External Human-Machine Interfaces on Autonomous Vehicles:

The Effects of Information Type on Pedestrian Crossing Decisions

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External Human-Machine Interfaces on Autonomous Vehicles:

The Effects of Information Type on Pedestrian Crossing Decisions

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Summary

Traffic is a self-organising, regulated system, but there are several ambiguous situations where no rules apply. In such situations, communication is important in order to achieve a smooth traffic flow and a safe situation. However, in the majority of traffic conflicts, adequate coordination between road users is lacking. Communication is particularly important for vulnerable users such as pedestrians, given their significant share in traffic accident statistics worldwide.

The increasing amount of automation in vehicles creates a potential social interaction void, which could further impede safety and a smooth traffic flow, as the chances of misinterpreting the behaviour of another road users might increase. Some researchers and companies have suggested that these problems could be addressed by adding additional means of communication to a vehicle. However, there is limited consensus as to what the most effective form and content of such communication would be.

The aim of this study is to investigate the effect of two different types of information on a pedestrian's crossing behaviour. This work describes the development and evaluation of a textual, external human-machine interface (eHMI), with the aim of complementing existing signals, such as vehicle movements, with explicit information addressed to human road users. Three conditions, specifically: (0) no information, (1), a pedestrian advice (Wait/Walk) and (2) a vehicle based status (Drive/Brake) are compared with respect to their effect on four variables related to the pedestrian: the minimum distance maintained to the vehicle, measured as a virtual 'Time to Collision', changes in the decision to cross (Decision Certainty), the feeling of safety as a percentage of the duration of a scenario (Decision Efficiency) and subjective acceptance.

28 participants participated in three repetitions of the same experiment in three different environments: a field test on a public road, an experiment in an animated virtual reality environment and an experiment using 360* video recordings. Participants stood on the pavement along an urban road in a European setting, and were asked to press a button when they felt safe to cross. During the experiment, a car drove by while showing one of the three types of information.

The total time that participants felt safe was significantly higher in scenarios where the car stopped, and significantly lower if the car did not stop, when information was offered. Time to Collision, decision changes and subjective acceptance also showed statistically significant differences in most scenarios, as these variables show a strong correlation among each other. However, one difference was found between the types of information for the Decision Efficiency variable. Here, effect sizes for the Wait/Walk eHMI (egocentric information) were larger than for Drive/Brake (allocentric information).

The results show that providing additional information could improve safety and traffic flow, although the type of information has a limited influence on the behaviour of a pedestrian. This suggests that when choosing a certain type of information, other factors should be taken into account that could perhaps be more decisive. Ultimately, this research contributes to finding the optimal characteristics of a standardised eHMI design.

Samenvatting

Verkeer is een zelf-organiserend, gereguleerd systeem, waar echter diverse dubbelzinnige situaties kunnen voorkomen waarvoor geen duidelijke regels bestaan. In zulke situaties is communicatie belangrijk om een voldoende verkeersdoorstroming en een veilige situatie te garanderen. Bij een groot deel van de verkeersconflicten ontbreekt het echter aan afdoende coördinatie tussen de weggebruikers. Zeker voor kwetsbare gebruikers, zoals voetgangers, is communicatie van groot belang, gezien hun aanzienlijke aandeel in de verkeersslachtofferstatistieken wereldwijd. De toenemende hoeveelheid automatisering in voertuigen creëert een mogelijk gebrek aan sociale interactie, waardoor de veiligheid en vlotte verkeersdoorstroming verder zou kunnen afnemen, daar de kans op een foutieve inschatting van het gedrag van een andere weggebruiker hierdoor toeneemt. Enkele onderzoekers en bedrijven hebben voorgesteld dat deze problemen geadresseerd zouden kunnen worden door extra communicatiemiddelen aan een voertuig toe te voegen. Er is echter maar beperkt consensus over wat de meest effectieve vorm en inhoud van zulke communicatie zou zijn.

Het doel van deze studie is het onderzoeken van het effect van twee verschillende typen informatie op het oversteekgedrag van een voetganger. In dit werk wordt de ontwikkeling en evaluatie van een tekstuele, externe mens-machine-interface (eHMI) beschreven, met het doel de bestaande signalen, zoals voertuigbewegingen, aan te vullen met expliciete informatie gericht aan andere, menselijke weggebruikers. Hiervoor worden drie condities, te weten: (0) geen informatie, (1), een aan de voetganger gericht advies (Wait/Walk), en (2) een op het voertuig gebaseerde status (Drive/Brake) vergeleken met betrekking tot hun effect op vier variabelen gerelateerd aan de voetganger: de minimum aangehouden afstand gemeten in de vorm een virtuele 'Time to Colission', wisselingen in het besluit om over te steken (Decision Certainty), het veiligheidsgevoel als percentage van de tijdsduur van een scenario (Decision Efficiency), en tot slot een subjectieve acceptatie.

