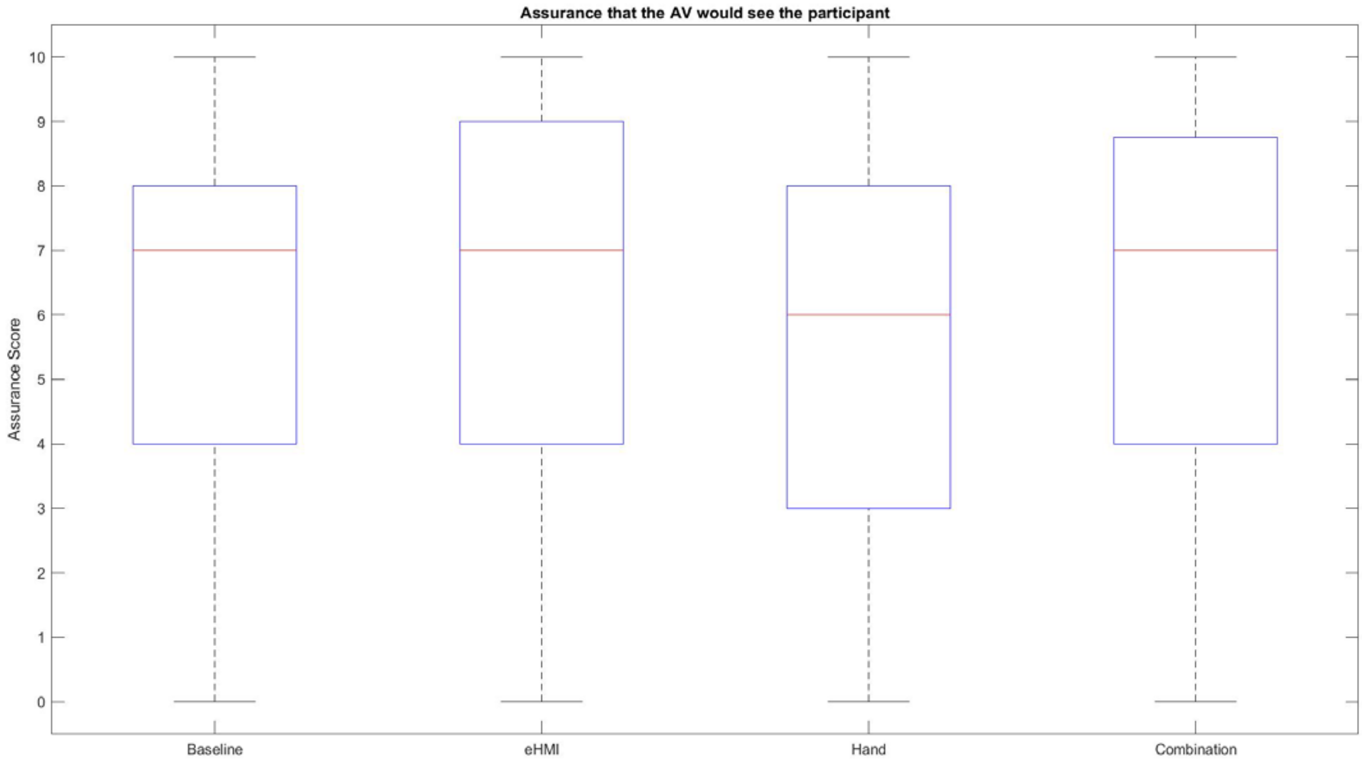


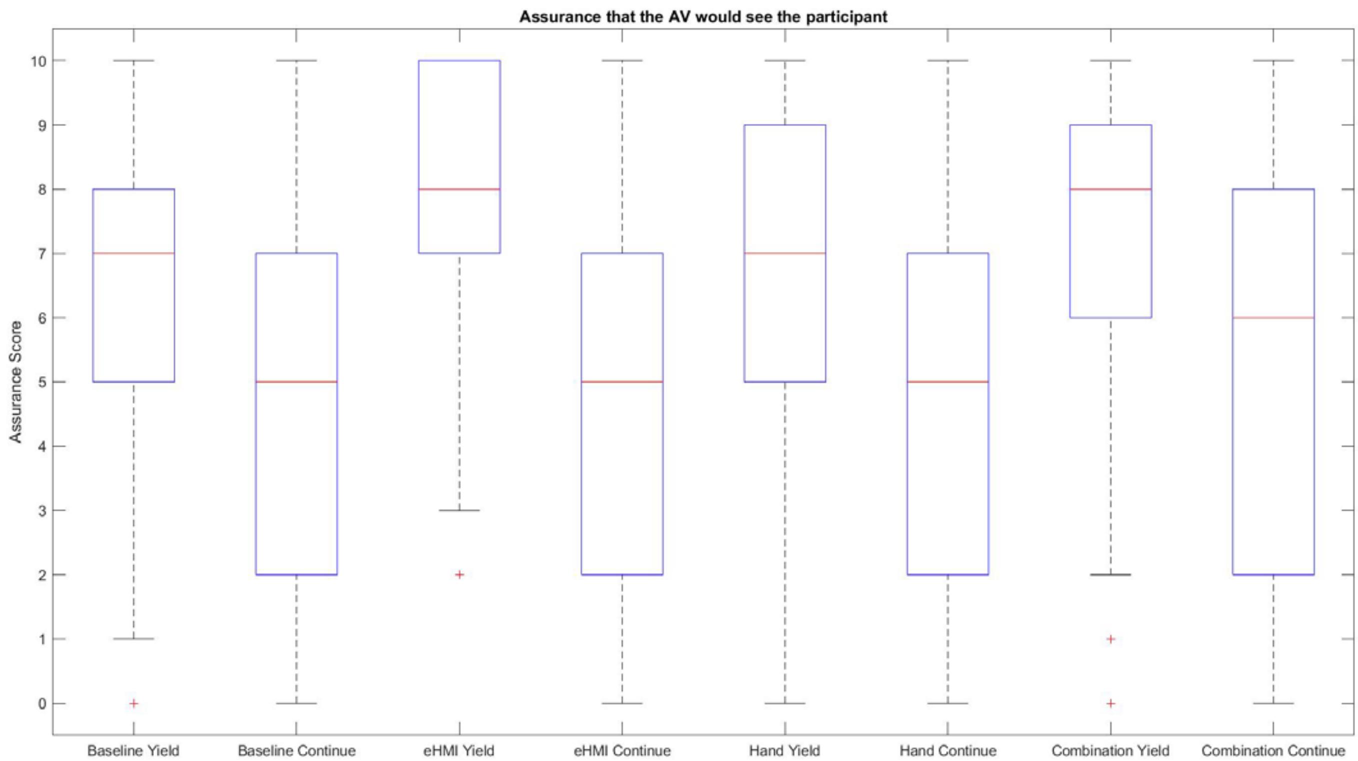
Ranking of which situation the participants prefer when interacting with an AV
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Baseline
eHMI
Hand
Combination
First choice
Second choice
Third choice
Fourth choice

APPENDIX I: Boxplots of difficulty and assurance per scenario

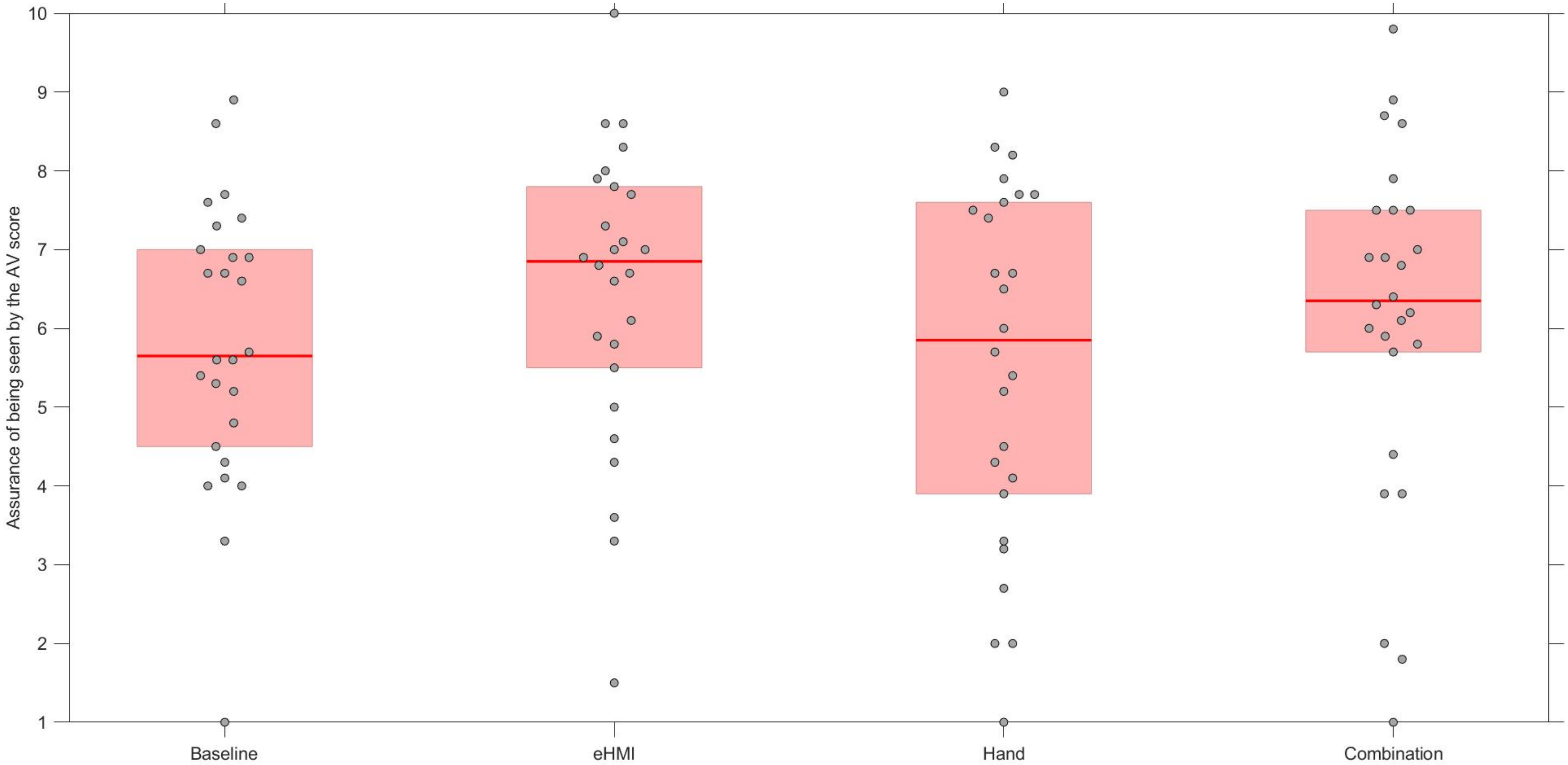


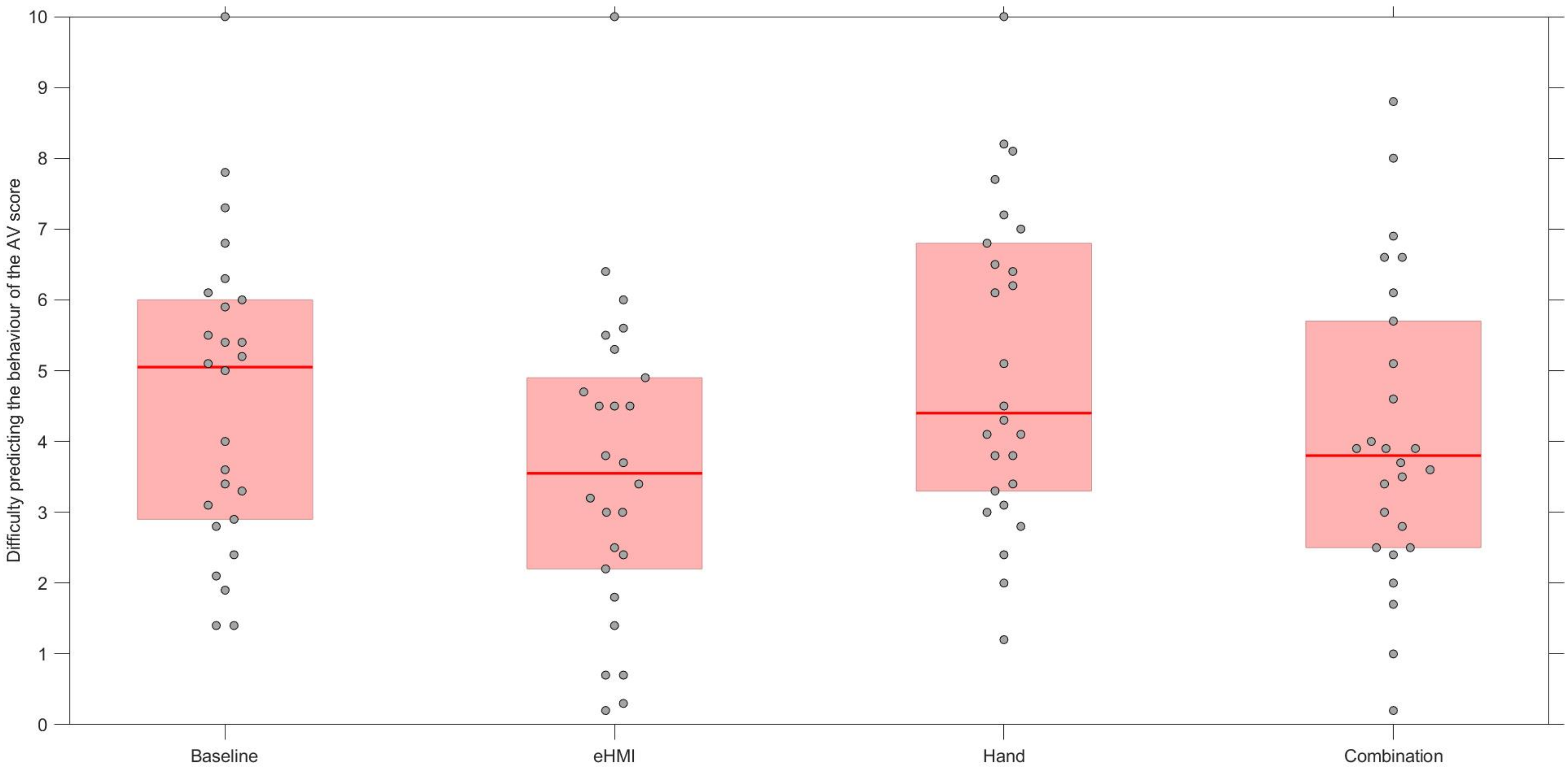



Assurance that the AV would see the participant
Assurance Score
10
9
8
7
6
5
4
3
2
1
0
Baseline
eHMI
Hand
Combination

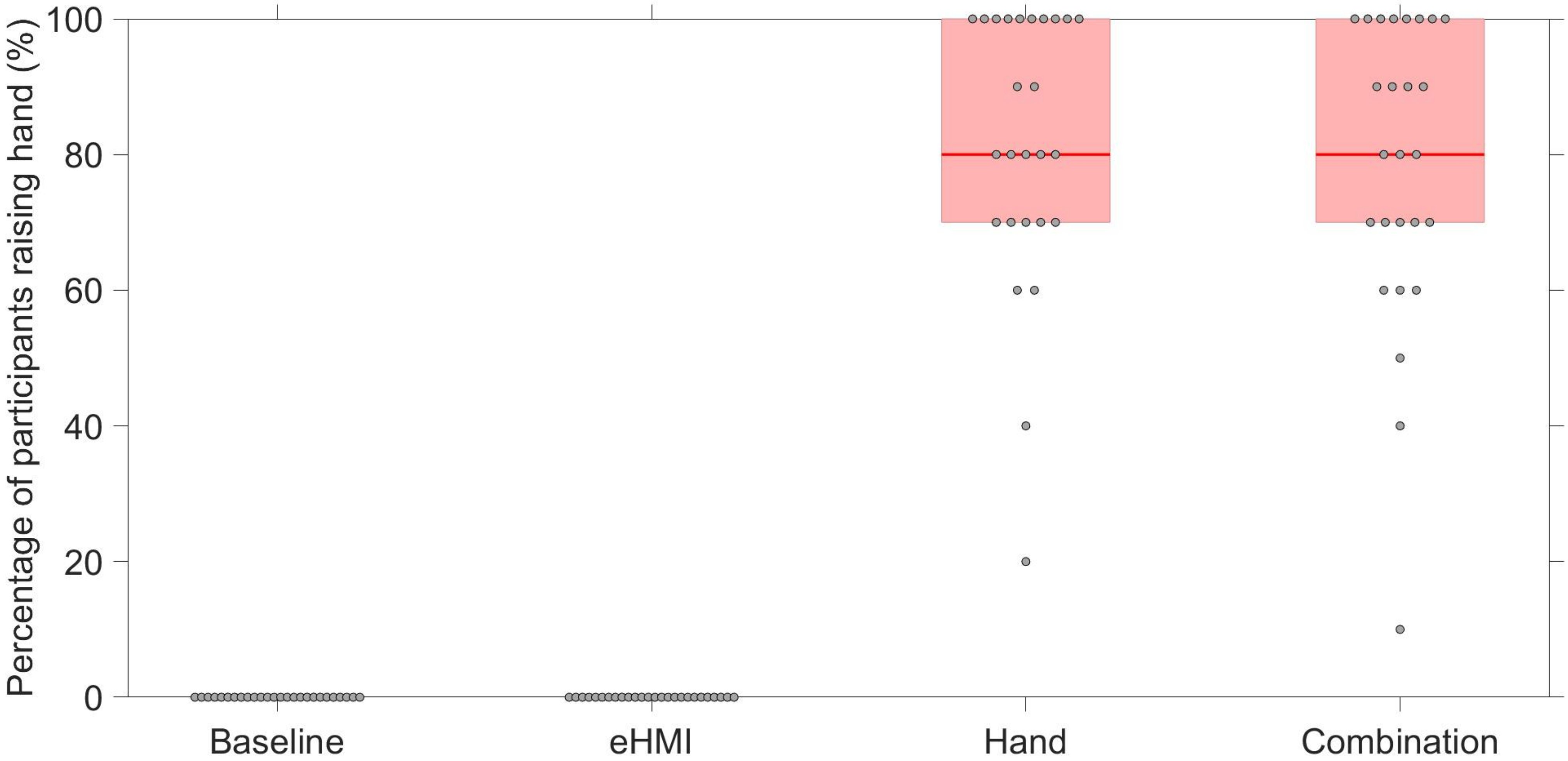

Assurance that the AV would see the participant
Assurance Score
10
9
8
7
6
5
4
3
2
1
0
Baseline Yield
Baseline Continue
eHMI Yield
eHMI Continue
Hand Yield
Hand Continue
Combination Yield
Combination Continue

APPENDIX J: Boxplots

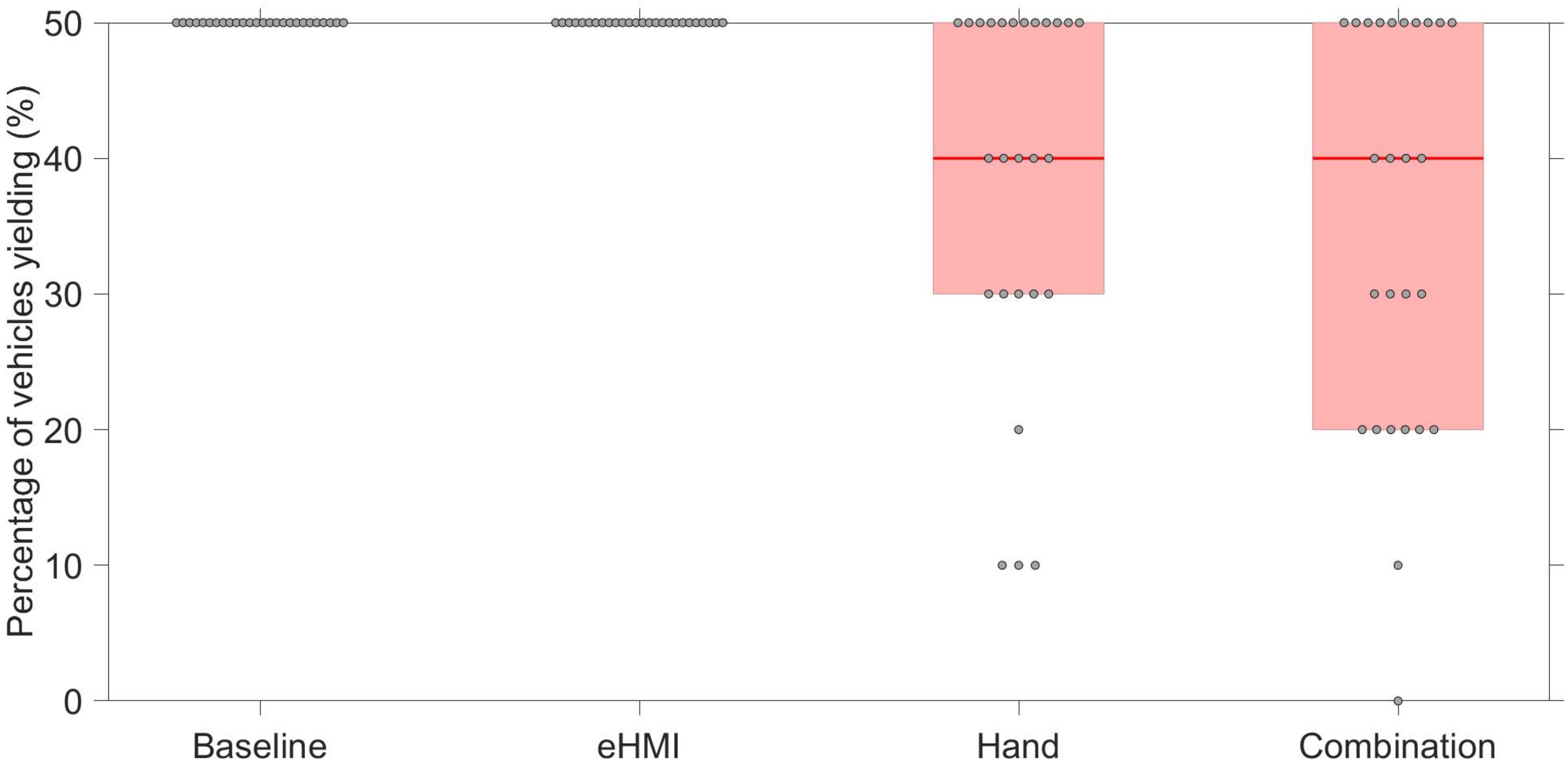


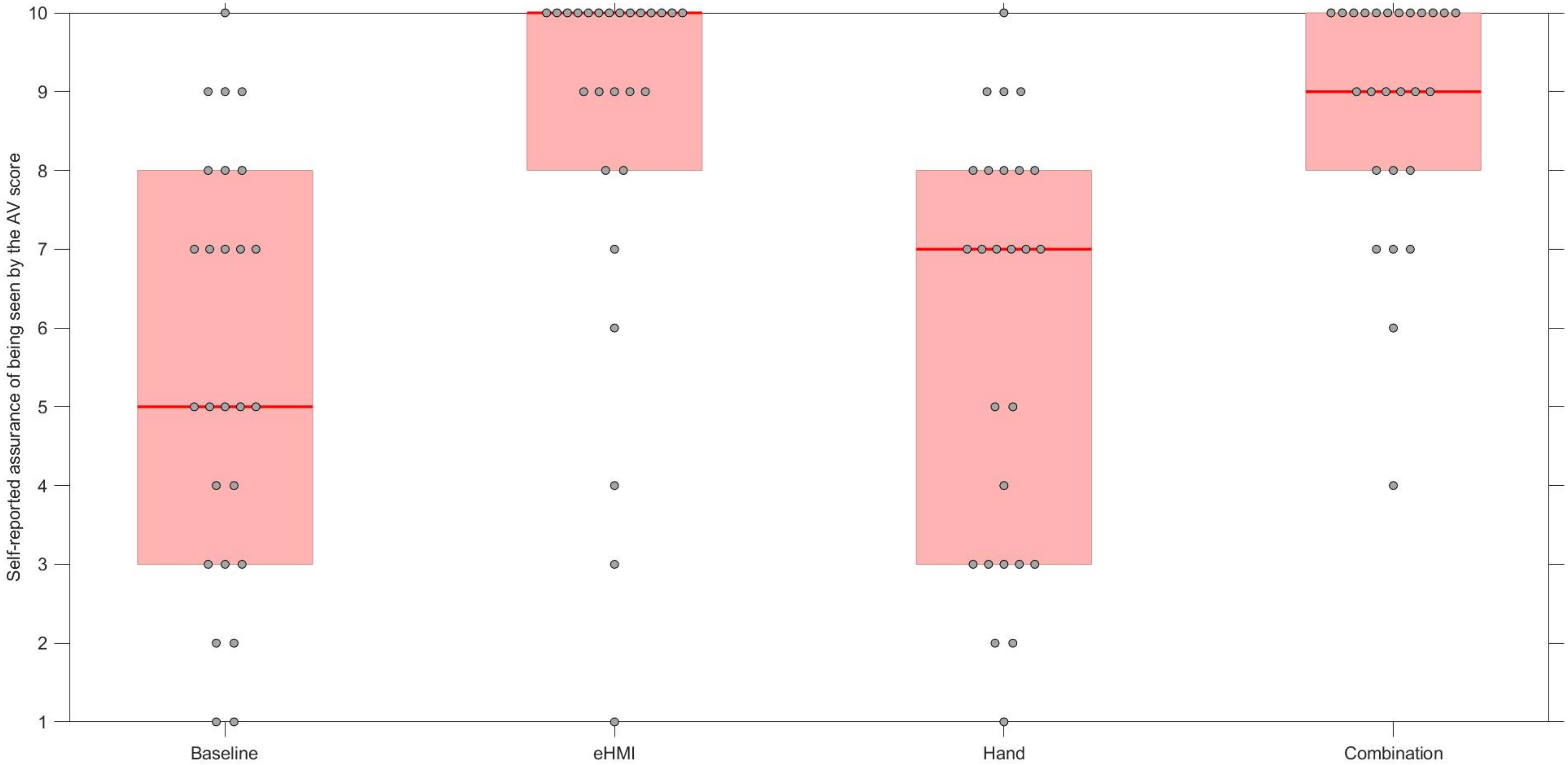


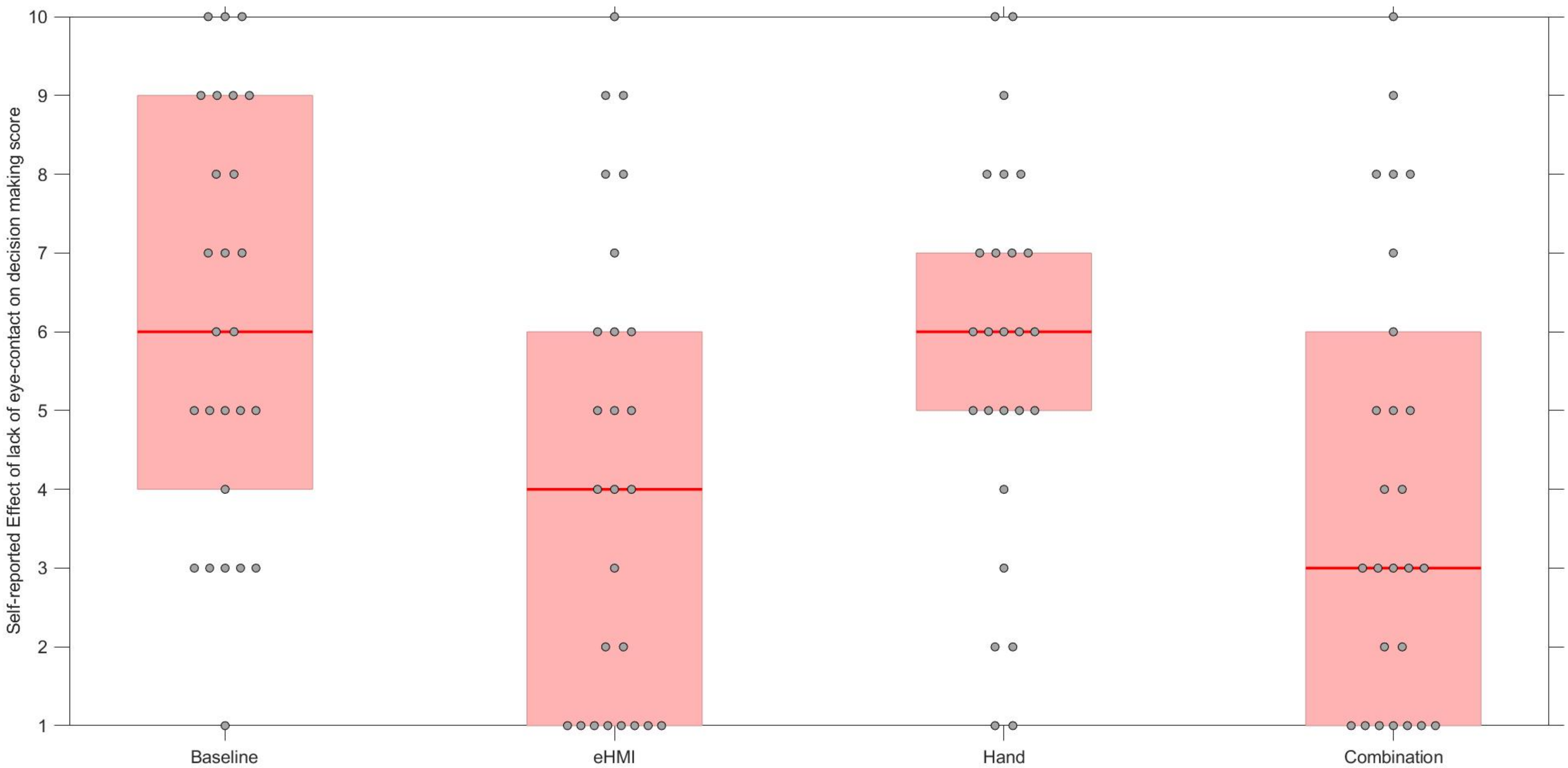
Difficulty predicting the behaviour of the AV score
10
9
8
7
6
5
4
3
2
1
0
Baseline
eHMI
Hand
Combination



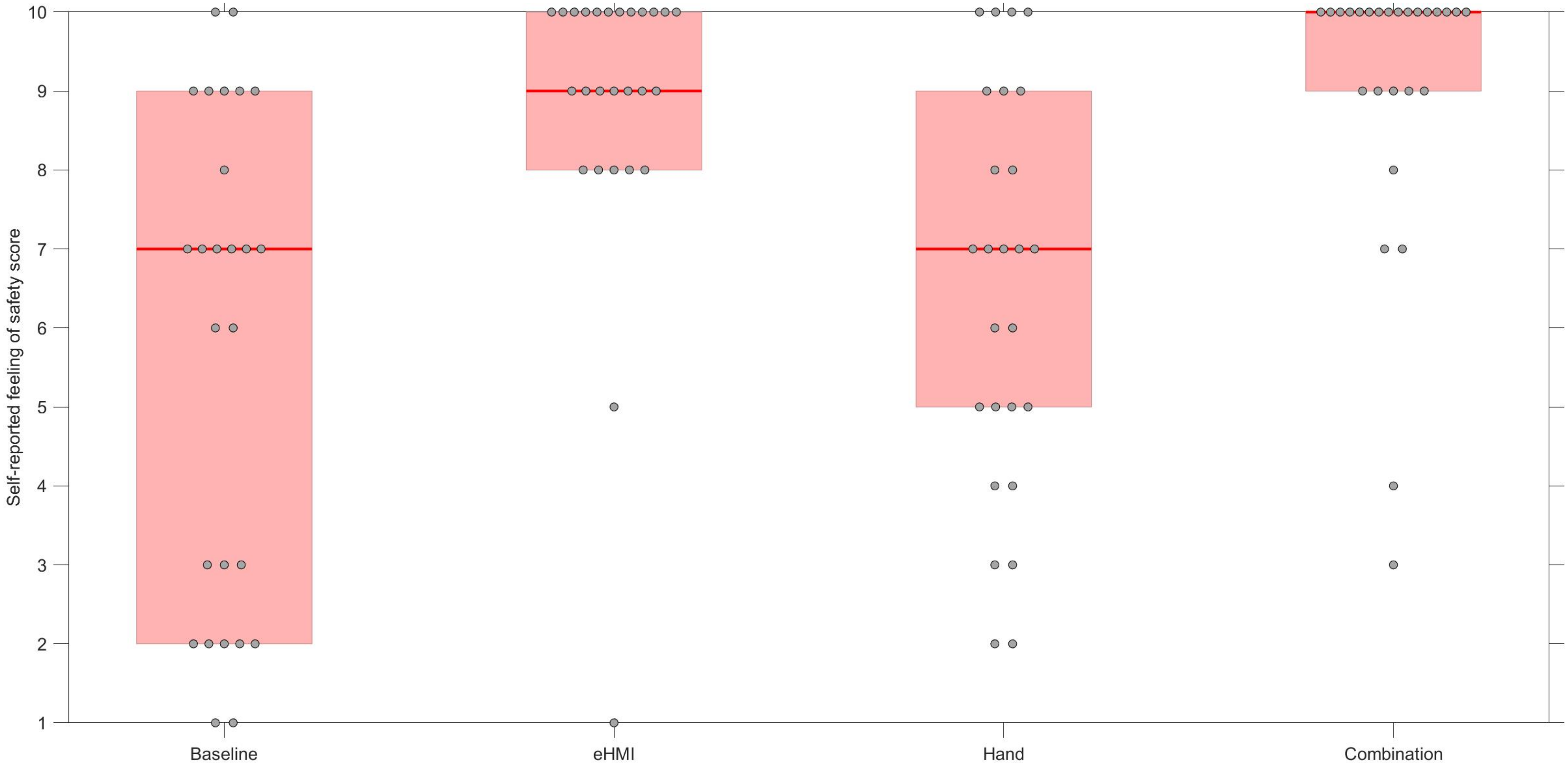
Percentage of participants raising hand (%)
100
80
60
40
20
0
Baseline
eHMI
Hand
Combination


Percentage of vehicles yielding (%)
50
40
30
20
10
0
Baseline
eHMI
Hand
Combination

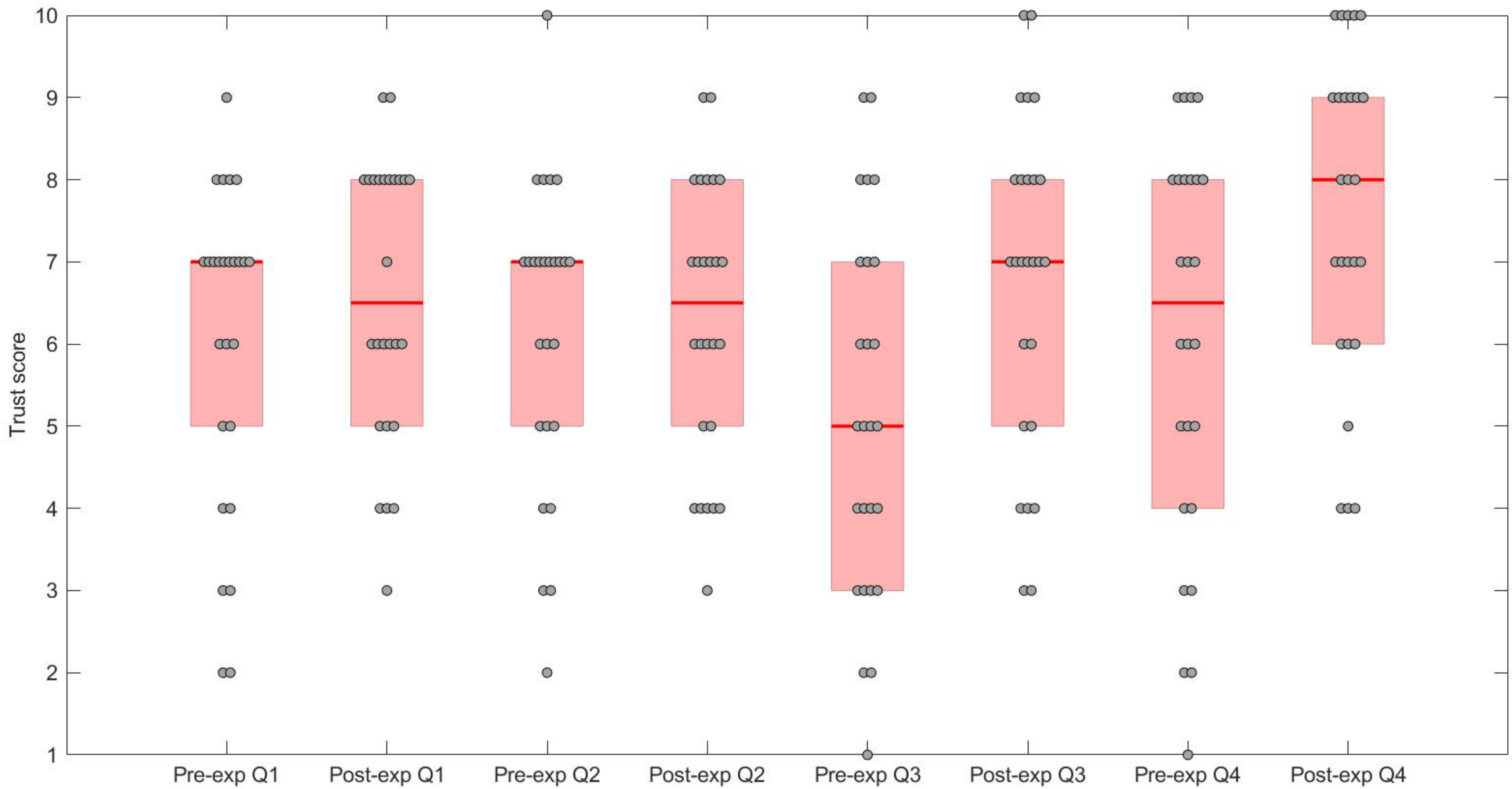

Self-reported assurance of being seen by the AV score
10
9
8
7
6
5
4
3
2
1
Baseline
eHMI
Hand
Combination



Self-reported Effect of lack of eye-contact on decision making score
10
9
8
7
6
5
4
3
2
1
Baseline
eHMI
Hand
Combination



Self-reported feeling of safety score
10
9
8
7
6
5
4
3
2
1
Baseline
eHMI
Hand
Combination



Trust score
10
9
8
7
6
5
4
3
2
1
Pre-exp Q1
Post-exp Q1
Pre-exp Q2
Post-exp Q2
Pre-exp Q3
Post-exp Q3
Pre-exp Q4
Post-exp Q4

APPENDIX K: Questionnaire data

Timestamp	What is your nationality?	What is your age	What is your gender?
10/4/2019 13:26:01	Greek	32	Male
10/4/2019 15:02:39	Indian	24	Male
10/4/2019 16:59:31	India	24	Male
10/7/2019 10:12:56	Indian	25	Male
10/7/2019 13:10:37	Dutch	26	Male
10/8/2019 8:38:18	Indian	25	Male
10/8/2019 10:27:20	Italian	24	Female
10/8/2019 12:09:04	Lithuanian	24	Male
10/8/2019 14:08:14	Dutch	29	Male
10/8/2019 15:44:36	Indian	26	Male
10/8/2019 17:10:27	Sudanese	25	Male
10/8/2019 19:11:01	China	33	Male
10/8/2019 20:23:42	Chinese	35	Female
10/9/2019 10:30:04	mex i can	27	Male
10/9/2019 12:48:36	Indian	23	Female
10/9/2019 18:34:43	Indian	26	Male
10/10/2019 14:54:56	Taiwanese	27	Male
10/10/2019 16:06:50	Colombian	25	Female
10/11/2019 10:06:39	Chinese	22	Male
10/11/2019 11:34:36	INDIAN	26	Male
10/11/2019 13:31:04	Polish	18	Male
10/11/2019 14:28:06	Polish	19	Male
10/11/2019 16:49:45	Dutch	28	Male
10/11/2019 17:45:16	Dutch	28	Male
10/11/2019 19:05:08	Dutch	28	Male
10/11/2019 19:59:33	Dutch	28	Male

How often did you commute to work or school by foot in the last 12 months on average?	Do you have computer gaming experience?
Less than once a month	Yes, but rarely / not anymore
4 to 6 days a week	No, I have never played computer games
4 to 6 days a week	Yes, I play approximately once a month
Less than once a week	Yes, but rarely / not anymore
Never	Yes, I play approximately once a month
Less than once a month	Yes, but rarely / not anymore
Daily	No, I have never played computer games
Once a month to once a week	Yes, but rarely / not anymore
Less than once a month	Yes, I play approximately once a month
Never	Yes, I play approximately once a month
Once a month to once a week	Yes, but rarely / not anymore
Less than once a week	Yes, but rarely / not anymore
Never	Yes, but rarely / not anymore
Once a month to once a week	Yes, but rarely / not anymore
Daily	Yes, but rarely / not anymore
Daily	Yes, I play several times a week
Less than once a month	Yes, I play several times a week
1 to 3 days a week	Yes, but rarely / not anymore
Never	Yes, I play several times a week
Never	Yes, but rarely / not anymore
4 to 6 days a week	Yes, I play approximately once a month
1 to 3 days a week	Yes, I play several times a week
1 to 3 days a week	Yes, I play several times a week
1 to 3 days a week	Yes, I play several times a week
4 to 6 days a week	Yes, but rarely / not anymore
Never	Yes, I play several times a week

Have you worn Virtual Reality-glasses before?
Yes, multiple times
No
Yes, once
No
Yes, multiple times
Yes, multiple times
No
Yes, multiple times
Yes, once
No
Yes, once
Yes, multiple times
Yes, once
Yes, once
Yes, once
Yes, multiple times
Yes, once
No
No
Yes, once
Yes, multiple times
Yes, multiple times
Yes, once
No
Yes, once
No

Do you have any experience encountering a vehicle with external Human-Machine Interface (eHMI) or participating in an experiment involving a vehicle with eHMI, befor
No
No
No
No
No
No
No
No
No
Yes
No
No
No
No
No
No
No
No
No
No
No
No
No
Yes
No
No

On a scale from 1 to 5, how likely are you to make eye-contact with the driver when you want to cross the road?
3
4
4
4
4
4
3
3
4
2
4
1
1
4
4
4
4
5
4
3
4
4
4
4
5
5

On a scale from 1 to 5, how likely are you to use hand gestures to communicate with the driver when you want to cross the road?	I walk for the pleasure of it
5	3
5	3
5	3
4	4
2	4
3	2
2	5
2	4
2	5
4	4
1	5
3	4
3	5
3	5
2	4
3	4
3	2
5	4
3	3
4	4
2	5
2	5
3	5
5	4
4	4
3	4

I walk because it is healthy	In short trips I prefer walking over other modes of transportation	Crossing roads is difficult
3	5	3
4	4	3
3	5	2
4	5	3
4	1	1
2	4	2
5	5	3
4	5	2
3	3	1
4	4	2
5	5	1
4	5	2
5	3	4
5	5	5
3	5	2
4	2	3
2	4	1
2	5	3
4	5	2
3	4	3
4	5	3
5	4	1
5	5	3
2	4	1
4	3	1
4	3	1

Crossing roads outside designated locations increases the risk of an accident	Crossing roads outside designated locations is wrong
3	3
5	4
1	5
3	5
5	4
4	4
5	5
4	4
5	2
2	4
1	3
5	5
5	5
5	5
5	5
5	
4	2
5	2
5	2
5	4
3	2
3	1
4	3
2	2
4	2
2	2

Crossing roads outside designated locations saves time	Crossing roads outside designated locations is acceptable because other people do it
3	3
3	1
4	4
2	1
5	1
2	2
3	4
4	2
4	4
3	2
5	1
4	2
4	4
4	2
2	5
4	2
5	1
4	4
4	3
5	3
4	3
5	3
4	3
4	4
4	2
2	1

I prefer routes with signalised crosswalks	I try to make as few road crossings as possible	I try to take the most direct route to my destination
3	3	2
4	4	4
3	4	4
4	3	4
1	1	5
4		3
5	4	5
3	3	4
3	5	3
4	3	5
4	4	4
5	4	5
5	2	4
5	5	4
5	5	5
3	3	3
5	4	2
3	1	5
5	5	5
4	4	5
5	4	3
2	2	4
3	1	4
2	5	4
4	5	4
3	3	5

I try to take the route to my destination on which I encounter the least amount of traffic	I am willing to make a detour to find a protected crossing
3	5
4	3
4	5
4	3
2	1
5	3
3	4
5	4
3	2
5	2
4	1
5	5
5	3
4	4
4	4
4	1
5	4
5	1
4	2
5	2
4	3
2	1
5	3
3	1
4	2
1	3

I am willing to take any opportunity to cross	I am willing to make dangerous actions as a pedestrian to save time
1	2
2	2
4	3
3	3
4	2
2	2
3	2
2	2
3	1
4	4
4	4
2	1
3	1
5	5
2	2
	2
4	2
5	2
3	3
5	4
3	2
4	2
3	2
2	2
4	2
3	1

I am less likely to be involved in a road crash than other pedestrians	I am faster than other pedestrians	I am more careful than other pedestrians
5	1	4
4	4	3
3	3	3
3	3	3
1	1	1
4	2	4
4	4	4
3	3	3
2	1	2
5	4	5
5	4	4
5	4	5
4	1	5
2	4	4
4	5	4
3	3	3
2	2	3
4	5	3
4	4	5
2	3	3
3	5	3
4	5	3
3	3	3
3	3	3
4	3	4
4	4	5

I have trust in self-driving vehicles.	I have trust that self-driving vehicles will notice me.	I have trust that self-driving vehicles will respond to hand gestures.
5	6	1
8	7	5
7	7	9
5	4	4
7	3	2
7	7	6
7	7	7
7	8	3
6	6	4
4	7	7
7	7	8
7	7	8
2	4	6
2	5	3
3	2	2
6	5	5
8	5	5
7	7	8
7	8	9
3	3	3
8	8	6
9	10	4
6	6	4
4	7	3
8	8	7
7	7	5

I have trust that hand gestures can be used to communicate with a self-driving vehicle.
1
8
9
5
2
6
7
6
4
8
8
8
9
3
2
5
8
9
9
3
7
6
7
4
8
5

Timestamp	Participant number	Interaction number	On a scale from 0 to 10, how difficult was it for you to predict the behaviors of the car?	On a scale from 0 to 10, how sure were you that the car would see you?
10/4/2019 13:44:38	1	1	0	10
10/4/2019 13:45:42	1	2	4	8
10/4/2019 13:46:31	1	3	10	7
10/4/2019 13:47:27	1	4	0	9
10/4/2019 13:48:11	1	5	0	8
10/4/2019 13:48:53	1	6	5	8
10/4/2019 13:49:48	1	7	2	9
10/4/2019 13:50:25	1	8	5	7
10/4/2019 13:51:07	1	9	7	7
10/4/2019 13:51:57	1	10	5	7
10/4/2019 13:53:26	1	11	5	6
10/4/2019 13:54:34	1	12	7	6
10/4/2019 13:55:28	1	13	5	7
10/4/2019 13:56:11	1	14	6	7
10/4/2019 13:56:52	1	15	5	9
10/4/2019 13:57:50	1	16	5	7
10/4/2019 13:58:42	1	17	4	8
10/4/2019 13:59:18	1	18	6	8
10/4/2019 14:00:03	1	19	6	9
10/4/2019 14:01:54	1	20	6	9
10/4/2019 14:16:09	1	21	5	10
10/4/2019 14:20:39	1	22	6	9
10/4/2019 14:21:11	1	23	6	0
10/4/2019 14:21:57	1	24	8	6
10/4/2019 14:22:30	1	25	8	7
10/4/2019 14:23:07	1	26	10	8
10/4/2019 14:23:41	1	27	10	5
10/4/2019 14:24:26	1	28	6	10
10/4/2019 14:25:09	1	29	6	10
10/4/2019 14:25:54	1	30	0	10
10/4/2019 14:27:13	1	31	8	7
10/4/2019 14:27:51	1	32	0	10
10/4/2019 14:28:19	1	33	5	5
10/4/2019 14:28:50	1	34	5	5
10/4/2019 14:29:27	1	35	6	6
10/4/2019 14:30:00	1	36	6	6
10/4/2019 14:30:39	1	37	0	10
10/4/2019 14:31:16	1	38	0	10
10/4/2019 14:32:01	1	39	0	10
10/4/2019 14:33:59	1	40	0	10
10/4/2019 15:20:22	2	1	1	7
10/4/2019 15:21:21	2	2	4	7
10/4/2019 15:22:06	2	3	2	7
10/4/2019 15:22:42	2	4	3	8
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10/11/2019 14:54:57	22	17	4	8
10/11/2019 14:55:28	22	18	6	8
10/11/2019 14:56:01	22	19	9	8
10/11/2019 14:56:17	22	20	10	7
10/11/2019 14:57:16	22	21	8	3
10/11/2019 14:57:48	22	22	9	2
10/11/2019 14:58:09	22	23	7	3
10/11/2019 14:58:38	22	24	10	3
10/11/2019 14:59:00	22	25	8	5
10/11/2019 14:59:20	22	26	8	7
10/11/2019 14:59:49	22	27	7	7
10/11/2019 15:00:11	22	28	6	6
10/11/2019 15:00:32	22	29	8	4
10/11/2019 15:01:11	22	30	7	8
10/11/2019 15:01:51	22	31	3	4
10/11/2019 15:02:10	22	32	2	7
10/11/2019 15:02:44	22	33	2	5
10/11/2019 15:03:02	22	34	1	8
10/11/2019 15:03:34	22	35	1	4
10/11/2019 15:03:49	22	36	1	9
10/11/2019 15:04:27	22	37	1	4
10/11/2019 15:04:47	22	38	1	4
10/11/2019 15:05:07	22	39	1	6
10/11/2019 15:05:22	22	40	1	10
10/11/2019 17:13:44	23	1	3	8
10/11/2019 17:14:29	23	2	5	9
10/11/2019 17:15:16	23	3	6	5
10/11/2019 17:15:46	23	4	8	3
10/11/2019 17:16:10	23	5	8	3
10/11/2019 17:17:17	23	6	2	2
10/11/2019 17:17:45	23	7	1	10
10/11/2019 17:18:17	23	8	10	1
10/11/2019 17:19:06	23	9	1	1
10/11/2019 17:19:38	23	10	1	1
10/11/2019 17:20:22	23	11	5	5
10/11/2019 17:21:12	23	12	5	5
10/11/2019 17:21:43	23	13	6	6
10/11/2019 17:22:33	23	14	7	2
10/11/2019 17:22:56	23	15	4	7
10/11/2019 17:23:31	23	16	3	7
10/11/2019 17:23:57	23	17	8	2
10/11/2019 17:24:29	23	18	7	3
10/11/2019 17:27:58	23	19	8	2
10/11/2019 17:28:16	23	20	8	2
10/11/2019 17:29:45	23	21	8	2
10/11/2019 17:30:20	23	22	9	1
10/11/2019 17:30:45	23	23	9	1
10/11/2019 17:31:13	23	24	3	9
10/11/2019 17:31:31	23	25	2	8
10/11/2019 17:31:56	23	26	2	8
10/11/2019 17:32:35	23	27	9	1
10/11/2019 17:33:00	23	28	10	1
10/11/2019 17:33:35	23	29	7	7

10/11/2019 17:34:01	23	30	10	1
10/11/2019 17:35:14	23	31	5	5
10/11/2019 17:35:35	23	32	10	1
10/11/2019 17:35:53	23	33	5	6
10/11/2019 17:36:21	23	34	5	5
10/11/2019 17:36:56	23	35	10	1
10/11/2019 17:37:10	23	36	10	1
10/11/2019 17:37:33	23	37	8	6
10/11/2019 17:38:05	23	38	8	5
10/11/2019 17:38:36	23	39	10	1
10/11/2019 17:40:19	23	40	10	1
10/11/2019 18:12:09	24	1	1	1
10/11/2019 18:13:26	24	2	1	2
10/11/2019 18:14:08	24	3	8	2
10/11/2019 18:15:03	24	4	7	2
10/11/2019 18:16:01	24	5	7	5
10/11/2019 18:16:36	24	6	7	5
10/11/2019 18:17:25	24	7	5	5
10/11/2019 18:17:52	24	8	5	5
10/11/2019 18:18:22	24	9	4	7
10/11/2019 18:18:51	24	10	6	7
10/11/2019 18:20:21	24	11	2	8
10/11/2019 18:20:46	24	12	2	10
10/11/2019 18:21:17	24	13	2	8
10/11/2019 18:21:53	24	14	1	10
10/11/2019 18:22:45	24	15	3	2
10/11/2019 18:23:17	24	16	8	1
10/11/2019 18:23:53	24	17	8	1
10/11/2019 18:24:26	24	18	6	1
10/11/2019 18:24:58	24	19	6	10
10/11/2019 18:25:33	24	20	1	10
10/11/2019 18:26:11	24	21	8	1
10/11/2019 18:26:46	24	22	8	5
10/11/2019 18:27:09	24	23	6	1
10/11/2019 18:27:28	24	24	5	1
10/11/2019 18:27:49	24	25	5	1
10/11/2019 18:28:22	24	26	4	8
10/11/2019 18:28:47	24	27	5	8
10/11/2019 18:29:22	24	28	6	7
10/11/2019 18:29:45	24	29	7	1
10/11/2019 18:30:11	24	30	5	7
10/11/2019 18:31:04	24	31	5	1
10/11/2019 18:31:29	24	32	8	10
10/11/2019 18:32:00	24	33	7	1
10/11/2019 18:32:21	24	34	7	1
10/11/2019 18:32:43	24	35	5	1
10/11/2019 18:34:32	24	36	3	10
10/11/2019 18:35:02	24	37	4	9
10/11/2019 18:35:32	24	38	2	10
10/11/2019 18:35:59	24	39	1	10
10/11/2019 18:36:36	24	40	7	2
10/11/2019 19:33:58	25	1	6	6
10/11/2019 19:34:36	25	2	7	4
10/11/2019 19:35:11	25	3	0	10
10/11/2019 19:35:50	25	4	7	7
10/11/2019 19:36:13	25	5	0	10
10/11/2019 19:36:43	25	6	10	0
10/11/2019 19:37:07	25	7	0	10
10/11/2019 19:37:37	25	8	7	3
10/11/2019 19:38:06	25	9	0	10
10/11/2019 19:38:32	25	10	0	10
10/11/2019 19:39:10	25	11	0	10
10/11/2019 19:39:40	25	12	2	8
10/11/2019 19:40:09	25	13	4	7
10/11/2019 19:40:42	25	14	5	3
10/11/2019 19:41:09	25	15	5	0
10/11/2019 19:41:43	25	16	6	6
10/11/2019 19:42:03	25	17	3	9
10/11/2019 19:42:33	25	18	3	3
10/11/2019 19:43:00	25	19	5	4
10/11/2019 19:43:25	25	20	3	8
10/11/2019 19:44:07	25	21	6	2
10/11/2019 19:44:32	25	22	3	6
10/11/2019 19:45:06	25	23	6	5
10/11/2019 19:45:27	25	24	8	0
10/11/2019 19:45:50	25	25	8	1
10/11/2019 19:46:10	25	26	8	1
10/11/2019 19:46:32	25	27	8	0
10/11/2019 19:47:00	25	28	6	9
10/11/2019 19:47:36	25	29	5	9
10/11/2019 19:48:10	25	30	6	6
10/11/2019 19:48:47	25	31	6	6
10/11/2019 19:49:05	25	32	4	8
10/11/2019 19:49:34	25	33	5	8
10/11/2019 19:50:13	25	34	10	3
10/11/2019 19:50:40	25	35	9	2
10/11/2019 19:51:05	25	36	4	7
10/11/2019 19:51:36	25	37	5	8
10/11/2019 19:52:05	25	38	3	3
10/11/2019 19:52:30	25	39	3	9
10/11/2019 19:53:01	25	40	3	3

10/11/2019 20:17:29	26	1	3	0
10/11/2019 20:18:10	26	2	0	10
10/11/2019 20:19:03	26	3	7	0
10/11/2019 20:19:34	26	4	7	2
10/11/2019 20:20:00	26	5	7	1
10/11/2019 20:20:24	26	6	7	1
10/11/2019 20:21:00	26	7	5	1
10/11/2019 20:21:26	26	8	5	1
10/11/2019 20:21:53	26	9	5	1
10/11/2019 20:22:15	26	10	5	1
10/11/2019 20:23:05	26	11	7	0
10/11/2019 20:23:42	26	12	6	6
10/11/2019 20:24:02	26	13	8	0
10/11/2019 20:24:23	26	14	6	7
10/11/2019 20:24:52	26	15	8	0
10/11/2019 20:25:22	26	16	5	7
10/11/2019 20:25:50	26	17	3	7
10/11/2019 20:26:11	26	18	8	0
10/11/2019 20:26:40	26	19	6	6
10/11/2019 20:27:00	25	20	3	0
10/11/2019 20:27:45	26	21	3	0
10/11/2019 20:28:08	26	22	0	0
10/11/2019 20:28:43	26	23	0	10
10/11/2019 20:29:00	26	24	0	10
10/11/2019 20:29:28	26	25	0	10
10/11/2019 20:30:07	26	26	0	0
10/11/2019 20:30:26	26	27	0	0
10/11/2019 20:30:49	26	28	0	10
10/11/2019 20:31:20	26	29	0	0
10/11/2019 20:31:38	26	30	0	10
10/11/2019 20:32:35	26	31	8	3
10/11/2019 20:32:55	26	32	8	1
10/11/2019 20:33:26	26	33	7	1
10/11/2019 20:33:54	26	34	8	2
10/11/2019 20:34:17	26	35	7	0
10/11/2019 20:34:36	26	36	7	0
10/11/2019 20:34:53	26	37	6	6
10/11/2019 20:35:25	26	38	7	0
10/11/2019 20:35:42	26	39	6	7
10/11/2019 20:36:09	26	40	6	7