28 deelnemers namen deel aan drie herhalingen van hetzelfde experiment in drie verschillende omgevingen: een veldtest op de openbare weg, een experiment in een geanimeerde virtuele omgeving, en een experiment gebruik makend van 360° video-opnames. Deelnemers stonden op de stoep langs een weg in een Europese setting, en werd gevraagd een knopje in te drukken wanneer ze zich veilig waanden om over te steken. Gedurende het experiment reed een auto langs, terwijl deze een van de drie typen informatie toonde.

De totale tijd waarbij deelnemers zich veilig voelden was significant hoger in scenario's waarin de auto stopte, en significant lager als de auto niet stopte, wanneer er aanvullende informatie aangeboden werd. Ook de Time to Colission, beslissingswisselingen en subjectieve acceptatie toonden in de meeste scenario's statistisch significante verschillen, daar de variabelen onderling een sterkte correlatie laten zien. Echter, tussen de typen informatie is alleen voor de Decision Efficiency-variable een verschil gevonden, waarbij de effectgrootten voor de Wait/Walk eHMI (egocentrische informatie) sterker zijn dan voor Drive/Brake (allocentrische informatie).

De resultaten tonen aan dat het aanbieden van informatie de veiligheid en verkeersdoorstroming zou kunnen verbeteren, maar dat het type informatie maar beperkt invloed heeft op het gedrag van een voetganger. Dit suggereert dat bij de keuze voor een type informatie ook andere factoren meegewogen dienen te worden, die wellicht doorslaggevender zouden kunnen zijn. Uiteindelijk draagt dit onderzoek bij aan het vinden van de optimale eigenschappen van een gestandaardiseerd eHMI-ontwerp.

Preface

In this work, the development and evaluation of a text-based external-human machine interface on a vehicle is presented, aimed at complementing vehicle motion cues with explicit information for human road users. I investigated the effect of two types of information on pedestrian behaviour: one from a pedestrian 'advisory', and one from a vehicle 'informative' perspective.

The experiments for this research were conducted together with Rakshit Agarwal, who performed his MSc. thesis on "The Validation of a Pedestrian Simulator for Interaction between Pedestrians and Autonomous Vehicles".

First of all, I thank Rakshit Agarwal for our collaboration while preparing and conducting the experiments. In particular for his efforts in editing all the video clips for the 360° video environment and his help in programming the virtual reality environment. Additionally, sections 2.1 to 2.3 of this report (apart from the eHMI details) have been jointly written.

I would like to thank my supervisors Joost de Winter and Riender Happee for their feedback and guidance. My gratitude also goes out to Kishore, Lisa, Michael and Vishwajeet for their help during the pilot study and field tests, and Edwin Scharp and Peter van Oossanen for handling the equipment and the vehicle. I would like to give many thanks to Lars Kooijman, for his problem solving skills in the Unity environment and C#, Pablo Nuñez Velasco, for his insights regarding the questionnaires and the design of the experiment, Wilco Vreugdenhil, for showing me how to create nice data visualisations and box plots, and Nagarjun Reddy and the Research lab Automated Driving Delft for the help in obtaining the right equipment and permissions for conducting the field test at the Heertjeslaan.

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I hope you enjoy reading.

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Nomenclature

Abbreviation	**Description**
(e)HMI	(external) Human-Machine Interface
(f)AV	(fully) Autonomous Vehicle
AMOLED	Active-Matrix Organic Light-Emitting Diode
ANOVA	ANalysis Of VAriance
BSSS	Brief Sensation Seeking Scale
DE	Distance Estimation
FT	Field Test
GA	Gap Acceptance
GPS	Global Positioning System
HMD	Head-Mounted Display
HRU	Human Road User
IR	Infrared
LED	Light Emitting Diode
P2V	Pedestrian to Vehicle
PWM	Pulse Width Modulation
RMS(e)	Root Mean Squared (error)
SAE	Society of Automotive Engineers
SE	Speed Estimation
TTC	Time to Collision
USB	Universal Serial Bus
V2P	Vehicle to Pedestrian
Vi	360° Video
VR	Virtual Reality

1
Introduction

Road traffic is a self-organising system that, although it is fundamentally governed by rules, may give rise to a myriad of ambiguous situations for which clear rules cannot be determined [2]. This can be illustrated by the fact that several countries have adopted broad provisions in traffic law which forbid all behaviour that can potentially cause danger [3][4][5].

A factor that seems to be important in resolving ambiguity is communication [6]. Communication seems to facilitate a better traffic flow [2], improve safety and protect a vehicle from malicious behaviour of other road users [7]. These effects may be attributed to the influence of communication on different phases in a traffic encounter: communication seems to fulfil a signalling function [8][9], improve comprehension of others [10] and promote the correct prediction of future events [7].