Timestamp	How safe do you feel to cross the road in this situation?	How safe do you feel to cross the road in this situation?
10/4/2019 14:38:29	1	10
10/4/2019 16:01:34	7	9
10/4/2019 17:58:22	7	10
10/7/2019 11:11:07	2	9
10/7/2019 13:59:24	2	8
10/8/2019 9:24:48	2	1
10/8/2019 11:00:11	9	9
10/8/2019 12:55:22	7	9
10/8/2019 15:01:08	9	9
10/8/2019 16:48:58	3	8
10/8/2019 18:00:05	3	8
10/8/2019 20:14:56	7	10
10/8/2019 21:21:43	8	10
10/9/2019 11:27:37	10	10
10/9/2019 13:35:34	2	5
10/9/2019 19:25:14	2	8
10/10/2019 15:48:07	9	9
10/10/2019 16:54:22	7	10
10/11/2019 11:03:09	3	8
10/11/2019 12:26:17	6	9
10/11/2019 14:14:56	6	10
10/11/2019 15:12:06	9	10
10/11/2019 17:54:27	7	10
10/11/2019 18:50:10	10	10
10/11/2019 20:12:27	9	10
10/11/2019 20:51:00	1	10

How sure are you that the car has seen you in this situation?	How sure are you that the car has seen you in this situation?
5	10
5	9
9	7
2	10
2	6
3	1
7	9
8	10
9	10
4	3
5	9
5	10
7	10
8	10
1	4
5	10
8	9
10	10
3	8
7	9
7	10
9	10
7	10
3	8
4	10
1	10

How strongly does the fact that you cannot make eye contact with a driver affect your decision to cross the road in this situation?
5
9
4
9
10
7
5
3
9
5
6
6
3
3
10
7
5
3
9
8
7
3
10
1
8
5

How strongly does the fact that you cannot make eye contact with a driver affect your decision to cross the road in this situation?
10
4
5
5
8
2
6
1
8
6
1
4
1
9
9
3
7
1
5
4
2
1
1
1
6
1

Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How safe do you feel to cross the road in this situation?
7
4
6
2
2
7
5
9
10
4
9
9
8
8
5
5
10
5
3
6
7
10
7
10
7
3

Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How safe do you feel to cross the road in this situation?
10
9
4
9
7
10
9
10
10
3
10
10
10
10
7
10
10
10
8
9
10
10
9
10
10
10

Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How sure are you that the car has seen you in this situation?
8
4
9
5
2
3
7
9
10
3
3
8
7
7
2
3
9
5
3
7
8
8
7
8
7
1

Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How sure are you that the car has seen you in this situation?
10
9
8
8
6
9
7
10
10
4
9
10
10
10
7
7
10
10
8
9
10
10
9
10
9
10

Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How strongly does the fact that you cannot make eye contact
6
8
7
6
10
6
5
2
7
4
2
5
5
5
10
8
5
9
8
6
6
3
7
1
7
1

Considering that you have used a hand gesture to communicate to the car that you want to cross the road: How strongly does the fact that you cannot make eye contact
10
4
6
9
8
8
5
1
7
5
1
3
1
1
8
3
3
3
4
5
2
1
2
1
3
1

Rank the following situations on your feeling of safety to cross the road. [Communication via eHMI]
First choice (most safe to cross)
Second Choice
First choice (most safe to cross)
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice
Third choice
First choice (most safe to cross)
Second Choice
Second Choice
First choice (most safe to cross)
Second Choice
Second Choice
First choice (most safe to cross)
Third choice
First choice (most safe to cross)
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice

Rank the following situations on your feeling of safety to cross the road. [No communication]
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Third choice
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Third choice
Third choice
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Third choice
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Second Choice
Fourth choice (least safe to cross)
Third choice
Third choice
Fourth choice (least safe to cross)
Third choice
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Third choice
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Third choice

Rank the following situations on your feeling of safety to cross the road. [Communication via eHMI after hand gesture is used]
Second Choice
First choice (most safe to cross)
Second Choice
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
Second Choice
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
Second Choice
First choice (most safe to cross)
Second Choice
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)
First choice (most safe to cross)

Rank the following situations on your feeling of safety to cross the road. [No communication after hand gesture is used]
Fourth choice (least safe to cross)
Third choice
Fourth choice (least safe to cross)
Third choice
Third choice
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Third choice
Second Choice
Third choice
Third choice
Third choice
Second Choice
Third choice
Fourth choice (least safe to cross)
Fourth choice (least safe to cross)
Second Choice
Fourth choice (least safe to cross)
Third choice
Third choice
Third choice
Fourth choice (least safe to cross)
Third choice
Third choice
Third choice
Fourth choice (least safe to cross)

Rank the following situations on how sure you would be that the car has seen you. [Communication via eHMI]
First choice (Surest that the car sees me)
Second Choice
First choice (Surest that the car sees me)
Second Choice
Third choice
Second Choice
Third choice
Second Choice
Third choice
Second Choice
Second Choice
Second Choice
First choice (Surest that the car sees me)
Second Choice
Second Choice
First choice (Surest that the car sees me)
Second Choice
First choice (Surest that the car sees me)
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice
Second Choice

Rank the following situations on how sure you would be that the car has seen you. [No communication]
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Third choice
Fourth choice (least sure that the car sees me)
Third choice
Fourth choice (least sure that the car sees me)
Third choice
Third choice
Fourth choice (least sure that the car sees me)
Second Choice
Fourth choice (least sure that the car sees me)
Third choice
Third choice
Fourth choice (least sure that the car sees me)
Third choice
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Third choice
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)

Rank the following situations on how sure you would be that the car has seen you. [Communication via eHMI after hand gesture is used]
Second Choice
First choice (Surest that the car sees me)
Second Choice
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
Third choice
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
Second Choice
First choice (Surest that the car sees me)
Second Choice
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)
First choice (Surest that the car sees me)

Rank the following situations on how sure you would be that the car has seen you. [No communication after hand gesture is used]
First choice (Surest that the car sees me)
Third choice
Third choice
Third choice
Second Choice
Fourth choice (least sure that the car sees me)
Third choice
Fourth choice (least sure that the car sees me)
Second Choice
Second Choice
Fourth choice (least sure that the car sees me)
Third choice
Second Choice
Third choice
Fourth choice (least sure that the car sees me)
Fourth choice (least sure that the car sees me)
Third choice
Fourth choice (least sure that the car sees me)
Third choice
Third choice
Third choice
Fourth choice (least sure that the car sees me)
Third choice
Third choice
Third choice
Third choice

Rank the following situations on how strongly your decision is affected by the fact that you cannot make eye contact with the driver. [Communication via eHMI]
Fourth choice (least affected)
Second Choice
First choice (Most affected)
Second Choice
Second Choice
Second Choice
Second Choice
Fourth choice (least affected)
Second Choice
First choice (Most affected)
Third choice
Third choice
Fourth choice (least affected)
Second Choice
Second Choice
Fourth choice (least affected)
Third choice
Third choice
Third choice
Third choice
Third choice
Third choice
Second Choice
Fourth choice (least affected)
Third choice
Fourth choice (least affected)

Rank the following situations on how strongly your decision is affected by the fact that you cannot make eye contact with the driver. [No communication]
Second Choice
Fourth choice (least affected)
Fourth choice (least affected)
Fourth choice (least affected)
First choice (Most affected)
Fourth choice (least affected)
First choice (Most affected)
Second Choice
First choice (Most affected)
Third choice
First choice (Most affected)
First choice (Most affected)
Third choice
Fourth choice (least affected)
Fourth choice (least affected)
First choice (Most affected)
First choice (Most affected)
Second Choice
First choice (Most affected)
First choice (Most affected)
First choice (Most affected)
Second Choice
Fourth choice (least affected)
Second Choice
First choice (Most affected)
First choice (Most affected)

Rank the following situations on how strongly your decision is affected by the fact that you cannot make eye contact with the driver. [Communication via eHMI after hand
Fourth choice (least affected)
First choice (Most affected)
Third choice
First choice (Most affected)
Third choice
First choice (Most affected)
Third choice
Third choice
Fourth choice (least affected)
First choice (Most affected)
Fourth choice (least affected)
Fourth choice (least affected)
Fourth choice (least affected)
First choice (Most affected)
First choice (Most affected)
Third choice
Fourth choice (least affected)
Fourth choice (least affected)
Fourth choice (least affected)
Fourth choice (least affected)
Fourth choice (least affected)
Fourth choice (least affected)
First choice (Most affected)
First choice (Most affected)
Fourth choice (least affected)
Third choice

Rank the following situations on how strongly your decision is affected by the fact that you cannot make eye contact with the driver. [No communication after hand gestur
Second Choice
Third choice
Second Choice
Third choice
Fourth choice (least affected)
Third choice
Second Choice
First choice (Most affected)
Third choice
Third choice
Second Choice
Second Choice
Third choice
Third choice
Third choice
Second Choice
Second Choice
First choice (Most affected)
Second Choice
Second Choice
Second Choice
First choice (Most affected)
Third choice
Third choice
Second Choice
Second Choice

Which of the following situations do you prefer when interacting with an automated vehicle? [Communication via eHMI]
Second Choice
Second Choice
First choice (most preferred)
Second Choice
Second Choice
Second Choice
Second Choice
First choice (most preferred)
Second Choice
Second Choice
Second Choice
Second Choice
First choice (most preferred)
Second Choice
Second Choice
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
Second Choice
Second Choice
Second Choice
First choice (most preferred)
Second Choice
Second Choice
Second Choice
Second Choice

Which of the following situations do you prefer when interacting with an automated vehicle? [No communication]
Fourth choice (least preferred)
Fourth choice (least preferred)
Third choice
Fourth choice (least preferred)
Fourth choice (least preferred)
Third choice
Third choice
Third choice
Fourth choice (least preferred)
Fourth choice (least preferred)
Fourth choice (least preferred)
Fourth choice (least preferred)
Second Choice
Fourth choice (least preferred)
Third choice
Third choice
Second Choice
Third choice
Fourth choice (least preferred)
Fourth choice (least preferred)
Fourth choice (least preferred)
Second Choice
Fourth choice (least preferred)
Fourth choice (least preferred)
Fourth choice (least preferred)
Third choice

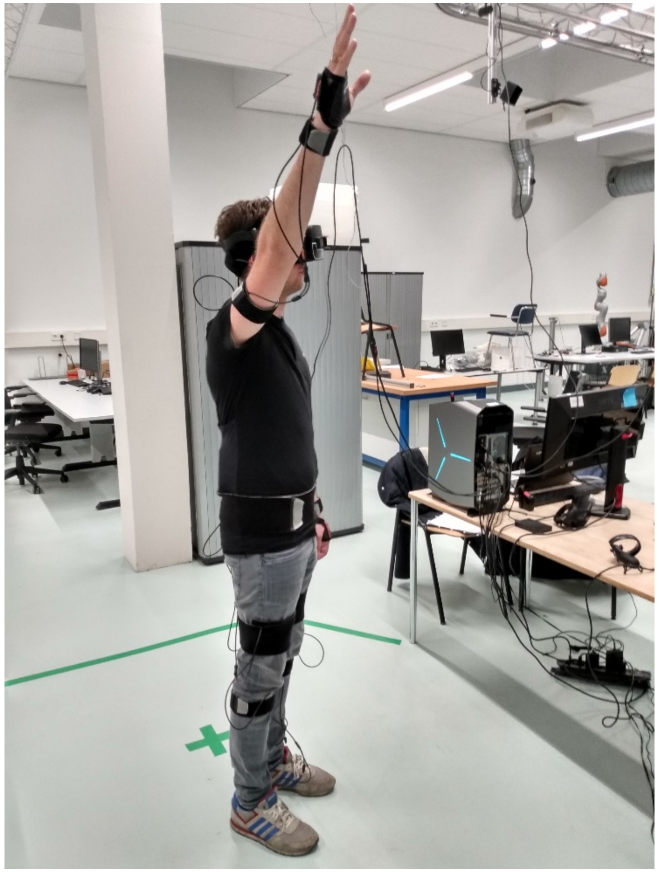
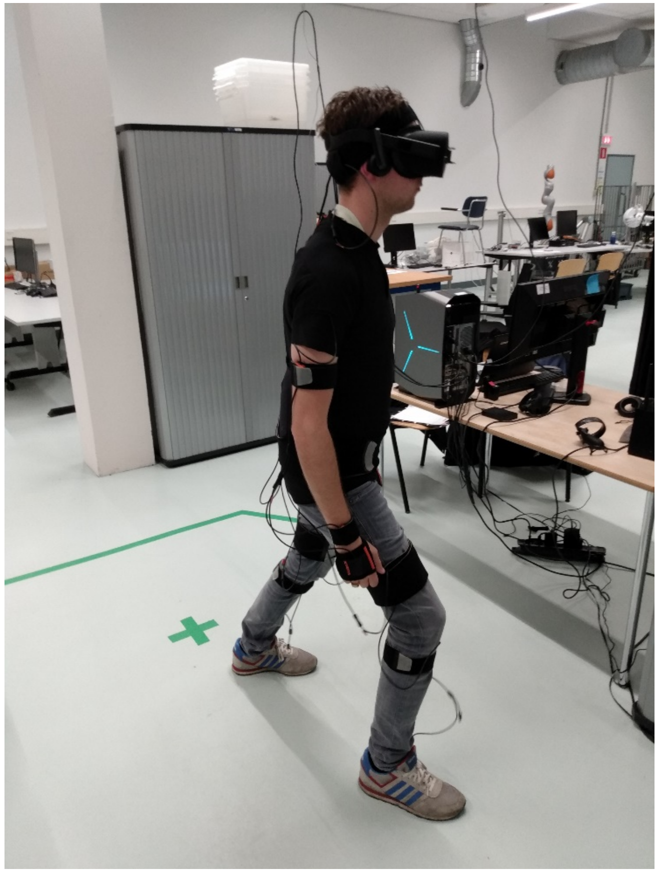
Which of the following situations do you prefer when interacting with an automated vehicle? [Communication via eHMI after hand gesture is used]
First choice (most preferred)
First choice (most preferred)
Second Choice
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
Second Choice
First choice (most preferred)
Second Choice
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
Second Choice
Third choice
Second Choice
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
Third choice
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)
First choice (most preferred)

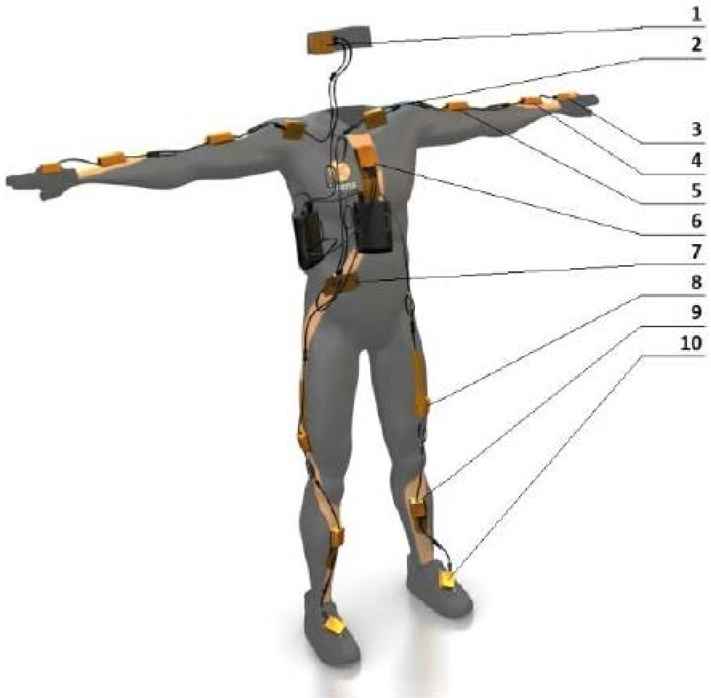
Which of the following situations do you prefer when interacting with an automated vehicle? [No communication after hand gesture is used]
Fourth choice (least preferred)
Third choice
Fourth choice (least preferred)
Third choice
Third choice
Fourth choice (least preferred)
Fourth choice (least preferred)
Fourth choice (least preferred)
Third choice
Fourth choice (least preferred)
Third choice
Third choice
Second Choice
Third choice
Fourth choice (least preferred)
Fourth choice (least preferred)
Fourth choice (least preferred)
Fourth choice (least preferred)
Third choice
Third choice
Third choice
Fourth choice (least preferred)
Third choice
Third choice
Third choice
Fourth choice (least preferred)

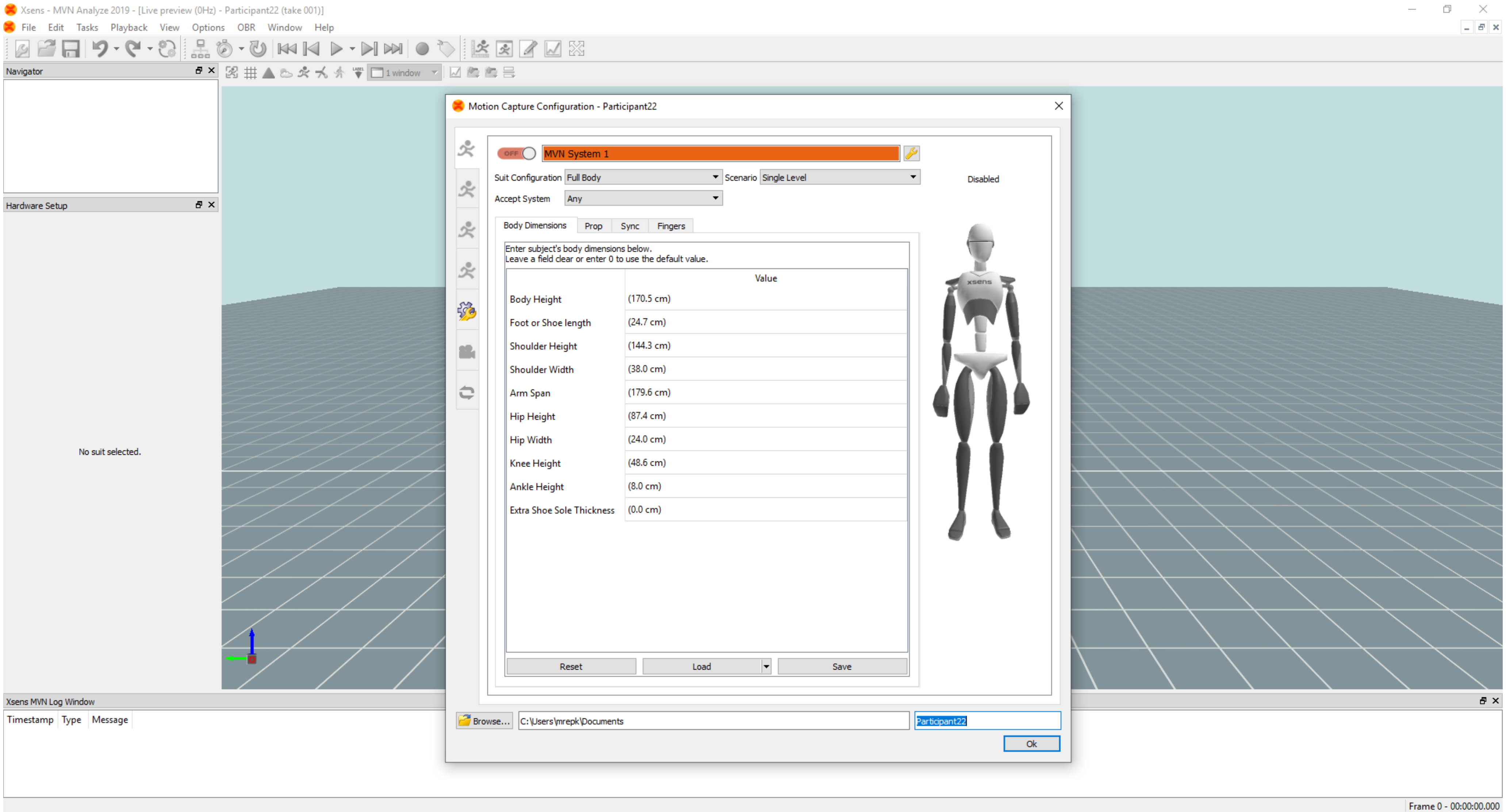
I have trust in self-driving vehicles.	I have trust that self-driving vehicles will notice me.	I have trust that self-driving vehicles will respond to hand gestures.
5	5	10
8	9	9
9	4	8
4	4	4
6	6	3
8	7	7
8	7	6
8	8	8
6	6	3
4	3	4
6	4	7
8	8	7
8	8	9
5	7	7
3	4	5
6	5	4
8	7	9
8	7	10
4	6	7
5	6	7
8	9	5
8	8	8
6	6	7
7	7	8
9	8	6
6	4	8

I have trust that hand gestures can be used to communicate with a self-driving vehicle.
10
9
6
7
4
6
9
9
4
7
10
8
10
9
4
5
9
10
8
7
7
9
7
8
6
10

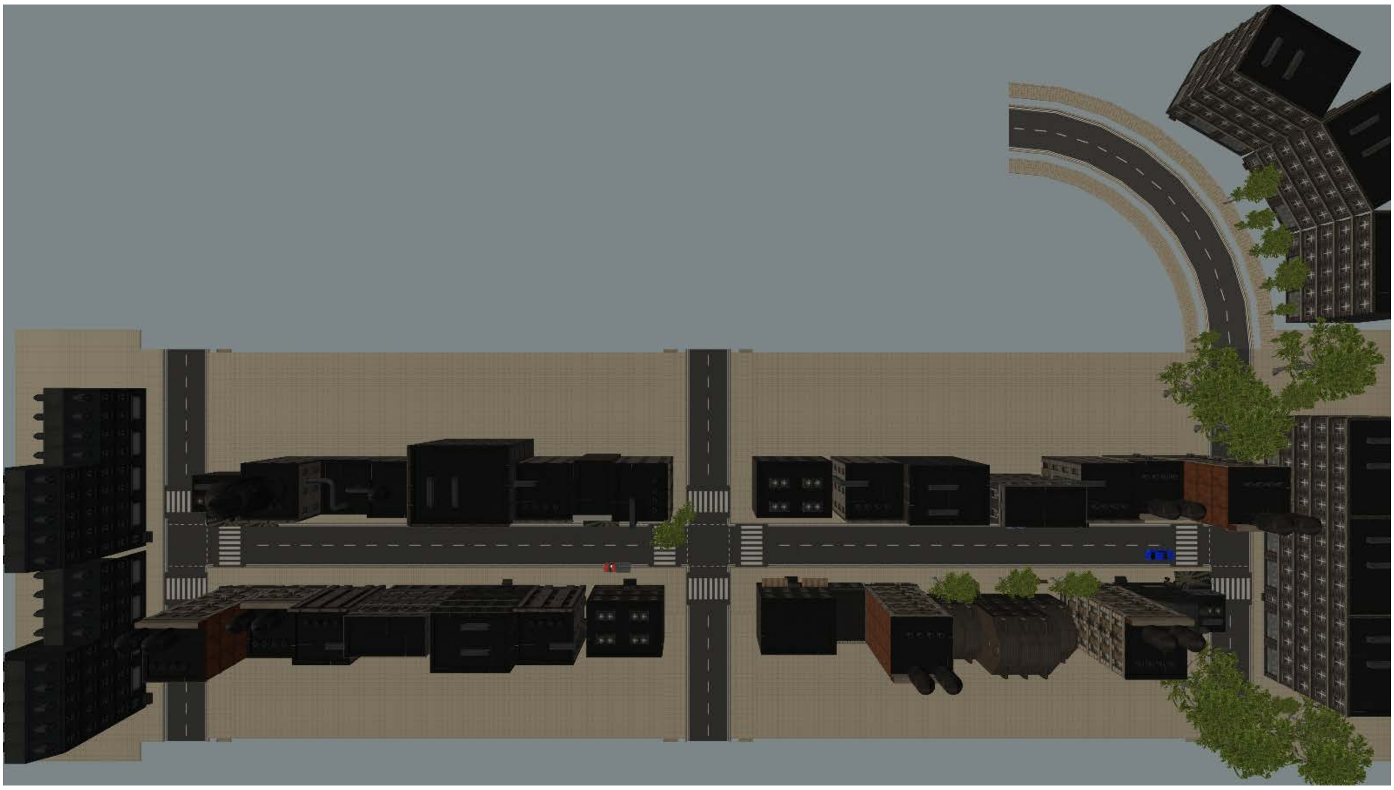
APPENDIX L: Experiment pictures


1
2
3
4
5
6
7
8
9
10


Xsens - MVN Analyze 2019 - [Live preview (0Hz) - Participant22 (take 001)]
File Edit Tasks Playback View Options OBR Window Help
Navigator
Hardware Setup
No suit selected.
Motion Capture Configuration - Participant22
MVN System 1
Suit Configuration Full Body
Scenario Single Level
Accept System Any
Disabled
Body Dimensions Prop Sync Fingers
Enter subject's body dimensions below.
Leave a field clear or enter 0 to use the default value.
Value
Body Height (170.5 cm)
Foot or Shoe length (24.7 cm)
Shoulder Height (144.3 cm)
Shoulder Width (38.0 cm)
Arm Span (179.6 cm)
Hip Height (87.4 cm)
Hip Width (24.0 cm)
Knee Height (48.6 cm)
Ankle Height (8.0 cm)
Extra Shoe Sole Thickness (0.0 cm)
Reset
Load
Save
Browse...
C:\Users\mrepk\Documents
Participant22
Ok
Xsens MVN Log Window
Timestamp Type Message
Frame 0 - 00:00:00.000

APPENDIX M: Virtual environment in Unity



APPENDIX N: Unity code for hand gesture detection

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Gesture : MonoBehaviour
{
    public bool correctgesture;
    Vector3 AlongSide;
    GameObject RightArm;
    GameObject RightForeArm;
    GameObject RightHand;
    GameObject LeftArm;
    GameObject LeftForeArm;
    GameObject LeftHand;


    // Start is called before the first frame update
    void Start()
    {
        AlongSide = new Vector3(0.0f, 1.0f, 0.0f);
        RightArm = GameObject.Find("RightArm");
        RightForeArm = GameObject.Find("RightForeArm");
        RightHand = GameObject.Find("RightHand");
        correctgesture = false;
        LeftArm = GameObject.Find("LeftArm");
        LeftForeArm = GameObject.Find("LeftForeArm");
        LeftHand = GameObject.Find("LeftHand");
    }

    // Update is called once per frame
    void Update()
    {
        Vector3 RarmDir = RightArm.transform.position - RightForeArm.transform.position;
        Vector3 RForearmDir = RightForeArm.transform.position - RightHand.transform.position;
        float angle = Vector3.Angle(RarmDir, AlongSide);
        float angle2 = Vector3.Angle(RForearmDir, RarmDir);

        Vector3 LarmDir = LeftArm.transform.position - LeftForeArm.transform.position;
        Vector3 LForearmDir = LeftForeArm.transform.position - LeftHand.transform.position;
        float angle3 = Vector3.Angle(LarmDir, AlongSide);
        float angle4 = Vector3.Angle(LForearmDir, LarmDir);

        if (angle > 45f | angle2 > 60f | RightHand.transform.position.y > RightForeArm.transform.position.y)
        {
            correctgesture = true;
        }
        if (angle3 > 45f | angle4 > 60f | LeftHand.transform.position.y > LeftForeArm.transform.position.y)
        {
            correctgesture = true;
        }
        if (angle3 < 45f && angle4 < 60f && LeftHand.transform.position.y < LeftForeArm.transform.position.y &&
angle < 45f && angle2 < 60f && RightHand.transform.position.y < RightForeArm.transform.position.y)
        {
            correctgesture = false;
        }
    }
}
```

APPENDIX O: Matlab main script

```
% MainScript: This script was developed by Michael Ray Epke for use in his
% MSc Thesis.
% The script loads both Unity and Xsens (MVNX) data and matches the samples by
% system-time.
% The script produces figures of the hand gestures used and steps taken by
% the participant, as well as the distance between the participant and the
% AV in the experiment.

clear all
close all

%% Main body of the script

for i=1:40

trialnumber=i; %Runs for all 40 trials of each participant
offset=3;   %Xsens logs the first 3 system-times as 00:00:00:000, therefore an offset is
used
foldername = pwd;   %Provides the foldername in which the data is stored
folderstructure = dir;  %Provies the directory in which the files are located

%%  Finds the participant number by the name of the folder

ParticipantNo=strfind(string(foldername),'\');
ParticipantNo=ParticipantNo(length(ParticipantNo))+1;
ParticipantNo=foldername(ParticipantNo:end);
ParticipantNumber=str2double(regexp(ParticipantNo,'\d+(\.\d+)?|\.\d+','match'))
[rowMVNfoldername,collumnMVNfoldername] = find(strcmp({folderstructure.name},
'MVN')==1);

%% Loads the MVN folder from the participant folder

MVNfoldername = struct2cell(folderstructure);
MVNfoldername =
string(MVNfoldername(rowMVNfoldername,collumnMVNfoldername));

MVNfolder = strcat(foldername,'\',MVNfoldername);
MVN = cell(1,4);
MVN = struct2cell(dir(MVNfolder));
MVN = MVN(1,:);

%% Counts and loads the trials done by the participant

MVNtrials=0;
for i = 1:length(MVN)
    if contains(MVN(i),'Participant')
```

```
        MVNtrials=MVNtrials+1;
    end
end

for i = 1:MVNtrials
    Trials(i) = strcat('Participant',string(ParticipantNumber),'-',string(sprintf('%03d',i)));
end
ParticipantTrialText = cell(1,1);
ParticipantTrialText =
textscan(fopen(char(strcat(MVNfolder,'\',Trials(trialnumber),'.mvnx'))),'%s','Delimiter','\n')
;


for i = 1:length(MVN)
    if contains(MVN(i),'Participant')
        MVNtrials=MVNtrials+1;
    end
end

%% Creates folders for the graphs and the output data

for i = 1:length(Trials)
    mkdir(strcat(foldername,'\Graphs\',Trials(i)));
end
for i = 1:length(Trials)
    mkdir(strcat(foldername,'\Workspace\',Trials(i)));
end
%% Counts the lines in the Xsens data containing the terms: position, orientation,
velocity, joint angle and the time of the sample (systemtime)

POS=0;
ORI=0;
VEL=0;
ANG=0;
TC=0;

POSindex=zeros([1,POS]);
ORIindex=zeros([1,ORI]);
VELindex=zeros([1,VEL]);
ANGindex=zeros([1,ANG]);
TCindex=zeros([1,TC]);

for i = 1:length(ParticipantTrialText{1,1})
    if contains(ParticipantTrialText{1,1}(i),'<position>')
        POS=POS+1;
        POSindex(POS)=i;
```

```
    end
    if contains(ParticipantTrialText{1,1}(i),'<orientation>')
        ORI=ORI+1;
        ORIindex(ORI)=i;
    end
    if contains(ParticipantTrialText{1,1}(i),'<velocity>') &&
~contains(ParticipantTrialText{1,1}(i),'Angular')
        VEL=VEL+1;
        VELindex(VEL)=i;
    end
    if contains(ParticipantTrialText{1,1}(i),'<jointAngle>')
        ANG=ANG+1;
        ANGindex(ANG)=i;
    end
    if contains(ParticipantTrialText{1,1}(i),'frame time')
        TC=TC+1;
        TCindex(TC)=i;
    end
end

%% Takes only the useful data (after the offset)

TC=TC-offset;
TCindex=TCindex(offset+1:end);
POS=POS-offset;
POSindex=POSindex(offset+1:end);
ORI=ORI-offset;
ORIindex=ORIindex(offset+1:end);

%% Reads sorts the Xsens data per term

Position=ParticipantTrialText{1,1}(POSindex);
Orientation=ParticipantTrialText{1,1}(ORIindex);
Velocity=ParticipantTrialText{1,1}(VELindex);
JointAngle=ParticipantTrialText{1,1}(ANGindex);
TimeCode=ParticipantTrialText{1,1}(TCindex);


%% Position data
for i = 1:POS
    POSStart(i)=strfind(Position{i,1},'<position>');
    POSEnd(i)=strfind(Position{i,1},'</position>');
end

MPOS=cell(POS,1);
for i = 1:POS
```

```
    MPOS(i)=cellstr(char(Position{i,1}(POSStart(i)+10:POSEnd(i)-1)));
end

%% Orientation data
for i = 1:ORI
    ORIStart(i)=strfind(Orientation{i,1},'<orientation>');
    ORIEnd(i)=strfind(Orientation{i,1},'</orientation>');
end

MORI=cell(ORI,1);
for i = 1:ORI
    MORI(i)=cellstr(char(Orientation{i,1}(ORIStart(i)+13:ORIEnd(i)-1)));
end

%% Velocity data
for i = 1:VEL
    VELStart(i)=strfind(Velocity{i,1},'<velocity>');
    VELEnd(i)=strfind(Velocity{i,1},'</velocity>');
end

MVEL=cell(VEL,1);
for i = 1:VEL
    MVEL(i)=cellstr(char(Velocity{i,1}(VELStart(i)+10:VELEnd(i)-1)));
end

%% Joint angle data
for i = 1:ANG
    ANGStart(i)=strfind(JointAngle{i,1},'<jointAngle>');
    ANGEnd(i)=strfind(JointAngle{i,1},'</jointAngle>');
end

MANG=cell(ANG,1);
for i = 1:ANG
    MANG(i)=cellstr(char(JointAngle{i,1}(ANGStart(i)+17:ANGEnd(i)-1)));
end

%% System-time
for i = 1:TC
    TimeStart(i)=strfind(TimeCode{i,1},'tc=');
    TimeEnd(i)=strfind(TimeCode{i,1},' ms=');
end

Time=cell(TC,1);
for i = 1:TC
    Time(i)=cellstr(char(TimeCode{i,1}(TimeStart(i)+4:TimeEnd(i)-2)));
end
```

```matlab
%% Converts the position to numerical values
Position = zeros([POS 69]);
for i = 1:POS
    Position(i,:) = str2num(MPOS{i,1});
end

%% Converts the orientation to numerical values
Orientation = zeros([ORI 92]);
for i = 1:ORI
    Orientation(i,:) = str2num(MORI{i,1});
end

%% Converts the velocity to numerical values
Velocity = zeros([VEL 69]);
for i = 1:VEL
    Velocity(i,:) = str2num(MVEL{i,1});
end

%% Converts the joint angle to numerical values
JointAngle = zeros([ANG 66]);
for i = 1:ANG
    JointAngle(i,:) = str2num(MANG{i,1});
end

%% Sorts the position data on body parts

POSPelvis=Position(:,1:3);
POSL5=Position(:,4:6);
POSL3=Position(:,7:9);
POST12=Position(:,10:12);
POST8=Position(:,13:15);
POSNeck=Position(:,16:18);
POSHead=Position(:,19:21);
POSRightShoulder=Position(:,22:24);
POSRightUpperArm=Position(:,25:27);
POSRightForearm=Position(:,28:30);
POSRightHand=Position(:,31:33);
POSLeftShoulder=Position(:,34:36);
POSLeftUpperArm=Position(:,37:39);
POSLeftForearm=Position(:,40:42);
POSLeftHand=Position(:,43:45);
POSRightUpperLeg=Position(:,46:48);
POSRightLowerLeg=Position(:,49:51);
POSRightFoot=Position(:,52:54);
POSRightToe=Position(:,55:57);
```

```
POSLeftUpperLeg=Position(:,58:60);
POSLeftLowerLeg=Position(:,61:63);
POSLeftFoot=Position(:,64:66);
POSLeftToe=Position(:,67:69);

%%  Sorts the orientation data on body parts

ORIPelvis=quat2eul(Orientation(:,1:4));
ORIL5=quat2eul(Orientation(:,5:8));
ORIL3=quat2eul(Orientation(:,9:12));
ORIT12=quat2eul(Orientation(:,13:16));
ORIT8=quat2eul(Orientation(:,17:20));
ORINeck=quat2eul(Orientation(:,21:24));
ORIHead=quat2eul(Orientation(:,25:28));
ORIRightShoulder=quat2eul(Orientation(:,29:32));
ORIRightUpperArm=quat2eul(Orientation(:,33:36));
ORIRightForearm=quat2eul(Orientation(:,37:40));
ORIRightHand=quat2eul(Orientation(:,41:44));
ORILeftShoulder=quat2eul(Orientation(:,45:48));
ORILeftUpperArm=quat2eul(Orientation(:,49:52));
ORILeftForearm=quat2eul(Orientation(:,53:56));
ORILeftHand=quat2eul(Orientation(:,57:60));
ORIRightUpperLeg=quat2eul(Orientation(:,61:64));
ORIRightLowerLeg=quat2eul(Orientation(:,65:68));
ORIRightFoot=quat2eul(Orientation(:,69:72));
ORIRightToe=quat2eul(Orientation(:,73:76));
ORILeftUpperLeg=quat2eul(Orientation(:,77:80));
ORILeftLowerLeg=quat2eul(Orientation(:,81:84));
ORILeftFoot=quat2eul(Orientation(:,85:88));
ORILeftToe=quat2eul(Orientation(:,89:92));

%%  Sorts the velocity data on body parts

VELPelvis=Velocity(:,1:3);
VELL5=Velocity(:,4:6);
VELL3=Velocity(:,7:9);
VELT12=Velocity(:,10:12);
VELT8=Velocity(:,13:15);
VELNeck=Velocity(:,16:18);
VELHead=Velocity(:,19:21);
VELRightShoulder=Velocity(:,22:24);
VELRightUpperArm=Velocity(:,25:27);
VELRightForearm=Velocity(:,28:30);
VELRightHand=Velocity(:,31:33);
VELLeftShoulder=Velocity(:,34:36);
VELLeftUpperArm=Velocity(:,37:39);
```

```matlab
VELLeftForearm=Velocity(:,40:42);
VELLeftHand=Velocity(:,43:45);
VELRightUpperLeg=Velocity(:,46:48);
VELRightLowerLeg=Velocity(:,49:51);
VELRightFoot=Velocity(:,52:54);
VELRightToe=Velocity(:,55:57);
VELLeftUpperLeg=Velocity(:,58:60);
VELLeftLowerLeg=Velocity(:,61:63);
VELLeftFoot=Velocity(:,64:66);
VELLeftToe=Velocity(:,67:69);

%%  Sorts the joint angle data on body parts

ANGL5S1=JointAngle(:,1:3);
ANGL4L3=JointAngle(:,4:6);
ANGL1T12=JointAngle(:,7:9);
ANGT9T8=JointAngle(:,10:12);
ANGT1C7=JointAngle(:,13:15);
ANGC1Head=JointAngle(:,16:18);
ANGRightC7Shoulder=JointAngle(:,19:21);
ANGRightShoulder=JointAngle(:,22:24);
ANGRightElbow=JointAngle(:,25:27);
ANGRightWrist=JointAngle(:,28:30);
ANGLeftC7Shoulder=JointAngle(:,31:33);
ANGLeftShoulder=JointAngle(:,34:36);
ANGLeftElbow=JointAngle(:,37:39);
ANGLeftWrist=JointAngle(:,40:42);
ANGRightHip=JointAngle(:,43:45);
ANGRightKnee=JointAngle(:,46:48);
ANGRightAnkle=JointAngle(:,49:51);
ANGRightBallFoot=JointAngle(:,52:54);
ANGLeftHip=JointAngle(:,55:57);
ANGLeftKnee=JointAngle(:,58:60);
ANGLeftAnkle=JointAngle(:,61:63);
ANGLeftBallFoot=JointAngle(:,64:66);

%% Converts the Xsens system-time from hertz to milliseconds

for i = 1:length(Time)
    TimeBar{i,1}=Time{i,1}(10:end);
end
XTime=round(str2double(TimeBar).*(1000/240));
for i=1:length(XTime)
    XTime2{i,1}=sprintf('%03d',XTime(i));
end
```

```
for i = 1:length(Time)
    NewTime{i,1}=Time{i,1}(1:9);
    NewTime{i,1}=strcat(NewTime{i,1},'.',XTime2{i,1});
    NewTime{i,1}=erase(NewTime{i,1},':');
    format long
    NewTime2(i) = str2num(NewTime{i,1})+2e4;
end

%% Plotting the graphs containing the position of both hands and the angle of both
elbows
fig1name=strcat('POSLeftHand',Trials(trialnumber));
fig2name=strcat('POSRightHand',Trials(trialnumber));
fig3name=strcat('ANGLeftElbow',Trials(trialnumber));
fig4name=strcat('ANGRightElbow',Trials(trialnumber));

fig1=figure
plot(NewTime2,POSLeftHand)
saveas(fig1,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig1name),'fig')
saveas(fig1,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig1name),'jpg')
fig2=figure
plot(NewTime2,POSRightHand)
saveas(fig2,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig2name),'fig')
saveas(fig2,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig2name),'jpg')
fig3=figure
plot(NewTime2,ANGLeftElbow)
saveas(fig3,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig3name),'fig')
saveas(fig3,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig3name),'jpg')
fig4=figure
plot(NewTime2,ANGRightElbow)
saveas(fig4,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig4name),'fig')
saveas(fig4,fullfile(strcat(foldername,'\Graphs\',Trials(trialnumber)),fig4name),'jpg')

foldernameoriginal = foldername;
trialnumberoriginal = trialnumber;
Trialsoriginal = Trials;

%% UNITY section

foldername = pwd;
folderstructure = dir;

ParticipantNo=strfind(string(foldername),'\');
ParticipantNo=ParticipantNo(length(ParticipantNo))+1;
ParticipantNo=foldername(ParticipantNo:end);
[rowUNITYfoldername,collumnUNITYfoldername] = find(strcmp({folderstructure.name},
'UNITY')==1);
```

```
UNITYfoldername = struct2cell(folderstructure);
UNITYfoldername =
string(UNITYfoldername(rowUNITYfoldername,collumnUNITYfoldername));

UNITYfolder = strcat(foldername,'\',UNITYfoldername);
UNITY = cell(1,4);
UNITY = struct2cell(dir(UNITYfolder));
UNITY = UNITY(1,:);

%% Finds the UNITY data per trial
UNITYtrials=0;
for i = 1:length(UNITY)
    if contains(UNITY(i),'Participant')
        UNITYtrials=UNITYtrials+1;
    end
end

for i = 1:UNITYtrials
    Trials(i) = strcat('Participant_',string(ParticipantNumber),'_',string(i));
end

ParticipantTrialText = cell(1,1);
ParticipantTrialText =
textscan(fopen(char(strcat(UNITYfolder,'\',Trials(trialnumber),'.txt'))),'%s','Delimiter','\n');

%% Sorts the UNITY data per term: Participant, SystemTime, FirstCar, SecondCar and
CorrectGesture
Participant=0;
Participantindex=zeros([1,Participant]);
SystemTime=0;
SystemTimeindex=zeros([1,SystemTime]);
FirstCar=0;
FirstCarindex=zeros([1,FirstCar]);
SecondCar=0;
SecondCarindex=zeros([1,SecondCar]);
CorrectGesture=0;
CorrectGestureindex=zeros([1,CorrectGesture]);
for i=1:length(ParticipantTrialText{1,1})
    if contains(ParticipantTrialText{1,1}(i),'Participant')
        Participant=Participant+1;
        Participantindex(Participant)=i;
    end
    if contains(ParticipantTrialText{1,1}(i),'SystemTime')
        SystemTime=SystemTime+1;
        SystemTimeindex(SystemTime)=i;
```

```
    end
    if contains(ParticipantTrialText{1,1}(i),'FirstCar')
        FirstCar=FirstCar+1;
        FirstCarindex(FirstCar)=i;
    end
    if contains(ParticipantTrialText{1,1}(i),'SecondCar')
        SecondCar=SecondCar+1;
        SecondCarindex(SecondCar)=i;
    end
    if contains(ParticipantTrialText{1,1}(i),'CorrectGesture')
        CorrectGesture=CorrectGesture+1;
        CorrectGestureindex(CorrectGesture)=i;
    end
end

%% Orders the data to the correct vehicle (First Car or Second Car)
k=1;
for i=1:FirstCar-1
    if FirstCarindex(i+1)==(FirstCarindex(i)+1)
        SecondCarindex(k)=FirstCarindex(i+1);
        k=k+1;
    end
end
for i=1:FirstCar-(k+1)
    if FirstCarindex(i+1)==(FirstCarindex(i)+1)
        FirstCarindex(i+1)=[];
    end
end
if FirstCarindex(1)<3
    for i=1:length(FirstCarindex)-1
        FirstCarindex(i)=FirstCarindex(i+1);
    end
    FirstCarindex(end)=[];
end
if SecondCarindex(1)<4
    for i=1:length(SecondCarindex)-1
        SecondCarindex(i)=SecondCarindex(i+1);
    end
    SecondCarindex(end)=[];
end


%% Selects the Participant's position, SystemTime, First car data, Second car data and
hand gesture data based on index

ParticipantPosition=ParticipantTrialText{1,1}(Participantindex);
```

```
SystemTimeTime=ParticipantTrialText{1,1}(SystemTimeindex);
FirstCarData=ParticipantTrialText{1,1}(FirstCarindex);
SecondCarData=ParticipantTrialText{1,1}(SecondCarindex);
CorrectGestureData=ParticipantTrialText{1,1}(CorrectGestureindex);

%% Takes out the data without system-time that was written to the file at the start of
UNITY
if trialnumber==1;
   for i=1:length(SystemTimeindex)-1
      NewSystemTimeindex(i)=SystemTimeindex(i+1);
   end
   for i=1:length(ParticipantPosition)-1
      NewParticipantPosition(i)=ParticipantPosition(i+1);
   end
   for i=1:length(Participantindex)-1
      NewParticipantindex(i)=Participantindex(i+1);
   end
else
   for i=1:length(SystemTimeindex)
      NewSystemTimeindex(i)=SystemTimeindex(i);
   end
   for i=1:length(ParticipantPosition)
      NewParticipantPosition(i)=ParticipantPosition(i);
   end
   for i=1:length(Participantindex)
      NewParticipantindex(i)=Participantindex(i);
   end
end

%% Converts the system-time from the UNITY data to the correct format
clear SystemTime
if trialnumber==1
   for i=1:length(SystemTimeTime)-1
      SystemTime{i,1}=SystemTimeTime{i+1,1}(12:end-1);
   end
else
   for i=1:length(SystemTimeTime)
      SystemTime{i,1}=SystemTimeTime{i,1}(12:end-1);
   end
end
for i=1:length(SystemTime)
   dividercounter(i,:)=strfind(SystemTime{i,1},':');
   HH{i,1}=SystemTime{i,1}(1:dividercounter(i,1)-1);
   MM{i,1}=SystemTime{i,1}(dividercounter(i,1)+1:dividercounter(i,2)-1);
   SS{i,1}=SystemTime{i,1}(dividercounter(i,2)+1:dividercounter(i,3)-1);
   MS{i,1}=SystemTime{i,1}(dividercounter(i,3)+1:end);
```

```
end

HH2=str2double(HH);
MM2=str2double(MM);
SS2=str2double(SS);
MS2=str2double(MS);

for i=1:length(HH2)
    HH3{i,1}=cellstr(sprintf('%02d',HH2(i)));
end
for i=1:length(MM2)
    MM3{i,1}=cellstr(sprintf('%02d',MM2(i)));
end
for i=1:length(SS2)
    SS3{i,1}=cellstr(sprintf('%02d',SS2(i)));
end
for i=1:length(MS2)
    MS3{i,1}=cellstr(sprintf('%03d',MS2(i)));
end

for i=1:length(SystemTime)
    NewSystemTime{i,1}=insertAfter(HH3{i,1},2,MM3{i,1});
    NewSystemTime{i,1}=insertAfter(NewSystemTime{i,1},4,SS3{i,1});
    NewSystemTime{i,1}=insertAfter(NewSystemTime{i,1},6,MS3{i,1});
    NewSystemTime{i,1}=cellstr(NewSystemTime{i,1});
    NewSystemTime{i,1}=insertAfter(NewSystemTime{i,1},6,'.');
    NewSystemTime2(i)=str2double(NewSystemTime{i,1});
end

%% Matches the system-time to the data of the First car
ParticipantTimeindex=Participantindex+1;
j=1;
for i=1:length(FirstCarindex)-1
    FirstCarTimeindexindex(j) = find(NewSystemTimeindex==(FirstCarindex(i+1)-2));
    j=j+1;
end
FirstCarTimeindexindex(length(FirstCarTimeindexindex)+1)=find(NewSystemTimeindex
==(FirstCarindex(j)-2));
FirstCarTime=NewSystemTime2(FirstCarTimeindexindex);

%% Matches the system-time to the data of the Second car

j=1;
if SecondCarindex(1)<4
    for i=1:length(SecondCarindex)-2
```

```
        SecondCarTimeindexindex(j) =
find(NewSystemTimeindex==(SecondCarindex(i+2)+3));
        j=j+1;
    end
else
    for i=1:length(SecondCarindex)
        SecondCarTimeindexindex(j) =
find(NewSystemTimeindex==(SecondCarindex(i)+3));
        j=j+1;
    end
end
SecondCarTime=NewSystemTime2(SecondCarTimeindexindex);

%% Sorts the data into X Y and Z for the first car
for i = 1:length(FirstCarData)
    FirstCarStart(i,:)=strfind(FirstCarData{i,1},'[');
    FirstCarEnd(i,:)=strfind(FirstCarData{i,1},']');
end

for i = 1:length(FirstCarData)
    FirstCarPos{i,1}=FirstCarData{i,1}(FirstCarStart(i,1)+1:FirstCarEnd(i,1)-1);
    FirstCarDividerStart(i,:)=strfind(FirstCarPos{i,1},';');
end

for i = 1:length(FirstCarPos)
    FirstCarPosX{i,1}=FirstCarPos{i,1}(1:FirstCarDividerStart(i,1)-1);

FirstCarPosY{i,1}=FirstCarPos{i,1}((FirstCarDividerStart(i,1)+1):(FirstCarDividerStart(i,2
)-1));
    FirstCarPosZ{i,1}=FirstCarPos{i,1}(FirstCarDividerStart(i,2)+1:end);
end

for i = 1:length(FirstCarData)
    FirstCarDivider(i,:)=strfind(FirstCarData{i,1},';');
end

[FCDlength FCDwidth] = size(FirstCarDivider);

if FCDwidth == 10;
    FirstCarSpeed{i,1}=FirstCarData{i,1}(FirstCarDivider(i,9)+1:FirstCarDivider(i,10)-1);
    FirstCarEHMI{i,1}=FirstCarData{i,1}(FirstCarDivider(i,10)+1);
    FCSpeed=str2double(FirstCarSpeed);
    FCEHMI=str2double(FirstCarEHMI);
end

FirstCarX=str2double(FirstCarPosX);
```

```
FirstCarY=str2double(FirstCarPosY);
FirstCarZ=str2double(FirstCarPosZ);

%% Sorts the data into X Y and Z for the second car
for i = 1:length(SecondCarData)
    SecondCarStart(i,:)=strfind(SecondCarData{i,1},'[');
    SecondCarEnd(i,:)=strfind(SecondCarData{i,1},']');
end

for i = 1:length(SecondCarData)
    SecondCarPos{i,1}=SecondCarData{i,1}(SecondCarStart(i,1)+1:SecondCarEnd(i,1)-
1);
    SecondCarDividerStart(i,:)=strfind(SecondCarPos{i,1},';');
end

for i = 1:length(SecondCarPos)
    SecondCarPosX{i,1}=SecondCarPos{i,1}(1:SecondCarDividerStart(i,1)-1);

SecondCarPosY{i,1}=SecondCarPos{i,1}((SecondCarDividerStart(i,1)+1):(SecondCarDi
viderStart(i,2)-1));
    SecondCarPosZ{i,1}=SecondCarPos{i,1}(SecondCarDividerStart(i,2)+1:end);
end

for i = 1:length(SecondCarData)
    SecondCarDivider(i,:)=strfind(SecondCarData{i,1},';');
end

[SCDlength SCDwidth] = size(SecondCarDivider);

if SCDwidth == 10;

SecondCarSpeed{i,1}=SecondCarData{i,1}(SecondCarDivider(i,9)+1:SecondCarDivider
(i,10)-1);
    SecondCarEHMI{i,1}=SecondCarData{i,1}(SecondCarDivider(i,10)+1);
    SCSpeed=str2double(SecondCarSpeed);
    SCEHMI=str2double(SecondCarEHMI);
end

SecondCarX=str2double(SecondCarPosX);
SecondCarY=str2double(SecondCarPosY);
SecondCarZ=str2double(SecondCarPosZ);

%% Sorts the data to make sure the first car was not mistaken for the second car
switchSecondCarSplit=false;
for i=1:length(FirstCarZ)-1
    if abs(abs(FirstCarZ(i+1))-abs(FirstCarZ(i)))>10
```

```
        SecondCarSplit(i+1)=FirstCarZ(i);
        switchSecondCarSplit=true;
    end
end
if switchSecondCarSplit==true
    indexSecondCarSplit=find(SecondCarSplit~=0);
    RemoveSecondCarZFromFirst=FirstCarZ(indexSecondCarSplit:end);
    RemoveSecondCarYFromFirst=FirstCarY(indexSecondCarSplit:end);
    RemoveSecondCarXFromFirst=FirstCarX(indexSecondCarSplit:end);
    RemoveSecondCarTimeFromFirst=FirstCarTime(indexSecondCarSplit:end);

SecondCarZ((length(SecondCarZ)+1):(length(SecondCarZ)+length(RemoveSecondCar
ZFromFirst)))=RemoveSecondCarZFromFirst;

SecondCarY((length(SecondCarY)+1):(length(SecondCarY)+length(RemoveSecondCar
YFromFirst)))=RemoveSecondCarYFromFirst;

SecondCarX((length(SecondCarX)+1):(length(SecondCarX)+length(RemoveSecondCar
XFromFirst)))=RemoveSecondCarXFromFirst;

SecondCarTime((length(SecondCarTime)+1):(length(SecondCarTime)+length(Remove
SecondCarTimeFromFirst)))=RemoveSecondCarTimeFromFirst;
    FirstCarZ(indexSecondCarSplit:end)=[];
    FirstCarY(indexSecondCarSplit:end)=[];
    FirstCarX(indexSecondCarSplit:end)=[];
    FirstCarTime(indexSecondCarSplit:end)=[];
end
%% Pythagorean distance

FirstCarDistance=sqrt((FirstCarX.^2)+(FirstCarZ.^2));
SecondCarDistance=sqrt((SecondCarX.^2)+(SecondCarZ.^2));

%% Plotting the graphs containing the distance of the second car
figure(4)
hold on
plot(FirstCarTime,FirstCarDistance);
hold on
plot(SecondCarTime,SecondCarDistance);
saveas(fig4,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig4name),'fig')
saveas(fig4,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig4name),'jpg')

fig5name=strcat('LeftHandVsDistanceSecondCar',Trials(trialnumber));

format longG
```

```
fig5=figure
yyaxis left
plot(NewTime2,POSLeftHand(:,3))
ylabel('Left Hand Height [m]')
yyaxis right
plot(SecondCarTime,SecondCarDistance);
ylabel('Distance of Second Vehicle to Pedestrian [m]')
saveas(fig5,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig5name),'fig')
saveas(fig5,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig5name),'jpg')
xt = cellstr(num2str(get(gca, 'XTick')'));
xt = insertAfter(xt,2,":");
xt = insertAfter(xt,5,":");
xticklabels(xt)
xlabel('System Time [HH:MM:SS]')
legend('Left Hand height over time','Distance of Second Car to Pedestrian over time')

fig6name=strcat('RightHandVsDistanceSecondCar',Trials(trialnumber));

format longG
fig6=figure
yyaxis left
plot(NewTime2,POSRightHand(:,3),NewTime2,POSRightToe(:,1),NewTime2,POSLeftT
oe(:,1))
ylabel('Right Hand Raise and Participant Steps  [m]')
yyaxis right
plot(SecondCarTime,SecondCarDistance);
ylabel('Distance of Second Vehicle to Pedestrian [m]')
saveas(fig6,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig6name),'fig')
saveas(fig6,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig6name),'jpg')

xt = cellstr(num2str(get(gca, 'XTick')'));
xt = insertAfter(xt,2,":");
xt = insertAfter(xt,5,":");
xticklabels(xt)
xlabel('System Time [HH:MM:SS]')
legend('Right Hand height over time','Distance of Second Car to Pedestrian over time')

%% Plotting the graphs containting the interaction (hand gesture, car behaviour and
step)
fig7name=strcat('InteractionSteps',Trials(trialnumber));
fig7=figure('Position', get(0, 'Screensize'));
subplot(3,1,1);
```

```
plot(NewTime2,POSLeftHand(:,3),NewTime2,POSRightHand(:,3));
title('Hand gesture of participant')
xt = cellstr(num2str(get(gca, 'XTick')'));
xt2 = insertAfter(xt,2,":");
xt2 = insertAfter(xt2,5,":");
xticklabels(xt2)
xlabel('System Time [HH:MM:SS]')
ylabel('Height of Hand in [m]')
legend('Left Hand','Right hand')
subplot(3,1,2);
plot(FirstCarTime,FirstCarDistance,SecondCarTime,SecondCarDistance);
title('Distance of vehicles to participant')
xlim([str2double(xt(1)) str2double(xt(end))])
xticklabels(xt2)
xlabel('System Time [HH:MM:SS]')
ylabel('Distance to pedestrian [m]')
legend('First Car','Second Car')
subplot(3,1,3);
plot(NewTime2,POSLeftFoot(:,1),NewTime2,POSRightFoot(:,1));
title('Step of participant')
xt = cellstr(num2str(get(gca, 'XTick')'));
xt = insertAfter(xt,2,":");
xt = insertAfter(xt,5,":");
xticklabels(xt)
xlabel('System Time [HH:MM:SS]')
ylabel('Footstep distance [m]')
legend('Left Foot','Right Foot')
saveas(fig7,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig7name),'fig')
saveas(fig7,fullfile(strcat(foldernameoriginal,'\Graphs\',Trialsoriginal(trialnumberoriginal))
,fig7name),'jpg')