Communication is especially important as it is reported that the majority of traffic conflicts and accidents are a result of a lack of coordination between multiple road users [11][12][13]. Especially for vulnerable road users, the assessment of a vehicle's behaviour is of vital importance. Pedestrians make up for 23% of traffic fatalities worldwide [14], and (within the EU) 70% of the fatalities occur in urban areas [15], while the urban population is growing. Critical events as 'no action' and 'premature action' (while a well-timed action is required to avoid an accident) are associated to the majority of pedestrian accidents in the EU, and the latter event is recorded far more frequently for pedestrians than for other actors in an incident [16]. Related factors as 'information failure', 'inadequate plan' and 'distraction' are among the most frequently recorded links between causes for pedestrians in the SafetyNet Accident Causation Database 2005-2008 [16]. As a result, being a pedestrian is regarded as relatively risky [17], and pedestrians tend show more co-operative behaviour than drivers, for example by actively seeking for eye contact [8] or by leaving priority to a vehicle [18].

The increasing amount of automation in vehicles creates a potential social interaction void [7], which might further decrease pedestrian safety by impeding efficient traffic decisions (in a sense that they are slower or less safe), as the chances of occurrence of an information failure, an inadequate plan or distraction will likely increase due to the absence of human communication. Consequently, pedestrians indicate they are concerned about the safety of future AVs [19]. Some scholars and companies have suggested that these issues could be addressed by introducing new modalities of communication to a vehicle.

1.1. External Human-Machine Interfaces

Additional communication to human road users (HRUs) could be provided indirectly, via phone applications [20][21][22][23] or wristbands [24]. Another option would be to communicate directly from the vehicle, which is more in line with current situation. Sounds or lights can be provided via an external human machine interface (eHMI), attached to the vehicle. A myriad of eHMIs have been proposed so far [25], however, there does not seem to be a consensus on the modality and content of the communication that is most effective. For example, there are indications that the presence of an eHMI improves trust [26] and decision efficiency [27] of HRUs. However, in other works, pedestrians do not seem to exhibit sufficient trust in an eHMI to change their behaviour and rely on legacy cues, such as vehicle kinematics, instead [28][29].

Although the effects of an eHMI are not yet fully understood, some conclusions about the communication medium can be drawn from previous research. In accordance with previous work and for easy adoption, this work will focus on visual eHMIs only. (Generally, it might be easier to detect that a certain HRU is blind, than to find out that he or she is deaf on a first observation.). Visual information can be provided using colours, texts and/or symbols. Familiar to existing traffic signs, a red colour seems to have the strongest correlation with 'do not cross' and a green one with 'cross', respectively [28][30][25]. However, colour alone can be regarded as ambiguous [31][32], but in combination with a congruent text message, colour increases clarity [25]. Text-only interfaces were found to have a stronger influence on decision-making than anthropomorphic interfaces and face-to-face communication [33]. Additionally, text messages are regarded as less ambiguous than symbols and require no learning [34]. Nonetheless, language appears to be processed from an egocentric perspective [35], and children and older persons appear to have difficulty in taking another agent's perspective [34]. Clarity ratings therefore depend on the language of the text message [25].

Regarding the content of the communication, four different types of information have been identified: 1. Current vehicle status, 2. Future vehicle intent, 3. The vehicle's perception of others in the environment, and 4. Active cooperation by providing instructions to other road users [36]. Automation status information has not been found to alter pedestrian decisions [37], in line with other studies where no difference in behaviour had been found [38][39]. Additionally, status information could potentially invoke risky behaviour [36][40]. The need for intent communication has been expressed in some works [29][41][42], and this type of information seems to increase predictability of pedestrian behaviour [26], and self-reported levels of safety and trust [43]. A confirmation of being perceived by the vehicle is regarded as important information by some [42]. One step further would be to use this information for providing a clear instruction to other road users. Pedestrians seem to react positively to such advisory information [36], while it is rated as clearer than other types [25]. However, in a field test, no difference in pedestrian behaviour was found when advisory information was presented instead of vehicle status [29]. As these findings seem to contradict, more research into the effects of different types of information could be useful to determine which information type leads to the highest safety and efficiency of pedestrian decisions, as amount of works that compare different types of information is limited.

1.2. Research Gap

From the exploratory research that has been stated in previous sections, some findings regarding the effectiveness of different types of modalities and contents of eHMIs is available. However, the research findings can be contradicting sometimes (such as [44]) as the effects of an eHMI on pedestrian perception and behaviour are not yet fully understood. The mixed findings in previous work might be attributed to one or multiple of the following factors:

1. Static: Photos or still images have been used [31]
2. Snapshot: Results have been measured using a course or non-continuous method [29]
3. Culture: The driving environment could be unfamiliar to respondents from different parts of the world [25].
4. Subjective questionnaires: Measure perception, no actual measurement of behaviour [42]
5. Road tests: No controlled environment, influence from extraneous variables [45]
6. Virtual Reality: Fidelity unknown or unverified [39]

The first two factors can be problematic as a traffic encounter is a dynamic situation. Road users interact continuously and make or revert decisions at any point in time. Therefore, a static or non-continuous measurement method might not be able to capture changes herein. The other shortcomings are inherent to the specific experimental method deployed, and an assessment of the experimental fidelity or a combination of data from different methods would be required to overcome these issues.