%% Saving the data to the folder workspace
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGL1
T12'),'ANGL1T12');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGL4
L3'),'ANGL4L3');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLef
tBallFoot'),'ANGLeftBallFoot');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLef
tElbow'),'ANGLeftElbow');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLef
tWrist'),'ANGLeftWrist');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLef
tKnee'),'ANGLeftKnee');
```

```
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLeftHip'),'ANGLeftHip');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLeftAnkle'),'ANGLeftAnkle');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLeftShoulder'),'ANGLeftShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGLeftC7Shoulder'),'ANGLeftC7Shoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGC1Head'),'ANGC1Head');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGT1C7'),'ANGT1C7');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGT9T8'),'ANGT9T8');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGL1T12'),'ANGL1T12');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightWrist'),'ANGRightWrist');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightElbow'),'ANGRightElbow');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightShoulder'),'ANGRightShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightC7Shoulder'),'ANGRightC7Shoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightHip'),'ANGRightHip');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightKnee'),'ANGRightKnee');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightAnkle'),'ANGRightAnkle');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ANGRightBallFoot'),'ANGRightBallFoot');

save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSL3'),'POSL3');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSL5'),'POSL5');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLeftFoot'),'POSLeftFoot');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLeftForearm'),'POSLeftForearm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLeftHand'),'POSLeftHand');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLeftLowerLeg'),'POSLeftLowerLeg');
```

```
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLef
tShoulder'),'POSLeftShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLef
tToe'),'POSLeftToe');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLef
tUpperArm'),'POSLeftUpperArm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSLef
tUpperLeg'),'POSLeftUpperLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSHe
ad'),'POSHead');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSPel
vis'),'POSPelvis');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htFoot'),'POSRightFoot');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htForearm'),'POSRightForearm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htHand'),'POSRightHand');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htLowerLeg'),'POSRightLowerLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htShoulder'),'POSRightShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htToe'),'POSRightToe');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htUpperArm'),'POSRightUpperArm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POSRig
htUpperLeg'),'POSRightUpperLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POST1
2'),'POST12');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\POST8'
),'POST8');

save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIL3'),
'ORIL3');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIL5'),
'ORIL5');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeft
Foot'),'ORILeftFoot');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeft
Forearm'),'ORILeftForearm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeft
Hand'),'ORILeftHand');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeft
LowerLeg'),'ORILeftLowerLeg');
```

```
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeftShoulder'),'ORILeftShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeftToe'),'ORILeftToe');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeftUpperArm'),'ORILeftUpperArm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORILeftUpperLeg'),'ORILeftUpperLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIHead'),'ORIHead');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIPelvis'),'ORIPelvis');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightFoot'),'ORIRightFoot');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightForearm'),'ORIRightForearm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightHand'),'ORIRightHand');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightLowerLeg'),'ORIRightLowerLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightShoulder'),'ORIRightShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightToe'),'ORIRightToe');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightUpperArm'),'ORIRightUpperArm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIRightUpperLeg'),'ORIRightUpperLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIT12'),'ORIT12');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\ORIT8'),'ORIT8');

save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELL3'),'VELL3');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELL5'),'VELL5');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeftFoot'),'VELLeftFoot');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeftForearm'),'VELLeftForearm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeftHand'),'VELLeftHand');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeftLowerLeg'),'VELLeftLowerLeg');
```

```
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeft
Shoulder'),'VELLeftShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeft
Toe'),'VELLeftToe');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeft
UpperArm'),'VELLeftUpperArm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELLeft
UpperLeg'),'VELLeftUpperLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELHea
d'),'VELHead');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELPel
vis'),'VELPelvis');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htFoot'),'VELRightFoot');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htForearm'),'VELRightForearm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htHand'),'VELRightHand');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htLowerLeg'),'VELRightLowerLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htShoulder'),'VELRightShoulder');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htToe'),'VELRightToe');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htUpperArm'),'VELRightUpperArm');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELRig
htUpperLeg'),'VELRightUpperLeg');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELT12
'),'VELT12');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\VELT8')
,'VELT8');

save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\FirstCar
Distance'),'FirstCarDistance');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\FirstCar
Time'),'FirstCarTime');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\FirstCar
X'),'FirstCarX');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\FirstCar
Y'),'FirstCarY');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\FirstCar
Z'),'FirstCarZ');

save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\Second
CarDistance'),'SecondCarDistance');
```

```
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\SecondCarTime'),'SecondCarTime');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\SecondCarX'),'SecondCarX');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\SecondCarY'),'SecondCarY');
save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\SecondCarZ'),'SecondCarZ');

save(strcat(foldernameoriginal,'\Workspace\',Trialsoriginal(trialnumberoriginal),'\NewTime2'),'NewTime2');
clear all
close all
end
```

APPENDIX P: Matlab questionnaire script

```
% QuestionnaireHandler_revised: This script was developed by Michael Ray Epke for
use in his
% MSc Thesis.
% The script loads both pre- and post-experiment data from the separate
% .xls files and performs t-tests and calculates the means and standard
% deviations of the results. As well as plots the graphs depicting the
% ranking that participants gave to the scenarios


clear all
close all

%% Finds and loads boths the pre- and post-experiment .xls files

foldername = pwd;
folderstructure = dir(strcat(foldername,'\FormsData\'));
for i=1:length(folderstructure)
    folderstructure(i).name;
    if contains(string(folderstructure(i).name),'Post-experiment')
        PostE=folderstructure(i).name;
    end
    if contains(string(folderstructure(i).name),'Pre-experiment')
        PreE=folderstructure(i).name;
    end
end
[~,~,RAWPostExperiment]=xlsread(strcat(foldername,'\FormsData\',PostE));
[~,~,RAWPreExperiment]=xlsread(strcat(foldername,'\FormsData\',PreE));

%% Sorts the Questions from Pre and Post questionnaire

PreTrust1=str2double(string(RAWPreExperiment(2:end,29)));
PreTrust2=str2double(string(RAWPreExperiment(2:end,30)));
PreTrust3=str2double(string(RAWPreExperiment(2:end,31)));
PreTrust4=str2double(string(RAWPreExperiment(2:end,32)));

PostTrust1=str2double(string(RAWPostExperiment(2:end,30)));
PostTrust2=str2double(string(RAWPostExperiment(2:end,31)));
PostTrust3=str2double(string(RAWPostExperiment(2:end,32)));
PostTrust4=str2double(string(RAWPostExperiment(2:end,33)));

%% Calculates the mean and standard deviation for the questions from both
questionnaires

PreMeanTrust1=mean(PreTrust1);
PreMeanTrust2=mean(PreTrust2);
PreMeanTrust3=mean(PreTrust3);
```

```
PreMeanTrust4=mean(PreTrust4);

PostMeanTrust1=mean(PostTrust1);
PostMeanTrust2=mean(PostTrust2);
PostMeanTrust3=mean(PostTrust3);
PostMeanTrust4=mean(PostTrust4);

PreSTDTrust1=std(PreTrust1);
PreSTDTrust2=std(PreTrust2);
PreSTDTrust3=std(PreTrust3);
PreSTDTrust4=std(PreTrust4);

PostSTDTrust1=std(PostTrust1);
PostSTDTrust2=std(PostTrust2);
PostSTDTrust3=std(PostTrust3);
PostSTDTrust4=std(PostTrust4);
%% T-tests for all four questions regarding the trust with the pre- and post-experiment
data paired together

[h_1,p_1,ci_1,stats_1]=ttest(PreTrust1,PostTrust1);
[h_2,p_2,ci_2,stats_2]=ttest(PreTrust2,PostTrust2);
[h_3,p_3,ci_3,stats_3]=ttest(PreTrust3,PostTrust3);
[h_4,p_4,ci_4,stats_4]=ttest(PreTrust4,PostTrust4);

%% Sorts the data regarding the feeling of safety from the post-experiment
questionnaire

Safety1=str2double(string(RAWPostExperiment(2:end,2)));
Safety2=str2double(string(RAWPostExperiment(2:end,3)));
Safety3=str2double(string(RAWPostExperiment(2:end,8)));
Safety4=str2double(string(RAWPostExperiment(2:end,9)));

MSafety=[Safety1 Safety2 Safety3 Safety4];

%% T-tests for all questions regarding the feeling of safety from the post-experiment
questionnaire

[h_5,p_5,ci_5,stats_5]=ttest(Safety1,Safety3);
[h_6,p_6,ci_6,stats_6]=ttest(Safety2,Safety4);
[h_7,p_7,ci_7,stats_7]=ttest(Safety1,Safety2);
[h_8,p_8,ci_8,stats_8]=ttest(Safety3,Safety4);
[h_9,p_9,ci_9,stats_9]=ttest(Safety1,Safety4);
[h_10,p_10,ci_10,stats_10]=ttest(Safety2,Safety3);
%% Sorts the data regarding the assurance of being seen by the AV from the post-
experiment questionnaire
Assurance1=str2double(string(RAWPostExperiment(2:end,4)));
```

```
Assurance2=str2double(string(RAWPostExperiment(2:end,5)));
Assurance3=str2double(string(RAWPostExperiment(2:end,10)));
Assurance4=str2double(string(RAWPostExperiment(2:end,11)));

MAssurance=[Assurance1 Assurance2 Assurance3 Assurance4];

%% T-tests for all questions regarding the assurance of being seen by the AV from the
post-experiment questionnaire

[h_11,p_11,ci_11,stats_11]=ttest(Assurance1,Assurance3);
[h_12,p_12,ci_12,stats_12]=ttest(Assurance2,Assurance4);
[h_13,p_13,ci_13,stats_13]=ttest(Assurance1,Assurance2);
[h_14,p_14,ci_14,stats_14]=ttest(Assurance3,Assurance4);
[h_15,p_15,ci_15,stats_15]=ttest(Assurance1,Assurance4);
[h_16,p_16,ci_16,stats_16]=ttest(Assurance2,Assurance3);

%% Sorts the data regarding the lack of eye contact from the post-experiment
questionnaire

EyeContact1=str2double(string(RAWPostExperiment(2:end,6)));
EyeContact2=str2double(string(RAWPostExperiment(2:end,7)));
EyeContact3=str2double(string(RAWPostExperiment(2:end,12)));
EyeContact4=str2double(string(RAWPostExperiment(2:end,13)));

MEyeContact=[EyeContact1 EyeContact2 EyeContact3 EyeContact4];

%% T-tests for all questions regarding the lack of eye contact from the post-experiment
questionnaire

[h_17,p_17,ci_17,stats_17]=ttest(EyeContact1,EyeContact3);
[h_18,p_18,ci_18,stats_18]=ttest(EyeContact2,EyeContact4);
[h_19,p_19,ci_19,stats_19]=ttest(EyeContact1,EyeContact2);
[h_20,p_20,ci_20,stats_20]=ttest(EyeContact3,EyeContact4);
[h_21,p_21,ci_21,stats_21]=ttest(EyeContact1,EyeContact4);
[h_22,p_22,ci_22,stats_22]=ttest(EyeContact2,EyeContact3);

%% Calculates the mean and standard deviations for the questions regarding feeling of
safety, assurance of being seen by the AV and the lack of eye contact

MeanSafety1=mean(Safety1);
MeanSafety2=mean(Safety2);
MeanSafety3=mean(Safety3);
MeanSafety4=mean(Safety4);
MeanSafety=mean(cat(1,Safety1,Safety2,Safety3,Safety4));

stdSafety1=std(Safety1);
```

```
stdSafety2=std(Safety2);
stdSafety3=std(Safety3);
stdSafety4=std(Safety4);
stdSafety=std(cat(1,Safety1,Safety2,Safety3,Safety4));

MeanAssurance1=mean(Assurance1);
MeanAssurance2=mean(Assurance2);
MeanAssurance3=mean(Assurance3);
MeanAssurance4=mean(Assurance4);
meanAssurance=mean(cat(1,Assurance1,Assurance2,Assurance3,Assurance4));

stdAssurance1=std(Assurance1);
stdAssurance2=std(Assurance2);
stdAssurance3=std(Assurance3);
stdAssurance4=std(Assurance4);
stdAssurance=std(cat(1,Assurance1,Assurance2,Assurance3,Assurance4));

MeanEyeContact1=mean(EyeContact1);
MeanEyeContact2=mean(EyeContact2);
MeanEyeContact3=mean(EyeContact3);
MeanEyeContact4=mean(EyeContact4);
meanEyeContact=mean(cat(1,EyeContact1,EyeContact2,EyeContact3,EyeContact4));

stdEyeContact1=std(EyeContact1);
stdEyeContact2=std(EyeContact2);
stdEyeContact3=std(EyeContact3);
stdEyeContact4=std(EyeContact4);
stdEyeContact=std(cat(1,EyeContact1,EyeContact2,EyeContact3,EyeContact4));

%% Sorts the data on ranking of scenarios from the post-experiment questionnaire

SafetyChoiceeHMI=string(RAWPostExperiment(2:end,14));
SafetyChoiceBaseline=string(RAWPostExperiment(2:end,15));
SafetyChoiceComb=string(RAWPostExperiment(2:end,16));
SafetyChoiceHand=string(RAWPostExperiment(2:end,17));

AssuranceChoiceeHMI=string(RAWPostExperiment(2:end,18));
AssuranceChoiceBaseline=string(RAWPostExperiment(2:end,19));
AssuranceChoiceComb=string(RAWPostExperiment(2:end,20));
AssuranceChoiceHand=string(RAWPostExperiment(2:end,21));

EyeContactChoiceeHMI=string(RAWPostExperiment(2:end,22));
EyeContactChoiceBaseline=string(RAWPostExperiment(2:end,23));
EyeContactChoiceComb=string(RAWPostExperiment(2:end,24));
EyeContactChoiceHand=string(RAWPostExperiment(2:end,25));
```

```
PreferenceChoiceeHMI=string(RAWPostExperiment(2:end,26));
PreferenceChoiceBaseline=string(RAWPostExperiment(2:end,27));
PreferenceChoiceComb=string(RAWPostExperiment(2:end,28));
PreferenceChoiceHand=string(RAWPostExperiment(2:end,29));


%% Determiens the ranking of the scenario for the questions regarding the feeling of safety, assurance of being seen by the AV and the lack of eye contact

SafetyChoice=zeros(4,4);
for i=1:26
   if contains(SafetyChoiceBaseline(i),'First')
      SafetyChoice(1,1)=SafetyChoice(1,1)+1;
   end
   if contains(SafetyChoiceeHMI(i),'First')
      SafetyChoice(2,1)=SafetyChoice(2,1)+1;
   end
    if contains(SafetyChoiceHand(i),'First')
      SafetyChoice(3,1)=SafetyChoice(3,1)+1;
   end
   if contains(SafetyChoiceComb(i),'First')
      SafetyChoice(4,1)=SafetyChoice(4,1)+1;
   end
   if contains(SafetyChoiceBaseline(i),'Second')
      SafetyChoice(1,2)=SafetyChoice(1,2)+1;
   end
   if contains(SafetyChoiceeHMI(i),'Second')
      SafetyChoice(2,2)=SafetyChoice(2,2)+1;
   end
    if contains(SafetyChoiceHand(i),'Second')
      SafetyChoice(3,2)=SafetyChoice(3,2)+1;
   end
   if contains(SafetyChoiceComb(i),'Second')
      SafetyChoice(4,2)=SafetyChoice(4,2)+1;
   end
   if contains(SafetyChoiceBaseline(i),'Third')
      SafetyChoice(1,3)=SafetyChoice(1,3)+1;
   end
   if contains(SafetyChoiceeHMI(i),'Third')
      SafetyChoice(2,3)=SafetyChoice(2,3)+1;
   end
    if contains(SafetyChoiceHand(i),'Third')
      SafetyChoice(3,3)=SafetyChoice(3,3)+1;
   end
   if contains(SafetyChoiceComb(i),'Third')
      SafetyChoice(4,3)=SafetyChoice(4,3)+1;
```

```
    end
    if contains(SafetyChoiceBaseline(i),'Fourth')
        SafetyChoice(1,4)=SafetyChoice(1,4)+1;
    end
    if contains(SafetyChoiceeHMI(i),'Fourth')
        SafetyChoice(2,4)=SafetyChoice(2,4)+1;
    end
     if contains(SafetyChoiceHand(i),'Fourth')
        SafetyChoice(3,4)=SafetyChoice(3,4)+1;
    end
    if contains(SafetyChoiceComb(i),'Fourth')
        SafetyChoice(4,4)=SafetyChoice(4,4)+1;
    end
end

AssuranceChoice=zeros(4,4);
for i=1:26
    if contains(AssuranceChoiceBaseline(i),'First')
        AssuranceChoice(1,1)=AssuranceChoice(1,1)+1;
    end
    if contains(AssuranceChoiceeHMI(i),'First')
        AssuranceChoice(2,1)=AssuranceChoice(2,1)+1;
    end
     if contains(AssuranceChoiceHand(i),'First')
        AssuranceChoice(3,1)=AssuranceChoice(3,1)+1;
    end
    if contains(AssuranceChoiceComb(i),'First')
        AssuranceChoice(4,1)=AssuranceChoice(4,1)+1;
    end
    if contains(AssuranceChoiceBaseline(i),'Second')
        AssuranceChoice(1,2)=AssuranceChoice(1,2)+1;
    end
    if contains(AssuranceChoiceeHMI(i),'Second')
        AssuranceChoice(2,2)=AssuranceChoice(2,2)+1;
    end
     if contains(AssuranceChoiceHand(i),'Second')
        AssuranceChoice(3,2)=AssuranceChoice(3,2)+1;
    end
    if contains(AssuranceChoiceComb(i),'Second')
        AssuranceChoice(4,2)=AssuranceChoice(4,2)+1;
    end
    if contains(AssuranceChoiceBaseline(i),'Third')
        AssuranceChoice(1,3)=AssuranceChoice(1,3)+1;
    end
    if contains(AssuranceChoiceeHMI(i),'Third')
        AssuranceChoice(2,3)=AssuranceChoice(2,3)+1;
```

```
    end
     if contains(AssuranceChoiceHand(i),'Third')
        AssuranceChoice(3,3)=AssuranceChoice(3,3)+1;
    end
    if contains(AssuranceChoiceComb(i),'Third')
        AssuranceChoice(4,3)=AssuranceChoice(4,3)+1;
    end
    if contains(AssuranceChoiceBaseline(i),'Fourth')
        AssuranceChoice(1,4)=AssuranceChoice(1,4)+1;
    end
    if contains(AssuranceChoiceeHMI(i),'Fourth')
        AssuranceChoice(2,4)=AssuranceChoice(2,4)+1;
    end
     if contains(AssuranceChoiceHand(i),'Fourth')
        AssuranceChoice(3,4)=AssuranceChoice(3,4)+1;
    end
    if contains(AssuranceChoiceComb(i),'Fourth')
        AssuranceChoice(4,4)=AssuranceChoice(4,4)+1;
    end
end

EyeContactChoice=zeros(4,4);
for i=1:26
    if contains(EyeContactChoiceBaseline(i),'First')
        EyeContactChoice(1,1)=EyeContactChoice(1,1)+1;
    end
    if contains(EyeContactChoiceeHMI(i),'First')
        EyeContactChoice(2,1)=EyeContactChoice(2,1)+1;
    end
     if contains(EyeContactChoiceHand(i),'First')
        EyeContactChoice(3,1)=EyeContactChoice(3,1)+1;
    end
    if contains(EyeContactChoiceComb(i),'First')
        EyeContactChoice(4,1)=EyeContactChoice(4,1)+1;
    end
    if contains(EyeContactChoiceBaseline(i),'Second')
        EyeContactChoice(1,2)=EyeContactChoice(1,2)+1;
    end
    if contains(EyeContactChoiceeHMI(i),'Second')
        EyeContactChoice(2,2)=EyeContactChoice(2,2)+1;
    end
     if contains(EyeContactChoiceHand(i),'Second')
        EyeContactChoice(3,2)=EyeContactChoice(3,2)+1;
    end
    if contains(EyeContactChoiceComb(i),'Second')
        EyeContactChoice(4,2)=EyeContactChoice(4,2)+1;
```

```
    end
    if contains(EyeContactChoiceBaseline(i),'Third')
        EyeContactChoice(1,3)=EyeContactChoice(1,3)+1;
    end
    if contains(EyeContactChoiceeHMI(i),'Third')
        EyeContactChoice(2,3)=EyeContactChoice(2,3)+1;
    end
     if contains(EyeContactChoiceHand(i),'Third')
        EyeContactChoice(3,3)=EyeContactChoice(3,3)+1;
    end
    if contains(EyeContactChoiceComb(i),'Third')
        EyeContactChoice(4,3)=EyeContactChoice(4,3)+1;
    end
    if contains(EyeContactChoiceBaseline(i),'Fourth')
        EyeContactChoice(1,4)=EyeContactChoice(1,4)+1;
    end
    if contains(EyeContactChoiceeHMI(i),'Fourth')
        EyeContactChoice(2,4)=EyeContactChoice(2,4)+1;
    end
     if contains(EyeContactChoiceHand(i),'Fourth')
        EyeContactChoice(3,4)=EyeContactChoice(3,4)+1;
    end
    if contains(EyeContactChoiceComb(i),'Fourth')
        EyeContactChoice(4,4)=EyeContactChoice(4,4)+1;
    end
end

PreferenceChoice=zeros(4,4);
for i=1:26
    if contains(PreferenceChoiceBaseline(i),'First')
        PreferenceChoice(1,1)=PreferenceChoice(1,1)+1;
    end
    if contains(PreferenceChoiceeHMI(i),'First')
        PreferenceChoice(2,1)=PreferenceChoice(2,1)+1;
    end
     if contains(PreferenceChoiceHand(i),'First')
        PreferenceChoice(3,1)=PreferenceChoice(3,1)+1;
    end
    if contains(PreferenceChoiceComb(i),'First')
        PreferenceChoice(4,1)=PreferenceChoice(4,1)+1;
    end
    if contains(PreferenceChoiceBaseline(i),'Second')
        PreferenceChoice(1,2)=PreferenceChoice(1,2)+1;
    end
    if contains(PreferenceChoiceeHMI(i),'Second')
        PreferenceChoice(2,2)=PreferenceChoice(2,2)+1;
```

```
    end
     if contains(PreferenceChoiceHand(i),'Second')
        PreferenceChoice(3,2)=PreferenceChoice(3,2)+1;
    end
    if contains(PreferenceChoiceComb(i),'Second')
        PreferenceChoice(4,2)=PreferenceChoice(4,2)+1;
    end
    if contains(PreferenceChoiceBaseline(i),'Third')
        PreferenceChoice(1,3)=PreferenceChoice(1,3)+1;
    end
    if contains(PreferenceChoiceeHMI(i),'Third')
        PreferenceChoice(2,3)=PreferenceChoice(2,3)+1;
    end
     if contains(PreferenceChoiceHand(i),'Third')
        PreferenceChoice(3,3)=PreferenceChoice(3,3)+1;
    end
    if contains(PreferenceChoiceComb(i),'Third')
        PreferenceChoice(4,3)=PreferenceChoice(4,3)+1;
    end
    if contains(PreferenceChoiceBaseline(i),'Fourth')
        PreferenceChoice(1,4)=PreferenceChoice(1,4)+1;
    end
    if contains(PreferenceChoiceeHMI(i),'Fourth')
        PreferenceChoice(2,4)=PreferenceChoice(2,4)+1;
    end
     if contains(PreferenceChoiceHand(i),'Fourth')
        PreferenceChoice(3,4)=PreferenceChoice(3,4)+1;
    end
    if contains(PreferenceChoiceComb(i),'Fourth')
        PreferenceChoice(4,4)=PreferenceChoice(4,4)+1;
    end
end
%% Plots all the graphs and saves them in graph folder

fig2=figure('Position', get(0, 'Screensize'));
bar(SafetyChoice,'stacked')
ylim([0 26])
yticks([0 2.6 5.2 7.8 10.4 13 15.6 18.2 20.8 23.4 26])
yticklabels({'0%' '10%' '20%' '30%' '40%' '50%' '60%' '70%' '80%' '90%' '100%'})
xticks([1 2 3 4])
xticklabels({'Baseline' 'eHMI' 'Hand' 'Combination'})
title('Ranking of participant feeling of safety to cross')
legend('First choice','Second choice','Third choice','Fourth choice')

saveas(fig2,strcat(foldername,'\Graphs\SafetyRanking'),'fig')
saveas(fig2,strcat(foldername,'\Graphs\SafetyRanking'),'jpg')
```

```
fig3=figure('Position', get(0, 'Screensize'));
bar(AssuranceChoice,'stacked')
ylim([0 26])
yticks([0 2.6 5.2 7.8 10.4 13 15.6 18.2 20.8 23.4 26])
yticklabels({'0%' '10%' '20%' '30%' '40%' '50%' '60%' '70%' '80%' '90%' '100%'})
xticks([1 2 3 4])
xticklabels({'Baseline' 'eHMI' 'Hand' 'Combination'})
title('Ranking of how sure the participants were that the AV would see them')
legend('First choice','Second choice','Third choice','Fourth choice')

saveas(fig3,strcat(foldername,'\Graphs\AssuranceRanking'),'fig')
saveas(fig3,strcat(foldername,'\Graphs\AssuranceRanking'),'jpg')

fig4=figure('Position', get(0, 'Screensize'));
bar(EyeContactChoice,'stacked')
ylim([0 26])
yticks([0 2.6 5.2 7.8 10.4 13 15.6 18.2 20.8 23.4 26])
yticklabels({'0%' '10%' '20%' '30%' '40%' '50%' '60%' '70%' '80%' '90%' '100%'})
xticks([1 2 3 4])
xticklabels({'Baseline' 'eHMI' 'Hand' 'Combination'})
title('Ranking of how strongly the lack of eye contact affected the participants decision to
cross')
legend('First choice','Second choice','Third choice','Fourth choice')

saveas(fig4,strcat(foldername,'\Graphs\EyeContactRanking'),'fig')
saveas(fig4,strcat(foldername,'\Graphs\EyeContactRanking'),'jpg')

fig5=figure('Position', get(0, 'Screensize'));
bar(PreferenceChoice,'stacked')
ylim([0 26])
yticks([0 2.6 5.2 7.8 10.4 13 15.6 18.2 20.8 23.4 26])
yticklabels({'0%' '10%' '20%' '30%' '40%' '50%' '60%' '70%' '80%' '90%' '100%'})
xticks([1 2 3 4])
xticklabels({'Baseline' 'eHMI' 'Hand' 'Combination'})
title('Ranking of which situation the participants prefer when interacting with an AV')
legend('First choice','Second choice','Third choice','Fourth choice')

saveas(fig5,strcat(foldername,'\Graphs\PreferenceRanking'),'fig')
saveas(fig5,strcat(foldername,'\Graphs\PreferenceRanking'),'jpg')

%% Creates matrix containing the data on the Trust question and saves this to
workspace folder

MTrust = [PreTrust1 PostTrust1 PreTrust2 PostTrust2 PreTrust3 PostTrust3 PreTrust4
PostTrust4];
```

```
save(strcat(foldername,'\Workspace\MTrust'),'MTrust');
```

APPENDIX Q: Video, data and script repository

For replication purposes the remaining data, unity files, matlab codes and a video showing a section of the experiment can be found through the following link: https://drive.google.com/open?id=14H-W2YaP_53X2_gDjARarZdYnVfDCnko

APPENDIX R: Literature report

The literature report in this appendix has previously been graded, and it is therefore not subject to the grading of the Master Thesis.

Literature Report

Pedestrian-Automated Vehicle communication

M.R. Epke

4095022
Technical University of Delft
21-05-2019

TU Delft

Literature Report

Pedestrian-Automated Vehicle communication

by

M.R. Epke

As part of the Master Thesis to obtain the degree of Master of Science
at the Delft University of Technology,

.

Student number:	4095022	
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Abstract

Automated vehicles (AVs) are the future of the automotive industry. They are expected to reduce traffic fatalities and change the way how we transport people and goods across the world. However, AVs will not have a human driver responsible for communicating the vehicle's intentions. Therefore, new solutions need to be investigated. Early research focussed on the technology behind AVs, while more recent research focussed on the communication from AV towards the pedestrian. This literature review focusses on the lack of studies about the communication from the pedestrian towards the AV. Moreover, this review tries to gather information about how the lack of eye communication as a form of communicating crossing intent, can be solved by teaching the pedestrian to use hand gestures instead. To do this, the review addresses the current forms of communication between pedestrians and drivers.

In order to provide an accurate view of AVs, the literature review starts by investigating the statistics behind road safety. Topics such as effects of country, gender, age and other influences on traffic fatalities, show the need for automated vehicles. Followed by a short introduction of current AV technology and classification, after which the future trends of automated vehicles are detailed which give the reader better insight into the other effect that AVs might have on our society.

The second part of the review discusses the communication methods of pedestrians, conventional vehicles and automated vehicles. For example, it reviews the various forms of non-verbal communication such as eye contact, gestures and vehicle behaviour, as well as solutions to solve the lack of communication between the driver and the pedestrians. This part of the review provides a detailed understanding of the communication issues and their possible solutions.

The third and final part of the review provides an overview of experimental methods commonly used in research of pedestrian-vehicle communication and AVs. This overview in combination with the previously discussed knowledge, is used to establish a basis for further research into pedestrian-AV communication.

What became clear from a large number of studies into crossing behaviour was that, a lot of the conventional vehicle-to-pedestrian research revolved around non-verbal communication, such as eye contact, hand gestures and vehicle behaviour. It was found that a majority of pedestrians use a form of attention to communicate their intention of crossing, and that a combination of vehicle behaviour and gestures have larger effect than when used separate.

The literature about non-verbal communication, eHMIs, implicit communication and anthropomorphism showed that communication from the AV to the pedestrian can improve feelings of trust of the pedestrian, and therefore provided a preliminary answer to the third question of this literature review. The question however, could not be completely answered, as there is a lack of knowledge about how the feedback of an AV to the pedestrians' communication would affect the pedestrians' crossing decision.

Through this review it became clear that AV literature requires more research about the communication problem between pedestrians and AVs which is caused by the absence of a human driver. As conventional vehicles and pedestrians have an established strategy for communication, the removal of the driver will require a new communication strategy to be developed.

The main part of the literature researched for this review, was selected based on its relation to communication between pedestrians, vulnerable road users, conventional vehicles and AVs. Besides communication, literature has been selected based on usefulness in providing background information.

Contents

1

Current road safety situation

Throughout history technological development has made life easier in a lot of cases. For example, vehicles have improved our way of travelling, by reducing the travel time and by increasing the range of our trips. This improvement of life does come at a price. As more people use cars and other motorised vehicles, the number of road traffic deaths also keeps rising. The World Health Organization (WHO) stated that the number of road traffic deaths reached 1.25 million globally in 2013 [1]. But as can be seen in figure 1.1, the number of road traffic deaths worldwide flattened out between 2001 and 2013. This flattening of the number of road traffic deaths worldwide showed a positive trend for road safety.

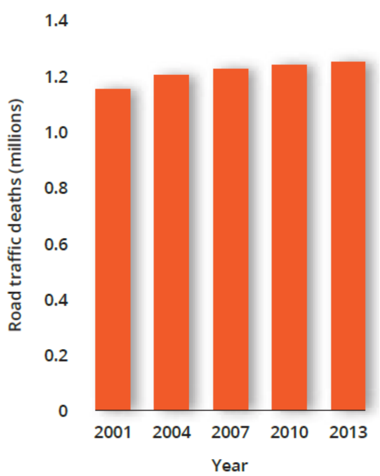

Figure 1.1: Number of road traffic deaths, worldwide, 2001-2013 [1]

1.1. Influence of region on traffic accidents

It is important to investigate the differences between countries and modes of transport involved in traffic deaths. This was done by the WHO in 2015 [1]. As can be seen in figure 1.2, in most of the continents the largest number of road traffic deaths involved car occupants and pedestrians, which corroborates with data provided by the European Union [2] and the United States Government [3]. This result however, strongly depends on the cultural differences and habits of traffic and road use in different countries, as each country might have other needs or preferences when it comes to transportation. [4].

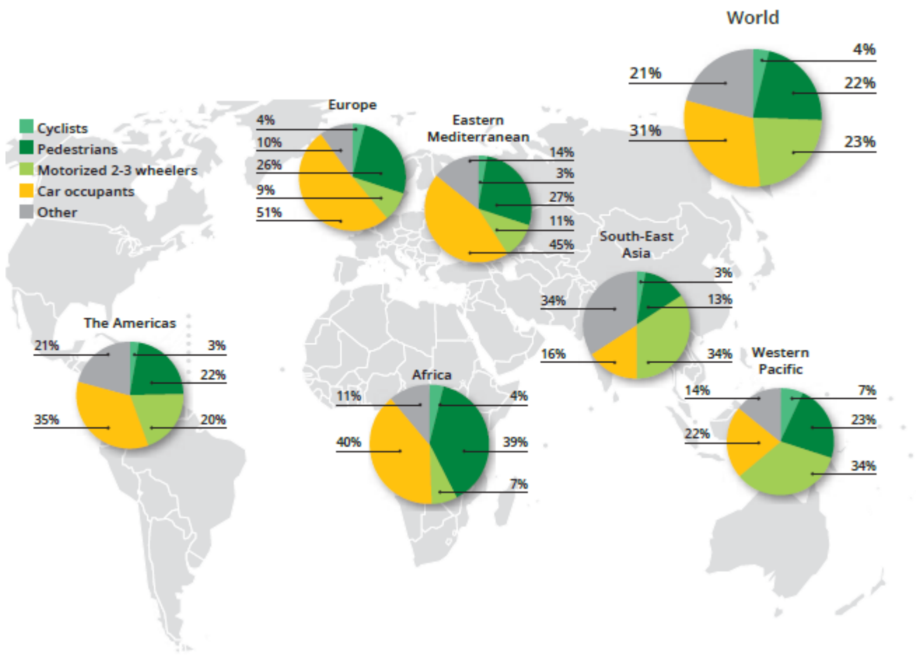

Figure 1.2: Road traffic deaths by type of road user, by WHO region [1]

1.2. Influence of road type on traffic accidents

Besides differences in traffic accidents related to the country or continent, there are also differences on a much smaller level. When looking within a large region such as a country or continent, there are clear differences between road type and their effect on traffic accidents. In March 2009 the RAC foundation published a background paper [5] related to their initial report of 2007. This paper showed the differences between rural roads, urban roads and motorways. As can be seen in figure 1.3, the largest share of road accidents occurred on urban roads.

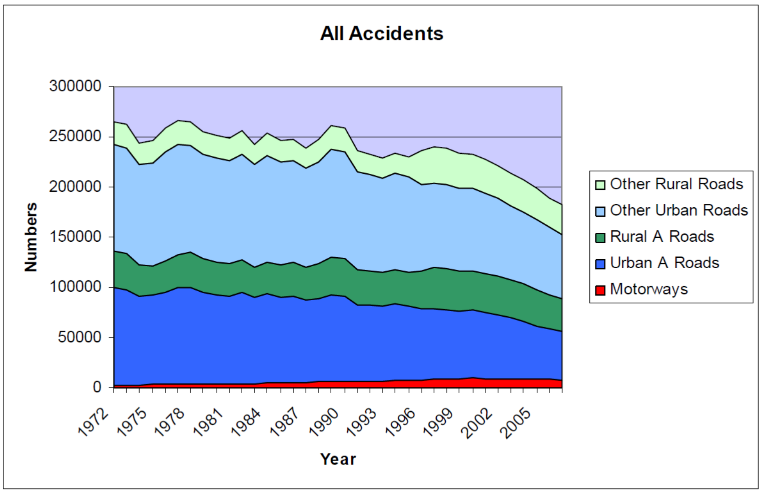

Figure 1.3: Number of accidents per road type [5]

Further research by the European Union [6] showed that the number of urban road fatalities had a share of around 37% of all road fatalities in 2015. This result seems intuitive because there are several modes of transport within close proximity of each other in urban areas. Pedestrians, bicycles, cars and other motorized vehicles often share the same road space, and thus there is a larger possibility of fatal accidents.

1.3. Influence of gender on traffic accidents

When it comes to traffic accidents and deaths, there are also differences between men and women. Researchers found that in Catalonia Spain in most cases men tended to be more risk taking than women, which led to more accidents involving men as the cause [7]. Other data provided by the Dutch Central Bureau for Statistics (CBS) and used by the Dutch Institute for Road Safety Research (SWOV) [8] showed that in the Netherlands in 2006 and 2015 more men were involved in road deaths than women, as illustrated in figure 1.4.

Figure 1.4: Age and gender of road death victims in 2015. The diameter of the circle is related to the number of road death victims [8]

1.4. Influence of age on traffic accidents

Age also plays a role in fatal accidents. The European Commission published a report in which it showed a clear difference in percentage of fatalities per age group. The data [9] in table 1.1 shows that 36% of road deaths happened to people of the age between 25 and 49. This group not only had the largest share of road deaths, it was also the largest share of the total population of the European Union. Another group that had a large share in road deaths is that of people over 65 years old with 25% of fatalities. This group came in second when it comes to the share of fatalities, but only comprised 18% of the total population. On the other hand the group of people aged below 15, had a share of 16% of the total population, but were only involved in less than 3% of all fatalities.

AGE GROUPS: SHARE OF ALL ROAD DEATHS AND SHARE OF TOTAL POPULATION

AGE GROUP*	% OF FATALITIES	% OF POPULATION
<15	<3	16
15-24	17	11
25-49	36	35
50-64	19	20
>65	25	18

Table 1.1: Age groups: Share of all road deaths and share of total population [9]

The difference in fatalities per age group was visible in data from other countries such as the U.S., where the NHTSA published a document containing comparisons of fatalities by gender and age groups [10]. However, a difference could be seen between that of U.S. and Europe. Where in the U.S. there were more road crash fatalities among young people (under 26) and middle aged people (i.e. ages 26 to 50), in Europe middle aged people (i.e. ages 25 to 49) and older people (i.e. ages 50 and older) formed the groups with the most road deaths and largest part of the population. Which again showed the difference in road traffic deaths according to country or continent, as discussed before.

1.5. Influence of risk factors on traffic accidents

As suggested by Habibovic et al. and NHTSA, pedestrians and car occupants are often involved in crashes with each other [11][3]. A possible reason behind this finding could be that pedestrians and drivers often have to interact with each other, for example at pedestrian crossings. Additionally, pedestrians and drivers are not always behaving in the safest way. As Nasar et al. and Hatfield et al. suggested, pedestrians that use a cellphone while participating in traffic show unsafe behaviour which increases the chances of accidents [12][13]. Similarly, jaywalking can lead to collisions [14]. Arguments for this were also found in data from the NHTSA, which published in their Fatality Analysis Reporting System that in the U.S. in 2016, 70.2% of all pedestrians fatalities, occurred at non-intersections, while only 17.6% of pedestrians died due to an accident at an intersection [15].

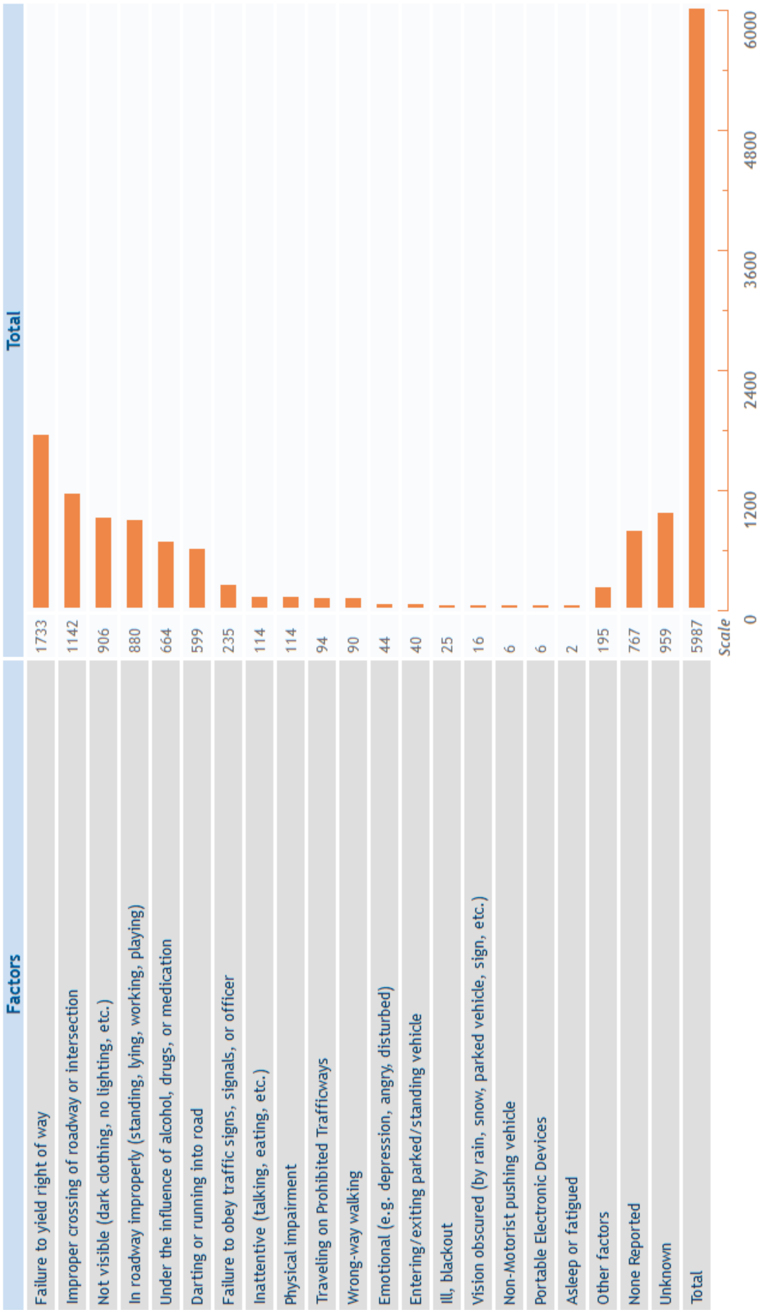

Figure 1.5: Number of pedestrians killed in the U.S. in 2016 by related factors [15]

Figure 1.5, shows the number of pedestrians killed in the U.S. in 2016 by related factors. This figure mostly shows the factors that related to the pedestrian. However, there are also factors that related to the motorised vehicle or location of the accident, such as visibility, vehicle speed, driver sobriety, vehicle or road condition and road design. The European project Safety CaUsation, Benefits and Efficiency (SafetyCube) published their findings [16] about risk factors, and created a taxonomy about road user related risk factors as shown in figure 1.6.

Risky	Probably risky	Unclear
• **Influenced driving – alcohol** • Influenced Driving – drugs (legal & illegal) • **Speeding and inappropriate speed** • Traffic rule violations – red light running • **Distraction – cell phone use (hand held)** • **Distraction – cell phone use (hands free)** • **Distraction – cell phone use (texting)** • **Fatigue – sleep disorders – sleep apnea**	• Risk taking – overtaking • Risk taking – close following behaviour • Insufficient knowledge and skills • **Functional impairment – cognitive impairment** • Functional impairment – vision loss • Diseases and disorders – diabetes • Personal factors – sensation seeking • Personal factors – ADHD • **Emotions – anger, aggression** • Fatigue – Not enough sleep/driving while tired • Distraction – conversation with passengers • Distraction – outside of vehicle • Distraction – cognitive overload and inattention	• Functional impairment – hearing loss (few studies) • Observation errors (few studies) • Distraction – music – entertainment systems (many studies, mixed results) • **Distraction – operating devices (many studies, mixed results)**

Figure 1.6: Taxation of Risky behaviour [16]

The data that we previously reviewed only accounts for traffic accidents and road fatalities, for current modes of transport, such as walking, cycling and driving motorised vehicles. Therefore a large knowledge and data gap exists about the effects of AVs in the current transport network. From the previous reported findings, it becomes clear that interaction between pedestrians and motorised vehicles is of great importance to increasing traffic safety. Therefore, the role of the AV in combination with pedestrians should be researched as well. The following chapter will provide a more in-depth overview of current AV technology and research.

2

Automated vehicles

The previous chapter showed that several factors influence traffic safety and traffic fatalities. A possible solution towards increased traffic safety might be the implementation of AVs to transport people and goods. For most of automotive history and even in the age of horse and chariot, self-driving vehicles were pure science fiction. Recent advances in technology are getting us closer to making self-driving vehicles a reality. While fully automated vehicles are still under development, some form of automation is already present in most cars such as cruise control. This chapter will explain the different levels of vehicle automation, the current technological state of AVs and the potential forms of communication between pedestrians and AVs in the future. Furthermore, in literature many different ways of naming a self-driving vehicle are used, such as Autonomous Vehicle, Self-driving Vehicle and Automated Vehicle. For this literature study however, the use of Automated Vehicle and Automated Driving are preferred.

2.1. Levels of Vehicle automation

As automation occurs on different levels, so are vehicles also divided into levels of automation. This ranges from no automation to full automation, with several levels in between. Each level corresponds to an added degree of automation of the driver tasks. Since research into AVs is still happening, the definitions and number of levels of automation are still being debated. Previously there were several organisations that defined a classification of automation, namely the NHTSA [17], SAE International, BASt [18] and VDA [19]. However, the taxonomy shown in figure 2.1 was published by SAE International [20] in 2014 and later on adopted by NHTSA [21].

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	OEDR		
Driver performs part or all of the *DDT*						
0	No Driving Automation	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	Driver Assistance	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	Partial Driving Automation	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
ADS ("*System*") performs the entire *DDT* (while engaged)						
3	Conditional Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	High Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	Full Driving Automation	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

Figure 2.1: Taxonomy of levels in Driving Automation by SAE International [20]

In the most recent taxonomy of SAE International they chose to divide automated driving over six levels, starting at level 0: No Driving Automation, and ending at level 5: Full Driving Automation. Another often mentioned taxonomy is that of the German Federal Highway Research Institute BASt [18], as shown in figure 2.2, which was published in 2012. However, in more recent articles BASt also adopted the SAE International taxonomy.

Nomenclature	Task of the driver according to automation level	degree of Automation
Fully automated	The system takes over lateral and longitudinal control completely within the individual specification of the application. ▪ The driver <u>need not</u> monitor the system ▪ Before the specified limits of the application are reached, the system requests the driver to take over with sufficient time buffer. ▪ In absence of a takeover, the system will return to the minimal risk condition by itself ▪ All system limits are detected by the system, the system is capable to return to the minimum risk condition in all situations.	↑
Highly automated	The system takes over lateral and longitudinal control for a certain amount of time in specific situations. ▪ The Driver <u>need not</u> permanently monitor the system as long as it is active ▪ If necessary, the driver is requested to take over control by the system with a certain time buffer. ▪ All system limits are detected by the system. The system is not capable of re-establishing the minimal risk condition from every initial state.	↑
Partially automated	The system takes over lateral <u>and</u> longitudinal control (for a certain amount of time and/ or in specific situations). ▪ The driver must permanently monitor the system ▪ The Driver must at any time be prepared to take over complete control of the vehicle	↑
Assisted	The driver continuously accomplishes <u>either</u> lateral <u>or</u> longitudinal control. The other/ remaining task is accomplished by the automating system to a certain level. ▪ The Driver must permanently monitor the system ▪ The Driver must at any time be prepared to take over complete control of the vehicle	↑
Driver only	The driver continuously (throughout the complete trip) accomplishes longitudinal (accelerating /braking) and lateral (steering) control.	

Figure 2.2: Taxonomy of levels in Driving Automation by BASt [18]

Because the taxonomy of SAE International seemed to be the preferred choice in literature, it will also be used in this report as the main taxonomy.

2.2. Brief history of the Automated Vehicle

AVs in various degrees have been in development since 1977 when the Tsukuba Mechanical Engineering Laboratory developed their first AV [22][23], which used a simple method of following markings on the road, in order to stay on the correct path. Later research by Ernst Dickmanns [23][24], the PROMETHEUS Project [23][25] and AHS [23] paved the way for further and more advanced research and development of AVs.

Though the advanced research by Ernst Dickmanns and the size of the PROMETHEUS project have helped start the rapidly increasing development of AVs, other projects smaller in size or less known such as CARSENSE, AHSRA, CHAMELEON, ARCOS, CarTALK 2000, INVENT and PREVENT have also been important. These however, usually did not last for a long time or did not gain large attention.

With the competition fuelled research "Grand Challenge", funded by The Defense Advanced Research Projects Agency (DARPA), the interest and scope of AV research sparked new life [26]. The effects of the "Grand Challenges" and others, can be seen in the rapid evolution of the technology and the rules for deployment. As DARPA states, "ten years later defense and commercial applications are proliferating." [27]. The rapid evolution of Automated Driving technology was already visible within the competition itself. As in the first edition of the Grand Challenge, none of the contestants finished, 18 months later five contestants were able to complete the challenge. For a third edition two years later, DARPA decided to increase the difficulty by hosting their challenge in an urban setting, instead of a desert, and implementing traffic regulations. This did not stop the contestants, as 6 out of 11 teams successfully completed the challenge, thus showing that the technology behind Automated Driving was rapidly improving. Currently there are multiple companies, organisations and universities that are developing AVs, both on the road and in the laboratory.

2.3. Currently under development or on the road

Several companies, organisations and universities are working on AVs, with some of their prototypes and even actual products already on the road. Each company has its own approach to developing Automated Driving features, and research is at different stages. The following are some of the companies and their models that currently have some Automated Driving features

- Tesla Autopilot
- Google self-driving car (WAYMO)
- Uber-Toyota
- Mercedes Benz F015/E-class/S-class
- WEpods
- BMW 5 / 7 series
- Volvo XC60
- Cadillac CT6
- Audi A8
- Lexus LS
- Nissan Leaf
- Smart vision EQ fortwo
- Acura RLX

A study done by Habibovic, Englund and Wedlin in 2014 concluded that while some car manufacturers are working on partly and even highly automated vehicles, the next step for many manufacturers is to introduce highly automated vehicles (level 4 and 5) to the real world [28]. Three examples of companies that are already doing this are Tesla [29], Waymo and the Uber-Toyota fleet of AVs [30].

2.4. Communication between automated vehicles and vulnerable road users

Other than studying and developing the technology behind automated driving, several universities and companies are also investigating possible forms of communication between AVs and pedestrians [31][32][33][34]. There is strong need for research into new communication strategies for pedestrians and AVs [35], because current pedestrian-driver communication relies on implicit communication, such as eye contact and posture. In the case of AVs, there is no implicit communication between pedestrian and driver, because the driver wouldn't be in control of the vehicle or there wouldn't be a driver in the vehicle at all.

In the case that implicit communication (i.e. messages that are understood but not clearly expressed) is not available, or the behaviour of approaching vehicles is not as expected, the road users involved apply explicit communication such has hand gestures [36]. Lack of implicit communication, however, poses a large problem, as Keferböck and Riener stated “One of the problems not brought up by autonomous vehicle manufacturers so far is when the “strongest” road user (vehicle or truck) is no longer human-driven as then the chance for vulnerable road users (VRUs) to communicate, interact and negotiate could be evicted too.” [37]. Therefore, a new communication strategy is needed, allowing pedestrians to communicate with AVs. The following chapter will briefly discuss other effects that AVs will have on future society, and show that communication will become increasingly more important in a world where all traffic is automated.

3

Prospect of the future

With the growth of studies focusing on automated driving, some current and future trends become clearer. Past studies mainly focused on the workings of AVs and defining the levels of automation, while current research concerns the reduction of accidents, communication between vehicle users, non-users and the vehicle itself, as well as research into reaching full automation. However, the trends for future research and use of AVs are still largely unknown, as researchers can only speculate, extrapolate current data and come up with experiments to estimate the possible trends. Based on the increasing number of scientific literature about reduction of traffic, fuel consumption, Greenhouse Gas (GHG) reduction, legislation, vehicle sharing, parking, use of travel time, ethics and cybersecurity, it can be speculated that these topics will be significantly important in future research. Therefore, this chapter will discuss some of these topics and trends in relation to the future of AVs. Though not entirely related to communication, this chapter will show that AVs will become an integral part of society, and thus humans will possibly have an increasing need of communication with AVs.

3.1. Reduction of traffic, fuel consumption and Greenhouse gas

As the world population keeps increasing, and more people gain access to motorised transport, the driving space on roads decreases and air pollution increases due to an increase of exhaust gases from motorised vehicles. However, some might argue that governments are building more and bigger roads, and that car manufacturers keep improving their engines to decrease air pollution. The fact is however, that more people have access to motorised vehicles, which counteracts these improvements. The use of AVs could potentially solve the problem of increasing pollution and decreasing driving space, because AVs are able to plan their trip more effectively by constantly communicating their status and obtaining that of others within a network of AVs and smart infrastructure [38]. This traffic optimisation allows the infrastructure (i.e. traffic lights) to calculate optimal arrival time and communicate this back to the vehicle, which in turn can reduce its speed to avoid waiting and minimise congestion. This traffic optimisation also allows for the use of fewer vehicles on the road.

Another solution to minimise traffic jams, decrease fuel consumption and decrease GHG emission is the formation of platoons of AVs. As AVs are able to drive more organised and closer to each other than human drivers are, AVs are able to form a platoon of vehicles that significantly reduces fuel consumption since drag is reduced [39], and thus also reduces vehicular pollution [40]. Secondary beneficial effects of platooning include increased safety [41], as the process of vehicle overtaking is coordinated by communication between all vehicles within the platoon, and possibly other vehicles and nearby infrastructure, as illustrated in figure 3.1. Therefore, the vehicle is continuously connected to its surroundings. In their research Tsugawa et al. stated that "this topic is important because truck platooning is likely to be one of the earliest applications of road vehicle automation to be commercially viable"[42].

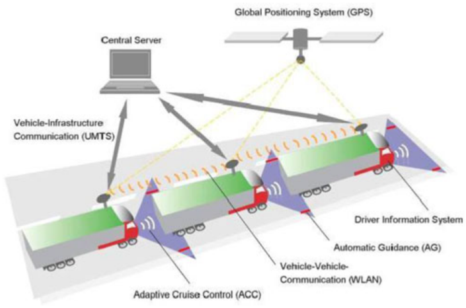

Figure 3.1: Platooning according to KONVOI [42]

Both previously mentioned solutions include or rely on vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) communication. Therefore, AVs need a method to communicate within 100 ms [43], which requires data networks such as long-term evolution (LTE), device-to-device (D2D) and fifth-generation (5G) communications. The topic of fast data networks, is currently an important trend, and can be expected to become increasingly more important in the future, as governments and tech companies are already actively discussing and pursuing the deployment of 5G infrastructure [44][45]. This will not only change automated driving, but other aspects of society as well.

3.2. Vehicle sharing, parking and the use of travel time

In the second half of the 20th century and the beginning of the 21st century, cars became more common, and in some societies even taken for granted. At the beginning of the 20th century, however, cars and other motorised vehicles were luxury items, or symbols of societal status. This change might be reverted or increased as Bengler et al. stated "The consequences of this trend are not yet clear. It could lead to the possession of a vehicle becoming increasingly less important in the course of increasingly rational choice of transport. Or it could promote an increasing emphasis on design features in a car to help it regain its function as a symbol of societal status." [46]

The importance of vehicles in our society is not only limited to how we value them, but also includes how we use them. There is a high probability that AVs will become more common as a form of commuting and that will not only have an effect on how we commute, but it will also affect how we deal with vehicle ownership. A new way of commuting might take shape in the form of car-sharing, as AVs allow travellers to use the same vehicle on-demand without owning it. As the growth of on-demand ride-sharing (Uber, Cabify, Lyft) is still quite recent, and AVs are not yet widely commercially available, the literature about this topic is scarce. The future of this trend, therefore remains uncertain [47]. However, Fagnant and Kockelman developed a simulation in which they investigated the potential of dynamic ride-sharing (DRS) from which they found that ride-sharing and DRS could reduce the number of conventional vehicles and vehicle-miles travelled (VMT) [48].

AVs might have another effect on commuting besides car ownership. Because AVs will have the capability of driving themselves, they allow the users to focus their attention on other tasks than driving. Therefore, the AV could be used in a similar way as current public transport methods. A study by Steck et al. found that automated driving can reduce the value of travel time savings (VTTS), which is similar to how much money commuters are willing to spend on saving time commuting. This relates to public transport in-vehicle time [49]. This suggests that commuters perceive the travel time in AVs as more useful to do other things, and have less need to save time on their trip. However, this does not mean they will spend more time working during their trip. A survey conducted by Cyganski et al. showed that 69% and 77% of respondents never work during long-distance and short-distance trips respectively, and only 6% to 8% work frequently or always during their commute [50].

Besides vehicle ownership and use of travel time, AVs are also expected to affect the need for parking space and reduce the time it takes to park the car. As AVs will not only be able to drive themselves, they will also be able to park themselves without any passenger or driver being present in the vehicle. Besides the time it takes to park the car, AVs would have implications on commuter time, as the vehicle would drop its passengers off at their destinations, and continue to park itself in an available parking space. Therefore, AVs can also impact land use, as parking space close to the destination is not necessary any longer [46]. Moreover, the trend of decreased need for land use will most likely also be stimulated by ride-sharing, because AVs won't need to be continuously parked until needed by their owners.

3.3. Cybersecurity, ethics and legislation

As trends in communication and connectivity are becoming more popular and common, their dangers and lack of security are also becoming clearer within society. Hackers and cyberterrorists have generated awareness of the importance of cybersecurity in AVs [51]. Especially in the case of AVs since AVs will require the use large amounts of data for communication. Moreover, the lack of adequate security related to connectivity, exposes the vehicle to both internal and external cyber threats. These range from high to low impact threats, in which for example, the driving capabilities of the AVs could be taken over or affected by attackers. The loss of control over the vehicle could result in potentially fatal accidents, as the driver might not be able to regain control of the vehicle on time [52]. To prevent large scale vulnerabilities in the future, new legislation needs to be developed which require AVs to be equipped with proper security measures.

In case of unauthorised take over or dangerous situations, the vehicle needs to be able to make decisions on which potential action would have the best possible outcome. Decision making, however, is not as straightforward as it seems, as ethics play a large role in the process. The problem lies in unavoidable crashes, because, in some cases there is no clear best choice for the vehicle to make. In some cases people will certainly get killed or property will get damaged, which leads to the question: who or what is less valuable, and thus better to hit? This dilemma raises another question: who is responsible for the outcome of the decision? Is it the vehicle, the driver, the victim or the programmer [53]? Similar to the topic of cybersecurity, ethical decisions about AVs need to be legislated in order to prevent confusion and grey areas.

What becomes clear from this chapter is that if AVs and Shared AVs become common within our society, governments (local, regional and national) need to create laws for the use of them. Not only laws concerning safety and ethics, but also laws about taxation, communication, licensing and business models such as ride-sharing [54]. In order to achieve a safe, sustainable and affordable future in which the majority of society has access to AVs, the need for appropriate legislation will become critical.

After having provided more in-depth knowledge about AVs, the following chapter will go into the topic of conventional vehicle communication. The following chapter allows for a better understanding of the current communication situation, and what will be lacking in pedestrian-AV communication.

4

Conventional vehicle-to-pedestrian (V2P) and pedestrian-to-vehicle (P2V) communication

In the future, pedestrians and AVs may be sharing the road with conventional vehicles and may to be able to communicate with each other. The way AVs and pedestrians will communicate will most likely take on a different form than current communication methods used by pedestrians and drivers. The reason for this is that interactions will not be between two humans, as in the current case between pedestrians and driver, but between a human and an automated system. As Straub and Schaeffer said, "Participants in the traffic systems are like a couple coordinating their movements across the dance floor – they use a combination of prescribed steps (e.g., rules on the road) and social norms (e.g. proximity, movement and turn- taking paradigms) ingrained with non-verbal communication (e.g., eye contact and other signals) to guide their individual actions and reactions from moment to moment in time with mood and music (e.g. environmental inputs)." [55]

Since humans have been "coordinating this dance" for many decades, they have become accustomed to these norms and steps. However, as the interaction between AVs and humans on the public road is still under development, humans have not yet experienced, developed and adopted any prescribed steps or social norms. However, several studies are already investigating the transition from no AVs in traffic to AVs sharing the road with other road users [31][56][32][35].

While some researchers are focussing on the transition period, others are studying the communication forms from AV to pedestrian through the use of external Human Machine Interfaces (eHMIs) and implicit communication. It is probable that both research in eHMI and implicit communication will have a significant impact on the implementation of AVs in the traffic systems, and that they will aid to establish new prescribed steps and social norms for interaction between AVs and pedestrians.

4.1. Eye contact and looking direction

Communication between conventional vehicles and pedestrians is a topic widely studied during the past decades, with researchers looking at both sides of the communication, from the driver to the pedestrian and vice versa. Though several studies were done on the use of eye contact between pedestrian and drivers [36][57][58][59][60], they did not lead to the same conclusion. For example, Dey and Terken said that their results indicated, that eye contact and gestures were not significantly important. [36]. During their experiment, they found that explicit communication was mainly used in cases when the approaching vehicle deviated from its expected behaviour.

However, other researchers have stated the opposite. For example a study performed by Ren et al. found that eye contact increased the Time To Collision (TTC) and decreased the occasions in which the driver had to brake drastically. Both TTC and braking frequency improve pedestrian safety [58]. Müller et al. suggested that pedestrians or road users establish eye contact with other road users to rapidly negotiate who has right of way. During this negotiation Müller et al. suggested that the exchange of information could occur in the form of a small wave, nod or a smile in combination with eye contact, to either negotiate who gets priority or to confirm mutual attention [59]. This paper however, does not refer to any data or experiment, and its conclusion is therefore disputable.

A further study by Rasouli et al. showed that gazing in the direction of the vehicle, instead of eye contact with the driver had a significant share in communicating the pedestrians intention of crossing. The study concluded that "more than 90% of pedestrians use some form of attention to communicate their intention of crossing". Of these forms of gaining attention, gazing or looking in the direction of the vehicle are the most important. [60].

4.2. Hand gestures

Another form of explicit communication between pedestrians and drivers that was briefly mentioned in the previous chapter is gestures. A gesture can be conducted in several ways, for example through the use of hand motions to movements with the head such as nodding or shaking. Dong et al. stated that speech and gestures are capabilities that come natural to humans, and thus especially hand shapes are useful for communicating different instructions [61]. One problem with hand gestures is that movement, environmental properties and distance make it difficult to recognise gestures. Therefore researchers such as Dong et al. are working on gesture recognition methods.

Gupta et al. discussed another problem with gestures, namely that they are difficult to interpret due to cultural variations [62]. Their study aimed to "formalise hand signals applied by officers"[62], in order to test their hypothesis that "a universally accepted set of gestures can be identified form the rules used by traffic control officers to direct road traffic."[62] Finding a gesture that is internationally recognised and has the same meaning everywhere, seems crucial for the effectiveness of communication between pedestrians and drivers, and especially when AVs will need to recognise gestures to anticipate the pedestrians' crossing intentions. Besides the assumed international differences in gestures , differences in the effectiveness of various gestures on yield rate is also currently investigated.

Each culture has its own set of gestures with their own level of effectiveness in conveying the intention of the driver or pedestrian. A study done by Zhuang and Wu investigated the yielding rate of drivers for several gestures. The study was done by exposing thirty-two drivers to a pedestrian displaying eleven different gestures signifying the driver to halt. The gestures are shown in figure 4.1, and were taken from several sources, namely they were either adapted from internet news, obtained through daily observations in Beijing China, copied from a paper by Crowley-Koch et al. (2011). Furthermore, some gestures used in the study are originally used in a different context than driver-pedestrian communication and are used to show praise, respect or accompany a request. The authors also combined gestures and included a gesture that is often used to represent "stop, terminate, and halt" in sports [63]. The researchers used a questionnaire containing six point Likert scale questions in combination with open questions. The questionnaire contained the following questions:

- Q1. Can you see pedestrian clearly?
- Q2. What do you think his/her gesture means in the current context?
- Q3. How definite is the gesture in conveying the meaning you answered in Q2?
- Q4. How often do you see this gesture on the road?
- Q5. Is the pedestrian commanding or politely asking someone to do something?
- Q6. What are you most likely to do in this case?

The researchers concluded that four of the eleven gestures (i.e., G1, G3, G6 and G11) scored higher for visibility, clarity and familiarity. In order to validate this result, the four gestures and a baseline situation were used in a field experiment including 500 drivers [63]. The participants (i.e. the drivers) were divided over 5 sites across China. Each driver was randomly presented with one of the four gestures or the baseline by the experimenters who posed as pedestrians wanting to cross the road. The results of this field experiment led the researchers to conclude that out of the four gestures, only gesture G3 (i.e., the "L-bent-level") significantly increased yielding rate.

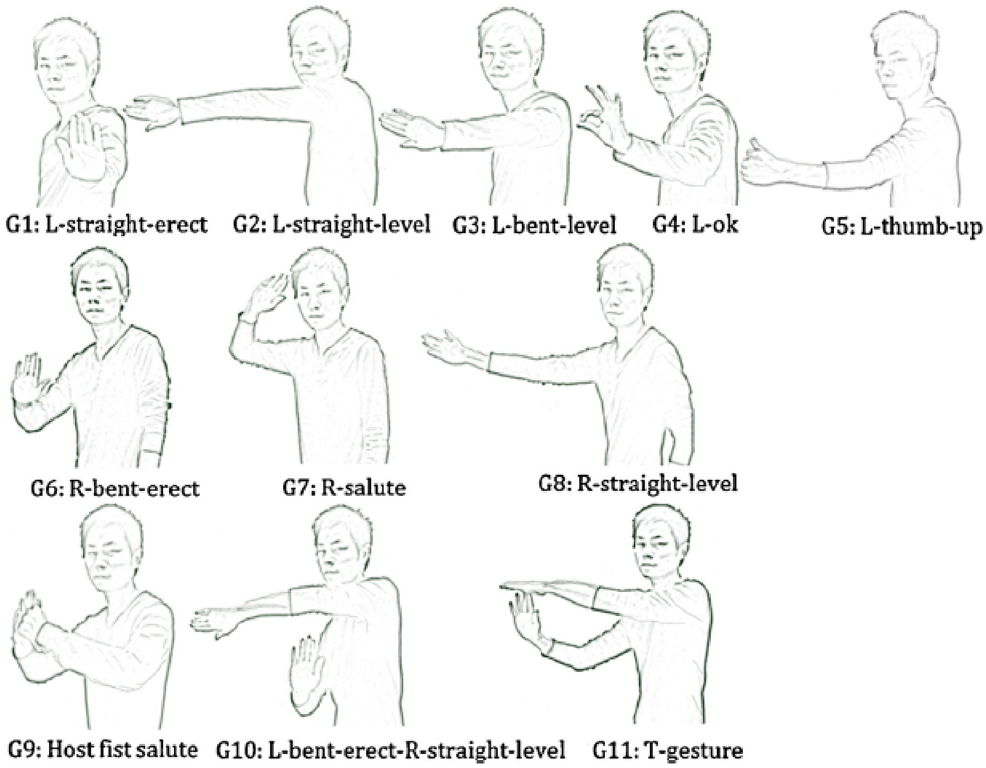

Figure 4.1: Illustration of eleven hand gestures [63]

4.3. Vehicle behaviour as a form of communication

Aside from eye contact and gestures, another form of communication that is used between drivers and pedestrians is vehicle behaviour. As vehicles can be interpreted as an extension of the driver's body, the driver can use the vehicle movement or behaviour as a way to communicate with the pedestrian. This was taken into account when Kitazaki and Myhre studied non-verbal communication and its effect on decisions and confidence.

Their experiment did not focus on a wide range of gestures, but more generally on non-verbal communication. The experiment focused especially on the behaviour of the car and the effect of hand gestures, rather than which hand gesture is more effective. The conditions consisted of constant speed (baseline), speeding up, slowing down, stop hand gesture combined with speeding up, and go hand gesture combined with slowing down. They concluded that the combination of behaviour and gesture has a larger effect than solely behaviour or gestures alone. However, both behaviour and gestures separately also affect pedestrians yielding decisions and confidence [64]. Implicit communication such as vehicle behaviour will be discussed in more detail in the next chapter.

This chapter showed that explicit communication plays a large role in pedestrian-vehicle interaction, and that the transition to automated vehicles can lead to a problem, because there will be no driver for the pedestrians to communicate with. The following chapter will discuss the communication from the automated vehicle towards the pedestrian in order to show possible methods of future communication between AVs and pedestrians.

5

Automated vehicle-to-pedestrian (AV2P) communication

In order to fill the previously mentioned gap in communication that is caused by the lack of driver-pedestrian communication, AVs need to take on the role of communicator to convey their intentions to pedestrians. Since some AVs lack a human-like body, humanoid robot, humanoid avatar or actual human in the driver seat, they need to rely on other methods to communicate, because pedestrians won't be able to rely on cues like eye contact and gestures. A study done by Lundgren et al. shows the importance of driver-pedestrian communication. They performed an experiment where 13 participants encountered scenarios involving manually driven vehicles. The behaviour that the driver and vehicle showed was varied among these scenarios For example, in one of these scenarios the driver pretended to be distracted by a cell phone or newspaper.

The results of their study showed that participants would not cross the road without any form of confirmation from the driver if they saw that the driver was distracted. Along with these results Lundgren et al. showed that "All pedestrians (N = 13 of 13) stated that (eye) contact with the driver, and the behaviour of the driver in general, made the greatest difference in their experience." [35]. The following chapter will therefore, discuss in more detail the importance of further research on automated vehicle-to-pedestrian (AV2P) interactions, and various forms that are currently being studied.

5.1. The interaction between automated vehicles and vulnerable road users

As mentioned in previous chapters, the number of AVs on the road is minimal. With 62 companies allowed to test AVs (although not without a driver) in the state of California as of January 2019 [65], and 50 companies in March 2018 [66], therefore, it can be estimated that the number of AVs on the road will increase rapidly during the next decade. Nevada and California are at the forefront of AV testing, since they both adopted policies regulating the testing of AVs and possible licensing of AVs in 2011 and 2012 [67][68] respectively.

However, California and Nevada might not be realistic references for the scale of testing and deployment of AVs on public roads, since both states usually experience ideal weather for testing AVs in comparison to other parts of the United States and the rest of the world. Furthermore, the fact that Google (Waymo), Apple, Uber and other companies in the field of AVs are situated in Silicon Valley and the rest of California, makes California more an experimental hub than a realistic preview of what to expect during the transition period in which pedestrians will have no or few interactions with this new type of vehicle. For most of the people living outside of California and Nevada, encounters with AVs are not yet everyday experiences, and Hancock et al. stated that "driverless vehicles are the ultimate strangers in our midst. They currently lack the required etiquette to operate as human beings do"[69]. Therefore, several studies [56][31] are focusing on the interaction between AVs and vulnerable road users, especially on the crossing behaviour and negotiation between AVs and pedestrian.

Two experimental methods in particular are applied in studies focussing on pedestrian crossing behaviour and negotiation between drivers and pedestrians. Wizard-of-Oz experiments are used to investigate the crossing behaviour of pedestrians when pedestrians encounter the "rare" AV during this transition period in which we will find ourselves in the next few years. A Wizard-of-Oz experiment is a type of experiment in which pedestrians are being deceived into thinking that they are interacting with an AV. In fact, the AV is not automated but operated by a disguised researcher. The researcher controls the system in a way that it seems the prototype is operating by itself [70]. The practicality of a Wizard-of-Oz experiment is that it allows the researchers to perform their studies in a realistic or naturalistic environment outside of laboratory or simulation environments [71]. Another benefit of Wizard-of-Oz experiments is that the experiments often can be performed without permission from legal authorities or additional legislation, since the experiment is not different from other non-proxy experiments and therefore usually does not break any rules for safe experimentation.

Wizard-of-Oz experiments are commonly used in AV research because there is no need for additional legislation, since the driver of the vehicle will always be present, and thus the vehicle remains in fact manually driven. Rodríguez Palmeiro et al. used this method to study whether the intended behaviour of pedestrians differed depending on vehicle type (traditional vehicle vs AV). In their experiment they exposed participants to situations in which either an “automated vehicle” or a “traditional vehicle” would drive along the road towards the pedestrian. In the scenarios with the AV the person in the driver seat was either reading a newspaper or driving without having their hands on the steering wheel.

Another variation among the scenarios was the sign used to indicate whether the vehicle was an AV. The participants were asked after each scenario and after the experiment if they perceived the vehicle to be an AV or not, and whether they trusted the vehicle to stop for them if they would make the decision to cross, or not. The experiment included a measurement of the critical gap, as the participant was asked to indicate when they would not cross the road any longer, with relation to the speed and distance of the vehicle. Rodriguez et al. concluded that the majority of their participants did not feel equally safe or sure about their decision to cross when interacting with an AV compared to when they were interacting with a traditional vehicle [31].

Another study that used the Wizard of Oz methodology was conducted by Habibovic et al. in which they compared pedestrian experience with regards to AVs in a controlled crossing situation. In which they used a similar situation to that of Rodriguez et al. to assess the willingness of pedestrians to cross the road. From the pedestrians’ willingness and answers to an interview, researchers could deduct their emotional experience and perceived safety in these situations. The results from their experiment show that “pedestrians’ willingness to cross the road decrease with an inattentive driver.” [56].

What both studies (i.e. Rodríguez Palmeiro et al. and Habibovic et al.) discussed was that eye contact with the driver might have a positive effect on the decision making of the pedestrians. This positive effect however, was only discussed and not concluded as certain. For example in the experiment of Habibovic et al. the researchers found that eye contact between driver and pedestrian led to calm interaction. Rodríguez et al. speculated that the feelings of unsafety could be caused by the lack of eye contact with the driver. According to Keferböck and Riener eye contract is the most common method of human drivers to communicate information [37].

However, it was Rothenbücher et al. who were the first to propose and use the Wizard-of-Oz method in their study to investigate how pedestrians and bicyclists would interact when encountering an AV without driver. Their experiment involved pedestrians and bicyclists who were unaware of the experiment before experiencing the encounter. After the encounters the researchers asked the participants if the car behaved as they expected an AV to behave. From their 22 participants, 19 answered the researchers that it did behave as they expected, while 2 participants did not have any expectations and there was only one participant who answered that the vehicle did not behave as expected. This, however, was not the main result from their experiment. The main result from the experiment was that participants had higher expectations that the AV would eliminate human error, but in contrast they were more forgiving of the AV for misbehaviour [32].

5.2. Using an external Human-Machine Interface as a means to aid driver-pedestrian communication

As mentioned in the previous subchapter, there is also a second method used in studies focussing on the crossing behaviour and negotiation. The second method is immersing the participant in a virtual world. This is done with the use of virtual reality (VR) glasses and even motion capturing equipment such as suits and/or motion tracking cameras. The use of VR in AV and eHMI research will be discussed in this subchapter.

One example of a study using VR to study eHMIs is that of de Clercq who for his master thesis developed a virtual world in which his participants could move around and experience interactions with three different vehicle types, each fitted with a different type of eHMI. Besides the type of vehicle and type of eHMI, de Clercq also studied the timing at which the eHMI changed and yielding behaviour of the vehicle. He found that the addition of an eHMI to a vehicle increased the time participants felt safe to cross when they encountered vehicles having an eHMI [72].

In his study de Clercq tried out three different eHMIs, namely (1) frontal braking lights, (2) a LED bar and (3) a display to show either a message or a smiley. Though the study of Ackermann et al. concluded that direct instructions, such as text, are preferred over information about the vehicle [73], there is not enough evidence that text-based messages are the solution to solving automated vehicle-pedestrian communication. Thus, several research groups are continuing studying various forms of eHMIs, as is shown in figure 5.1. Matthews et al. for example used LED light strips and word displays on a golf cart to communicate intent towards the pedestrians [74]. While Hwang et al. suggested using the external surface of the car such as windscreen, chassis and tail lights as displays to convey messages from the driver/passenger to other road users [75].

Besides vehicle mounted displays and LED bars, another method of displaying messages is used by Suwa et al. They propose the use of "LED Projection Module" [76]. The idea behind this method is that the vehicle projects a message onto the road surface ahead of the vehicle to inform pedestrians of its intent, or to provide suggested actions such as cross or stop. Though this method has its flaws, such as lack of visibility during daylight, it has also been used in concept designs by Mercedes such as the Mercedes-Benz F-015 [77].

A study by Fridman et al. showed the extent of eHMI forms. They used their study to assess 30 designs, in which they vary between the location of the eHMI, type of the eHMI and message displayed by the eHMI. For example their study contains eHMIs in which a text or symbol is displayed on the windscreen of the vehicle, where the driver originally is situated. Also using the grill of the vehicle to display animations or arrows is assessed. Using lights such as LED bars or driving lights to show intent was also part of the study by Fridman et al., as well as projections of colours, symbols and text on the road ahead. The researchers found that with all designs, though in varying degree, the messages led to uncertainty and misinterpretation. Therefore, the participants were also trained in the understanding the intended meaning of the messages, after which all participants were able to correctly assess the intention, except for the designs in which the intended message was that the vehicle operated in automated mode [78]. This suggests that finding the optimal eHMI design is not the sole solution to the problem of communication between pedestrians and AVs, but as well is training the population to correctly understand the intended message of the eHMI.

Figure 5.1: various forms and designs of eHMI [77][79][75][34][78]

Besides pedestrians' understanding of intention, studies also investigated feelings of trust, comfort and safety of pedestrians in encounters with AVs equipped with eHMIs. Böckle et al. found that AVs with an interface improved perceived comfort and safety of pedestrians over AVs without interface [79]. Though most of the studies do raise the believe that eHMIs improve the participants' understanding of intent and feelings of trust, comfort and safety, there are also studies that suggested that eHMIs are merely of secondary importance when it comes to the pedestrian making the decision to cross the road. Clamann et al. for example found that though helpful, the eHMIs are less important than distance, speed and traffic density [34]. This, however, should not dismiss the use of an eHMI to convey messages, as they should be considered alongside other measures of informing the pedestrian.

5.3. Anthropomorphism of automated vehicles as a replacement of driver-pedestrian communication

While many studies focus on eHMIs as displays attached to vehicles to show messages, symbols or animations to pedestrians, Chang et al. were one of the first to deviate from this type of eHMI. They proposed a vehicle with eyes and was called "Eyes on a Car." The eyes as shown in figure 5.2 followed the pedestrian, and thereby made eye contact as a form of non-verbal communication possible. The researchers reason to propose a vehicle with eyes was that pedestrians should be able to detect the intention of AVs. They performed a VR experiment in which participants used a VR headset. The pedestrians experienced a virtual world in which the car (with eyes) would establish eye contact in order to communicate.

Using a questionnaire, the researchers discovered that: "All the participants noticed the eyes on the car in the VR simulation, while 80% of participants noticed the movement of the eyes and 66.7% of them noticed the behaviour of the eyes in part 1. In addition, 100% of participants noticed the eyes on the car and their movement, while 86.7% of participants noticed the behaviour of the eyes in part 2"[80]. Part 1 refers to participants discovering the eyes by themselves and part 2 refers to participants discovering the eyes after being given a hint. The use of human-like features is rare in this type of studies, as most companies (with the exception of Jaguar LandRover [81]) and institutes studying eHMIs have focused on other types of eHMIs.

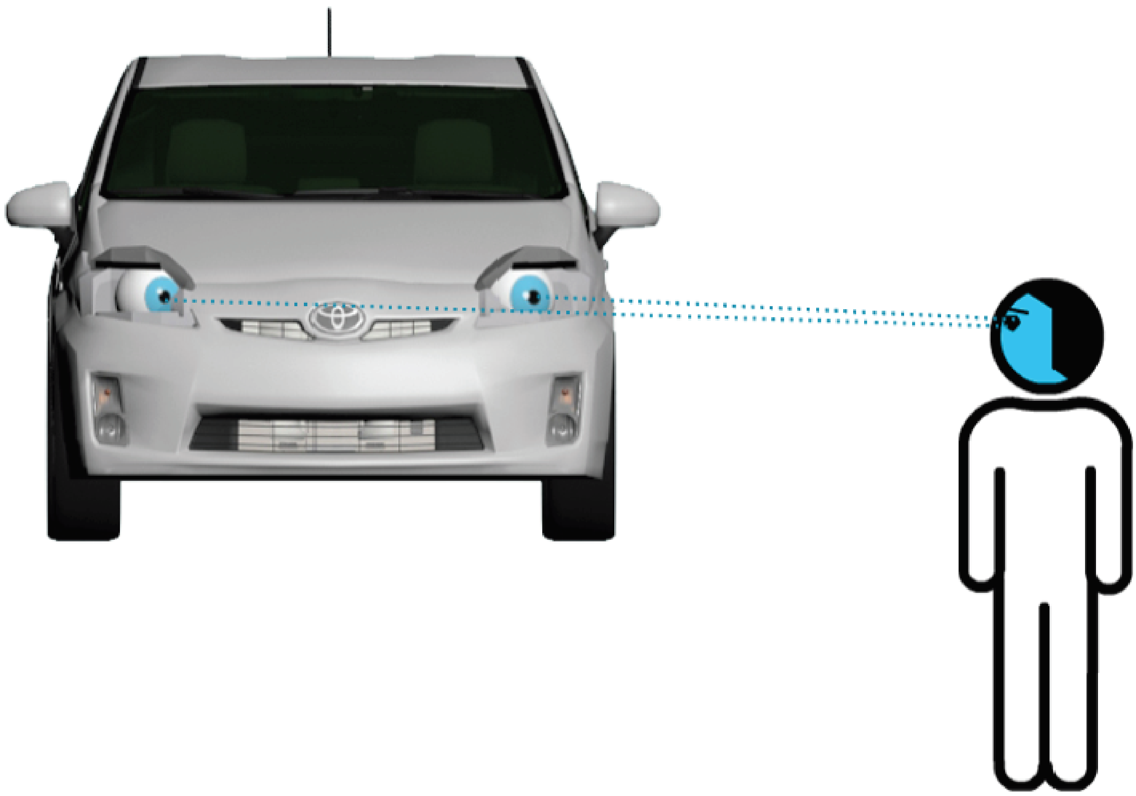

Figure 5.2: A form of anthropomorphism "Eyes on a Car"
[80]

However, Chang et al. is not unique in suggesting or applying anthropomorphism in AVs. Mahadevan et al. suggested that physical cues also enhance visual cues, and suggest that an actuated hand could be used to signal to the pedestrian [82]. However, overall they found that information from interfaces in combination with vehicle movement accounted for the largest improvement. In a literature study done by Farber, he mentions a project at MIT, where they have built a prototype vehicle that has "eyes" as shown in figure 5.3. The vehicle could look at a pedestrian in order to communicate that the pedestrian had been spotted [83].

Another form of anthropomorphising the AV is discussed by Mirnig et al. who among one of their strategies for communication, propose the idea of a social robot as the driver of the vehicle [84]. This method would lead to communication between the pedestrian and the "social robot" who would take the place of the human driver. Besides their method of placing a social robot in the driver seat they also mention two other strategies, namely, machine-like communication as in using the windshield as a screen for pedestrians, and anthropomorphising the car to use its features such as the grill to create a face, and its side mirrors as "arms" to provide the pedestrian with gestures. However, the method in which the social robot takes place in the driving seat needs further research. This is order to see how the system would function if the driving task remains within the car, and the robot merely functions as a communication interface for the pedestrians.

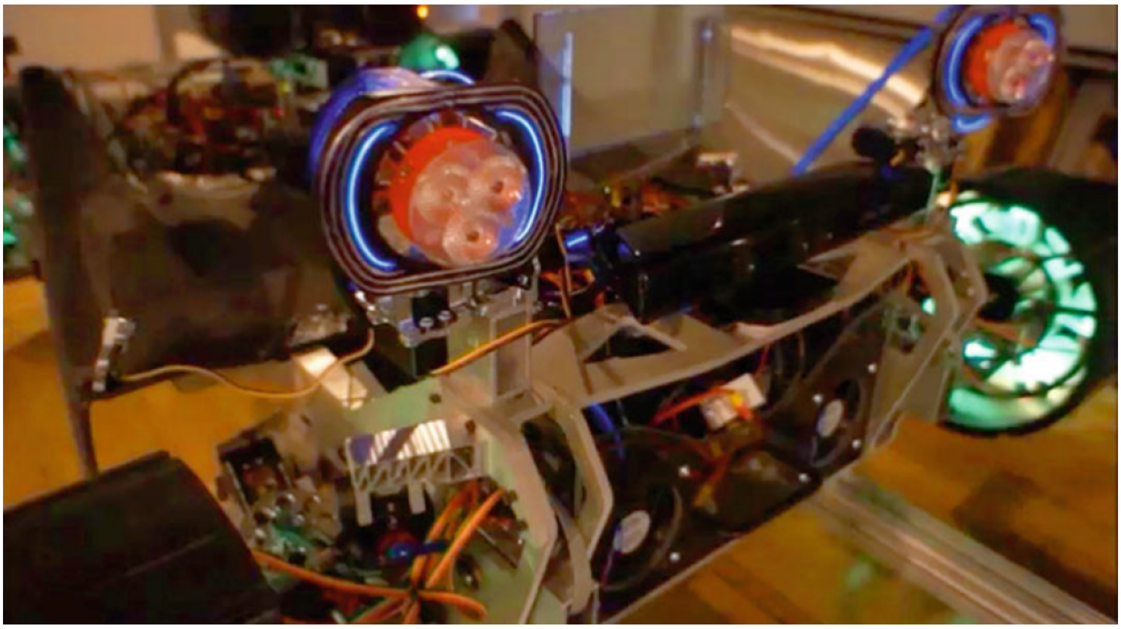

Figure 5.3: Research at MIT with anthropomorphism
[83]

Waytz et al. investigated the trust people put in anthropomorphised AVs. Their study focused on the side of the driver or passenger but could be extended to pedestrians as well. Their study consisted of a driving simulator in which participants would either drive a normal car, AV or an anthropomorphic AV. They predicted that the self-driving capability of the vehicle would make it seem mindful, and that human-like qualities such as looks, and name would increase this feeling even more. Through their experiment they confirmed their predictions, as most of the pedestrians had higher overall trust in the anthropomorphic vehicle and self-driving vehicle than in the normal vehicle. Besides trust they found that participants blamed the anthropomorphic vehicle and self-driving vehicle less than the normal car in case of an accident [85].

As stated previously, some benefits may occur when anthropomorphising vehicles in order to let them communicate with humans. However, some studies advise caution or state the disadvantages. Florentine et al. for example mention in their research that in applying anthropomorphism, which leads to human-like features, some humans may get confused or misled when interacting with these vehicles [86] . Because humans might expect or associate certain capabilities such as full human understanding from anthropomorphic vehicles, they might put unwarranted trust in them. Amongst the opponents of anthropomorphism is Duffy who stated that "Anthropomorphism should not be seen as the "solution" to all human-machine interaction problems but rather it needs to be researched more to provide the "language" of interaction between man and machine" [87]. He bases this conclusion on research by others such as Shneiderman and Nass and Moon.

Shneiderman explains that tools should not be overly anthropomorphised but their design should be intuitive to what the tool is supposed to do. Otherwise the design could be vague or its functions/behaviour unpredictable [88]. Nass and Moon discussed a different problem in their paper and stated that people have the tendency to “mindlessly apply social rules and expectations to computers” [89]. Applying social rules and expectations to computers could lead to unpredictability, unwarranted trust and disappointment, as the “computers” will most likely not perform as expected in all situations. Although Duffy, Shneiderman, Nass and Moon talk about robots instead of AVs, their research might still apply to AVs as well. Duffy in his paper raised the question what the ideal set of human features is that would lead to optimal anthropomorphism, and where anthropomorphism would go too far.

5.4. Implicit communication in the form of vehicle movement

Besides eHMIs to communicate intent to pedestrians, other forms of communication are also part of the interaction between pedestrians and AVs, such as implicit communication. Implicit communication occurs when the message content is not directly heard but “hidden” in the message [90]. Implicit communication is the way in which a vehicle, human or robot communicates its intention through movement or subtle changes in behaviour. While “explicit” communication as for example eHMIs or break lights and blinkers is observed directly and understood more easily, the context of implicit communication can have the same or even higher importance in making a decision to cross the road.

Recent studies found that, while pedestrians are able to make the decision to cross with only implicit communication [32], they do suggest that a combination of implicit and explicit communication is preferred [82][91][92]. As Dey and Terken even stated that “Pedestrians do not appear to rely on explicit communication to convey their intentions in current traffic situations involving manually driven cars, and in extension it is fair to conclude that the lack of explicit communication will not become a cause of roadblock for autonomous vehicles in the future.” [36] Another argument for the importance of implicit communication is the fact that pedestrians value receiving feedback from the driver, or in this case the AV, and are unwilling to cross when feedback is not provided [35].

Though several studies found that implicit communication or vehicle behaviour is sufficient information for pedestrians to make a crossing decision, others have found the opposite results. For example, Kitazaki and Myhre found that vehicle behaviour without explicit communication was not enough for pedestrians to make a decision [64], they did state that in combination with hand gestures, it would be enough to make a decision.

While implicit communication might sound as a valuable form of negotiation between road users, it is limited by what message is conveyed, since the vehicle is only able to use signals such as stopping, continuing, changing direction or by giving preference or taking it [91][93][94].

Within this limited range of “messages” is the variation of appropriateness or effectiveness of these messages, as Ackermann et al. stated that for example “deceleration is the more appropriate implicit communication solution compared to accelerations.”[95] Part of the reason behind this is possibly that people expect behaviour like that of good human drivers from AVs, meaning that the vehicle would drive as they say that they drive, such as clear communication in sufficient time before crossing, and smooth driving behaviour [96]. As it becomes clear from these studies, implicit communication is important but should not be seen as a easily implemented solution for AVs, as Beggiato et al. said “braking initiation for automated vehicles cannot be based on a single time-to-contact-value for all speeds. In order to be “naturally” perceived as informal signal by pedestrians, brake initiation needs to be adjusted according to the speed-dependent time gap curves.” [97]

As shown in this chapter, the variation of experimental methods is subject to what type and what specific topic the research is about. It is therefore, important to do a literature review about the different research methods, before developing an experiment and setup. The following chapter will discuss the two methods mentioned in this chapter, and add another form, in order to provide a clear overview before concluding this literature review and starting the follow up study.

6 Experimental methods

Previous chapters have shown that there is a great need for research into (automated) vehicle-pedestrian communication. This need will continue for many decades, certainly until AVs have proven to be safe and fully implemented in society. Choice of methods and tools used in research seems to be varying throughout the field, as some researchers prefer to use either surveys, Wizard-of-Oz, (VR) simulators or any other form of experimental method, and on the tool level either mainly rely on the answers from a questionnaire or the data received from measurements to base their results on. This chapter will discuss some of the methods that are commonly used in vehicle-pedestrian communication research.

6.1. Wizard-of-Oz studies

One of the most common methods when it comes to automated vehicle-pedestrian communication is the use of a Wizard-of-Oz study [31][56][32][35]. Wizard-of-Oz means that a pedestrian interacts with a system, in this case a vehicle, that seems to be operating autonomously without the control of an operator or "wizard" (such as a driver), while in fact the system is secretly being controlled by an operator/wizard [98]. A possible setup for such a Wizard-of-Oz vehicle is shown in figure 6.1. The benefit and in some cases necessity of Wizard-of-Oz is to understand how drivers or pedestrians will act when encountering or driving AVs, without the exposure to dangerous situations or the use of expensive or hard to obtain AVs [99].

Wizard-of-Oz studies were first used in language experiments in which they found that in dialogues, users adapted to the language of the person they were speaking with. Because communication with already developed natural language interfaces is useful until a certain level, it becomes clear that studies about human communication with experimental natural language interfaces are very valuable for further research and development. This is where Wizard-of-Oz shows its importance, because it allows humans to communicate with experimental interfaces without the actual existence or use of these systems. However, the use of Wizard-of-Oz is not the sole method that should be used in research, but merely a useful preliminary study for developing future communication methods [100].

On the negative side of Wizard-of-Oz is that when the process becomes too complex, it can become difficult or impossible to provide a fluent and believable Wizard-of-Oz experience for the pedestrian [101]. In general the use of Wizard-of-Oz is recommended for preliminary studies or in situations in which use of a real AV is too expensive, difficult, unethical, dangerous or not yet possible.

Figure 6.1: Inside of Wizard-of-Oz vehicle [33]

6.2. Virtual Reality studies

Another popular method in automated vehicle-pedestrian studies is the use of a simulator or virtual reality (VR) as shown in figure 6.2 [72][37][102][80][79][96][103]. The use of VR and simulators is a method in which participants are placed in situations which in real life are dangerous or costly to create. The difference between VR studies and studies where the participant is only subjected to a screen, is the immersion of the Virtual World. The use of VR comes with a lot of benefits compared to real-life experiments, because Virtual Reality lets the participants experience potentially dangerous situations without having to leave the laboratory. However, the problem with VR is that participants may behave differently because they realise that they are in a Virtual World.

In order to evaluate if VR is a viable method, without the previously stated problem, is to do experiments to find if participants behave the same as in real life. One research group that focused on this was Doric et al. who asked their participants “to rate realism of the simulator” [104]. Their results confirmed that pedestrians would act the same in both the real world experiment as in the virtual experiment, confirming the realism of the simulator.

Another problem that VR experiments for automated vehicle-pedestrian studies are currently facing is that the participant interacts with a preprogrammed vehicle, and that variations such as other drivers or participants are not part of the experiment. This limits the realism and influence of external factors on the experiment [105]. However, so far the benefits outweigh the negatives, as Feldstein et al. stated that VR “enables a reproducible, safe and relatively cost-efficient way to evaluate pedestrian behavior in urban environments.” [106] This study by Feldstein et al. not only stated the advantages, but also presented an idea for connecting driving simulators to pedestrian simulators, which solves the problem previously mentioned by Lehsing et al.

Because perception of reality is a large factor in VR research, a lot of studies involve the effect of realism and impact on the usability and user experience. Brade et al. conducted an experiment in which participants were asked to explore and compare the real and virtual city centre of Chemnitz, Germany. When participating in the Virtual Reality part of the study, the participants were asked to step into a Cave Automatic Virtual Environment (CAVE) which is a room in which the virtual world is projected onto the world. From their study they concluded that virtual worlds should be considered as a valid alternative to real-world experiments for evaluating products such as AVs [107].

The combination of motion capturing equipment enhances the interaction and realism of the VR experiment. For example, the study of Lehsing et al. used motion capturing suit to capture the movement of the participant to allow the participant to move within the virtual work. While Lehsing et al. applied motion sensors, Feldstein et al. and Brade et al. used motion cameras to do the same, this however limits the movement field to the area in which the cameras are placed, instead of the possibility to move around anywhere the participant wants, such as is possible with motion capture suits like Xsense as used by Kooijman [103].

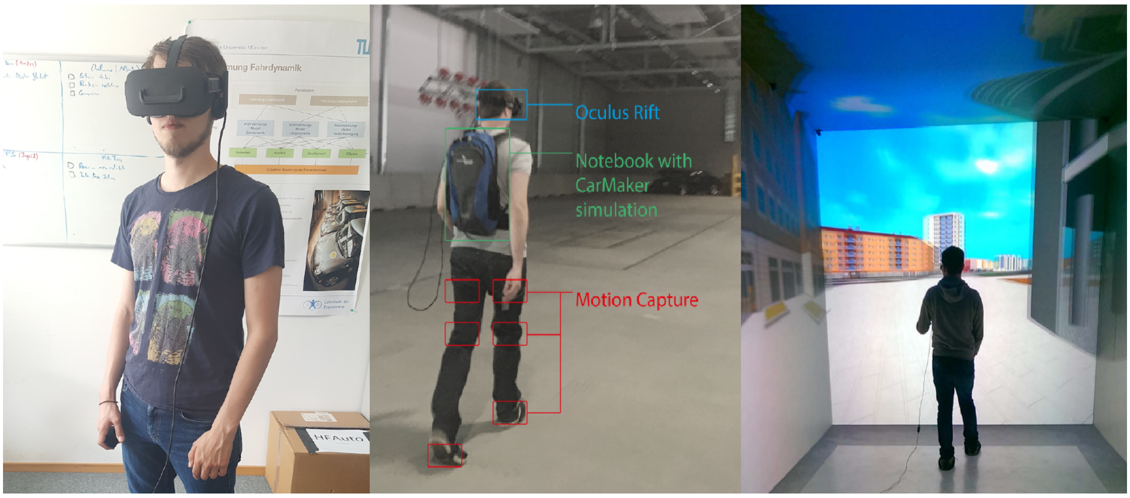

Figure 6.2: Three different VR setups [72][104][107]

6.3. Surveys, photo studies and crowdsourced experiments

Common misconception is that surveys and questionnaires are the same. This might be because questionnaires are generally used in surveys, but this is not always the case. Slattery et al. described questionnaires as the tools to perform surveys which are general methodologies for the collection and processing of information about certain populations [108]. Surveys can also be measurements, in which for example the number of cyclists passing through a certain tunnel during the morning traffic is counted. In this case the cyclists are not asked to fill in a questionnaire but just counted.

Questionnaires are also not only limited to surveys but can be used in a wide variety of other experimental methods, for example in the field of vehicle-pedestrian communication using Wizard-of-Oz or VR simulators [31][32][103]. The benefits of questionnaires and surveys are that they can be large scale or small scale, and that they are cost and time effective. But they should mainly be used as a starting point for research before applying more in-depth research methods such as VR and Wizard-of-Oz [109].

The problem with questionnaires and surveys is that they generally require the participant to have previous experience, knowledge or understanding about the concept or the topic of the study. The reason for this becomes clear from van der Kint et al. who found that the use of static images could lead to different behaviour of the participant from that in the real world. Because for example the static images do not provide the participants with enough information about the real situation (speed, acceleration, depth) [110]. This could thus also be the case for questionnaires which only use text to gather and provide information.

Another problem with questionnaires is that the researcher has to decide between open and closed questions, which both have their strength and weaknesses. The strength of open questions is that they allow participants to place fill-in answers, this however requires the researcher to do additional data processing, while closed questions limit the amount of data that needs to be processed, but also limits the answers participants could provide [108]. This could be compensated by using video or photo studies combined with eye tracking, this way the data about fixation and dwell times complements the gathered data from the questionnaire [110]. In general the advice would be to use questionnaires and surveys as a beginning before more in-depth research [109].

A variation of traditional surveys and photo studies is the use of crowdsourcing to engage a large group of participants to perform an experiment. The experiment is performed online and thus has the potential to reach a large group of participants. It allows researchers to gather large amounts of data without participant recruitment.

7 Discussion

The goal of this literature review was to gather knowledge that could answer questions about the communication between pedestrians and AVs. Questions such as why communication between pedestrians and AVs is important, and what will change in the communication when the AV does not have a driver that the pedestrian can communicate with. Aside from these two questions, the literature review also hoped to find how communication from the AV to the pedestrian would affect the pedestrians' decision making and overall feeling during encounters with AVs.

In order to reach the goal of this review, the structure of this report needed to provide a basis such as knowledge about the statistics of road safety and the taxonomy, history and future of AVs to introduce the reader to the topic of AVs. After creating a basis, the interaction between traditional vehicles and pedestrians was provided, which showed how pedestrians communicate their intentions to drivers of conventional vehicles. The review also included knowledge about communication from the AV to the pedestrians, in order to provide a complete view of communication between pedestrians and AVs. The review ended with an overview of experimental methods commonly used in AV research, to help determine which experimental method is best suited to research these subjects. In this chapter the findings of the previously stated basis are discussed.

Statistics showed that the increase of technology did improve traffic safety. However, because of the increase of the world population, the number of yearly road fatalities has not yet decreased. Because more people gained access to motorised transportation, the effect of improved technology has not yet reached the desired trend. Part of this was found in the influence of region, age and risk factors such as cellphone use in traffic. Literature showed that the majority of road traffic fatalities around the world were car occupants, but this, however, was not the case for all continents. Part of this continental or regional difference was also found in the different age groups that were involved with road traffic deaths, as there was a clear difference between U.S. and Europe. In the U.S. the majority consisted of young and elderly, while in Europe the majority consisted of middle-aged people. The data clearly showed that safer motorised vehicles could prevent fatalities relating car occupants. Since AVs are in theory safer than conventional vehicles, they form a solution for decreasing traffic fatalities.

Initial papers about AVs showed that research has been gaining rapid momentum since around the 90s and the start of this millennium, partially due to several competitions and large-scale projects. Research groups such as the PROMETHEUS project and DARPA not only documented early research, but also showed the evolution of AV research. A review of more recent research showed the large number of companies that are working on AVs and technologies or topics related to AVs.

Aside from focusing on research centred on the workings of AVs and their implications for traffic safety, this review also provided a look into the possible trends that can come from future AVs. Several scientific papers have been published about the effects that AVs could have on reduction of traffic, fuel consumption and greenhouse gas emissions. These papers showed that platooning and V2I/V2X communication can play a large role in future mobility, as they could reduce traffic, fuel consumption and greenhouse gas emissions. These, however, are not the only topics that will be of importance in the future, as vehicle sharing, parking, the use of travel time, cybersecurity, ethics and legislation will most likely also be of importance in future AV research.

These findings showed that AVs can form a solution to solve existing problems with regard to traffic safety and pollution due to motorised vehicles. However, the use of AVs in traffic can also cause problems in communication between pedestrians and AVs, as the lack of a driver can change the way pedestrians communicate and are communicated to. The problem created by the lack of a driver answered the first question of this literature review "Why is communication between pedestrians and AVs important."In order to answer the other questions related to the goal of this report, the literature review investigated the communication between pedestrians and drivers of conventional vehicles, communication from AVs to pedestrians, as well as crossing behaviour of pedestrians. This led to the following results.

What became clear from a large number of studies into crossing behaviour was that, a lot of the conventional vehicle-to-pedestrian research revolved around non-verbal communication, such as eye contact, hand gestures and vehicle behaviour. It was found that a majority of pedestrians use a form of attention to communicate their intention of crossing, and that a combination of vehicle behaviour and gestures a have larger effect than when used separately. Nevertheless, the use of hand gestures still requires further research, because of the lack of knowledge about their effect on communication between pedestrians and AVs. Part of this lack of knowledge comes from the difficult interpretation due to cultural variations. However, it can be concluded that non-verbal communication such as hand gestures can be an effective form of communicating crossing intent of the pedestrian to the AV. Therefore, the study following this literature review should involve hand gestures as the method of communication. This however, showed that the second question of this literature review could not be answered based on the literature used found, and that a gap in the literature was found on what would change in communication from pedestrian to AV in comparison to communication from pedestrian to the driver of a conventional vehicle.

The main body of this literature review explored the importance of filling the gap that would be caused by the lack of driver-pedestrian communication. From the papers reviewed for this research it became clear that eye contact with the driver aids the pedestrian in making crossing decisions, and that lack of eye contact, could cause feelings of lack of safety for the pedestrian. The use of gestures to communicate crossing intent to the AV could therefore increase the feeling of safety to the pedestrian, as it provides the pedestrian with a replacement for the lack of eye contact. Besides the effect of non-verbal communication on crossing behaviour, it was found that participants had high expectations that AVs would reduce accidents. However, the participants were more willing to forgive the AV for mistakes it made, compared to a human driver making mistakes.

In order to fill the gap left by the lack of eye contact, several studies have focused on new ways of communicating intentions from the vehicle to the pedestrian. The majority of these studies focused on external Human-Machine interfaces. Most of the researchers that focused on new ways of communicating intentions from the vehicle to the pedestrian, concluded that eHMIs can improve understanding of intent and feelings of trust, comfort and safety. There are, however, some researchers that concluded that the use of eHMIs is only of secondary importance, and thus should be used in combination with vehicle behaviour, similar to the recommendation of a combination between gestures and vehicle behaviour for conventional vehicles.

Besides eHMIs, this review also provided information about the use of anthropomorphism and implicit communication in the form of vehicle movement. Though anthropomorphism of vehicles is a possibility for increasing trust in AVs, it is not a definitive solution for interaction between man and machine, because anthropomorphism can lead to unwarranted trust. Therefore, the anthropomorphism of AVs needs further research. Implicit communication, however, is shown to be important, but should also not be seen as an easily implemented solution for AVs, and also needs further research.

From the literature about eHMIs and anthropomorphism it was found that feedback provided by the AV can increase feelings of trust for the pedestrian. However, providing feedback to the pedestrian can also lead to unwarranted trust depending on the method of providing feedback. Therefore, it can be concluded that the implementation of eHMIs should be taken into consideration for the follow-up study of this literature review.

The literature about non-verbal communication, eHMIs, implicit communication and anthropomorphism showed that communication from the AV to the pedestrian can improve feelings of trust of the pedestrian, and therefore provided a preliminary answer to the third question of this literature review. The question however, could not be completely answered, as there is a lack of knowledge about how the feedback of an AV to the pedestrians' communication would affect the pedestrians' crossing decision. Thus only the first question could be answered by this literature review. This leaves the other two questions "What will change in the communication when the AV does not have a driver that the pedestrian can communicate with?" and "How will communication from the AV to the pedestrian affect the pedestrians' decision making and overall feeling during encounters with AVs?" to be unanswered. In order to answer these two questions, the following study will focus on providing knowledge about these gaps in literature.

To conclude the literature review, three forms of experimental methods were discussed. All three methodologies have the advantage of being safer than experimenting with real-life participants and actual AVs. The disadvantage of these methods is that pedestrians might behave differently than how they would encountering a real AV. These methods have been reviewed because of their frequent use within the field of AV research and will most likely play a large role in future research as well. Because of the good reproducibility, safety and relative low cost, VR forms a good method for experiments concerning pedestrian-AV communication. Therefore, VR should be considered for the study following this literature review.

7.1. Research gaps

This literature review has found that there is a sufficiently large number of scientific papers that investigate the communication needs and means for both conventional and AVs with pedestrians. These vary from research about the use and importance of non-verbal communication to alternative methods for replacing driver-pedestrian communication.

Another well-researched field is that of pedestrian-to-conventional vehicle interactions, with respect to non-verbal communication. Literature such as [36][57][58][59][61][62][63][64] all focus on eye contact, hand gestures and vehicle behaviour as forms of non-verbal communication between the pedestrian and the driver. The fact that research about communication methods for pedestrians and conventional vehicles is more abundant is likely the result of AVs being a relatively new field of research, while conventional vehicles have been around for several decades.

However, this literature review has not encountered sufficient literature about communication from the pedestrian to the AV. While some papers have mentioned this direction of communication, they have not discussed its implications. Lack of literature about this topic suggests that research has focused more on the AV side than on the pedestrian side. Although there is literature available on how AVs communicate their intentions to other vulnerable road users, and how pedestrians interpret these signals, this review found little literature about pedestrians communicating their intentions to AVs, and the effect of feedback from the AV on their initial communication.

Overall, this review has found that there are gaps in the literature about the communication of intent from the pedestrian towards the AV, and that there is a lack of literature about how pedestrians will use or abuse their form of communication.

7.2. Problem definition

Without knowledge of how to communicate their intentions to the AV, pedestrians might get confused or afraid and resort to dangerous behaviour such as crossing when it is not safe. This situation could also occur with a mix of AVs and conventional vehicles. Other effects of this problem might be that pedestrians lose trust or understanding of AVs, and not interact with them at all. This could lead to a difficult integration of AVs into society, as trust and understanding are important factors in the acceptance of technology.

This problem is best illustrated in a diagram, in which a hand gesture is taken as the form of communication from the pedestrian. Figure 7.1 shows the situation that might occur when a pedestrian encounters an AV and wants to communicate his or her intent to the vehicle.

The situation in figure 7.1 exposes more subtle gaps in the literature, as the process gives an overview of the problem and the specific elements that are essential to the crossing mechanism. As can be seen in the figure, the pedestrian will not only communicate his or her intention, but will also be communicated to by the AV. This is made even more complex by the effects of different methods that the AV can use to respond to the pedestrian, or even the lack of a response from the AV. The figure raises the question "Will the AV's response affect the pedestrians' crossing decision, and if so, does it have a positive or negative effect on the pedestrian's crossing decision? These questions relate to encounters with multiple AVs. This is because a situation might arise where the pedestrian allows a first AV to pass before crossing, while another AV nears the crossing. Does

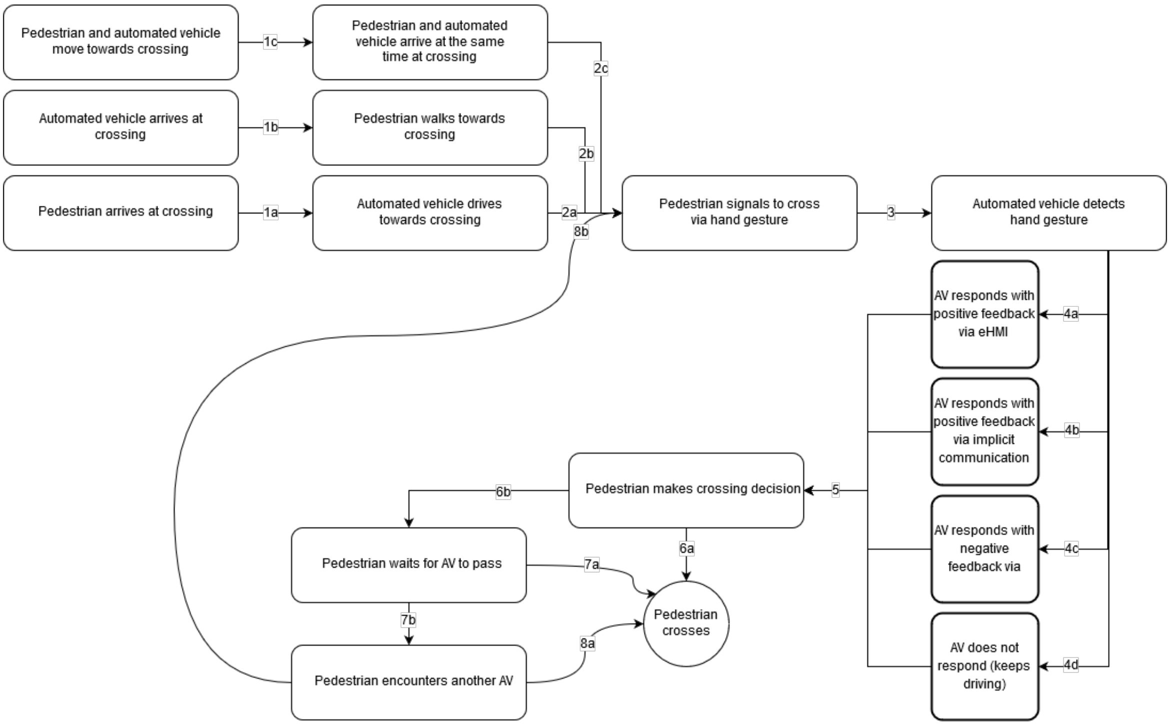

Figure 7.1: Situation in which a pedestrian encounters an AV and communicates crossing intent

the pedestrian in this situation take a different decision when interacting with the second AV than in the previous crossing situation, or does the cycle repeat exactly the same? These questions form a problem that requires further research such as with the follow-up study of this literature review.

Because of the lack of driver-pedestrian communication that might follow from AV integration into our traffic system, research should be done to investigate if the use of hand gestures by pedestrians is a useful form of non-verbal communication for communicating crossing intent of the pedestrian. In order to do so, it could be useful that the research includes feedback from the AV to the pedestrian's hand gesture (e.g. eHMI or implicit communication), in order to simulate a two way conversation. The way the pedestrian reacts to this feedback could provide insight into the acceptance of hand gestures as a useful method to communicate the pedestrian's crossing intent to the AV, because if the pedestrian does not trust hand gestures to work in conveying his or her crossing intent to the AV, he or she might not adopt this form of communication for future encounters with other AVs.

7.3. research questions

The literature review has provided the basis for further research of communication methods from pedestrians to AVs, which also showed that this research is needed to ensure a safer and cleaner future. The research gaps and the problem definition have led to the formulation of the following research question:

- What is the effect of positive and negative feedback from an automated vehicle, provided by an external human-machine interface and as implicit communication, on the time between the moment the pedestrian starts using a hand gesture to communicate crossing intent and the actual crossing moment?

This research question comes forth from the subtle problems exposed in the previous diagram. Figure 7.1 showed a situation in which a pedestrian wants to cross the road, but before crossing the road the pedestrian needs to communicate its intent towards the nearing AV. The pedestrian could for example make a hand gesture to request the AV to yield. The AV will in turn recognise the hand gesture and make a decision based on factors such as traffic flow and safety. After the AV has made its decision it could provide the pedestrian with positive or negative feedback in various forms (i.e. eHMI or implicit).

The form and message of the feedback could affect the crossing decision of the pedestrian, for example, the pedestrian could decide to cross, if the feedback was positive (i.e. the AV communicates that it will yield). However, the pedestrian might also be discouraged from crossing if the AV provides negative feedback. How the pedestrian handles the feedback of the AV could determine how the pedestrian will communicate with AVs in following encounters.

One of the variables of this crossing situation that could provide valuable information is time. Especially the time measured between the moment of gesturing and the actual crossing time provides a lot of insight into the crossing decision, as it can for example show hesitation or confidence of the pedestrian among others. Both hesitation and confidence could be seen as measures of how the pedestrian values the effectiveness of hand gestures in asking for a chance to cross. The same variable might be different for a second or third encounter, as the feedback of the first AV might influence the decision making of the pedestrian for further encounters with AVs. As a pedestrian might have more confidence that the second AV will yield to the same hand gesture, and thus the pedestrian might cross the road sooner after providing the hand gesture. The opposite could also happen, if the AV did not respond as expected by the pedestrian. Therefore, it seems important to investigate what the effect is of the feedback and on the time between gesture and crossing moment, in order to see the confidence of the pedestrian in the communication method.

As this situation does not only involve the time between the gesture and the crossing moment, it is important to also look at other aspects of the situation. A secondary research question could be about what the pedestrian's body language tells us about stress levels in the pedestrian during the encounter. Because, stress represents how comfortable a person is with a situation, it could be a valuable variable in research on communication between pedestrian and an AV, since these encounters will be new to the pedestrian. In order to measure stress, the posture of the body could be measured during the encounter. The following sub-question is therefore defined:

- How does body posture of the pedestrian change during encountering and communicating with an automated vehicle.

Another sub-question can be formulated based on the possible abuse of AVs as discussed before. The second sub-question is therefore defined:

- What is the effect of pedestrians having the ability to communicate crossing intention, on the deliberation to abuse this ability.

The following section will discuss several hypotheses that are defined after the research questions.

7.4. Hypotheses

The previously defined problems could apply for many forms of communication, however, in order to narrow down the results, it is chosen to focus the hypotheses and research questions on the use of hand gestures. This has led to the following hypotheses:

- If automated vehicles respond with positive feedback to the use of hand gestures, pedestrians will quickly get more confident in using hand gestures for communicating their crossing intent. This will be reflected by:
  - Increase of trust in this form of communication.
  - Less time between the moment of signalling intent and crossing.
- If automated vehicles respond with negative feedback to the use of hand gestures, pedestrians will quickly get less confident in using hand gestures for communicating their crossing intent. This will be reflected by:
  - Decrease of trust in this form of communication.
  - More time between the moment of signalling intent and crossing.
  - More occasions in which the pedestrian does not cross after signalling intent.
- Pedestrians gain more confidence in using hand gestures for communicating their crossing intent, if the automated vehicle provides positive feedback via eHMI, compared to implicit communication. This will be reflected by:

  - Less time between the moment of signalling intent and crossing for the scenario with the eHMI compared to the scenario with implicit communication.
  - More trust in the feedback from the eHMI than from implicit communication.

- Pedestrians will eventually abuse the yielding effect of hand gestures by crossing before they have confirmation that the automated vehicle will yield. This will be reflected by:
  - Increase of confidence that the vehicle will yield.
  - Less time between the moment of signalling intent and crossing.
  - Lower levels of stress when crossing after communicating intent.

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