For the visual features of an eHMI, it has been found that a text combined with red and green colours seems to be a promising approach that has been rated high on clarity and low on ambiguity. However, this specific visual eHMI has not yet been tested using a dynamic (non-static) method. Regarding the information content, most studies express a need for certain information types, but the resulting differences in pedestrian behaviour have barely been compared in a dynamic setup. Information about the vehicle automation status does not seem to alter behaviour. Advisory information has been rated as more clear, while it has not been found to influence behaviour either.

Having an eHMI that is perceived as clear and unambiguous, while it does not require learning, could lead to more efficient and safer pedestrian decisions. A distinctive interface could fulfil a signalling function (avoid distraction), and its information might result in better comprehension (avoid an information failure), which would help to predict future events (avoid an adequate plan): thus, an eHMI influences a vehicle-HRU encounter at different stages, underlining the need for a precise and continuous measurement method. Such a method would be particularly suited to evaluate different information types, but it has never been deployed outside of a virtual reality environment.

1.3. Aim

The aim of this study is to examine the effect of type of information on the decision ’to cross’ or ’not to cross’ the road, as made by a pedestrian when he or she encounters a vehicle on a colliding path. Both the pedestrian behaviour (objective) and perception (subjective) are evaluated. The pedestrian’s crossing intention will be measured continuously to represent the continuity of the crossing task. Additionally, questionnaires will be provided to measure subjective perception of the interface. To avoid any influence of the factors inherent to a specific experimental method, as mentioned above, the experiment will be repeated using three different approaches: A road test, video test and an animated virtual reality test will be conducted, within test environments that closely replicate each other. In summary, the following research question is proposed:
"What is the influence of different types of information, presented by an external human-machine interface, on the crossing intention of a pedestrian, as measured continuously with varying levels of fidelity?"
Based on the purpose of communication as mentioned in previous sections, it is hypothesised that:

- **H1:** As the eHMI fulfils a signalling function at a larger distance range then vehicle motion only, it is expected that pedestrians decide to cross the road from a larger vehicle distance and till a smaller distance (*Gap Acceptance*);
- **H2:** the enhanced comprehension of the vehicle’s behaviour will contribute to a higher acceptance (*Subjective Acceptance*) and fewer changes in the pedestrian’s judgement (*Decision Certainty*); and
- **H3:** the improved prediction of future events will eventually lead to more efficient, safer, pedestrian decisions; i.e., a higher percentage of them is in accordance with the intentions of the vehicle during the whole scenario (*Decision Efficiency*).
- **H4:** It is expected that these effects will be more distinct for an eHMI that is clearer and less ambiguous.

As egocentric information (from the pedestrian’s perspective) is rated as less ambiguous and clearer, this perspective is expected to improve signalling, comprehension and prediction of the vehicle’s behaviour most effectively. Therefore, egocentric information is expected to show larger differences in the metrics than allocentric information (from the vehicle’s perspective) compared to a baseline scenario.

It may be noted that a pedestrian acceptance of a larger range of distances, combined with fewer decision changes would automatically result in a higher decision efficiency. Hence, the three variables are correlated. The reason for including all variables is twofold: 1. A continuous binary measurement of decision efficiency is relatively new and has been used in only one work known to the author [34]. The evaluation of gap acceptance allows for a comparison with other works as well. 2. Evaluating all variables enables an exploration of the underlying working mechanism of the eHMI: does it work solely by improving the signalling range of vehicle behaviour, does an eHMI improve the perceived certainty of this behavioural information, or both? One efficiency percentage would not allow for this distinction in itself.

Finally, the experimental part of this thesis was carried out in conjunction with Rakshit Agarwal, for his master thesis ”Validation of Pedestrian simulators for interaction between pedestrians and autonomous vehicles”. For this reason, two types of virtual reality with different fidelities are used in addition to a field test: a 360-degree video recording, and an animated virtual environment. The benefit of having multiple environments is possibly an improved generalisability of the findings, as the influence of environment-specific factors is reduced, which have been shown to influence pedestrian behaviour [46][7]. Possible differences in effects for different environments might illustrate this. However, a detailed assessment of effect sizes and their relation with fidelity is outside the scope of this thesis. For an in-depth comparison of the test environments and their influence on pedestrian perception and behaviour, the reader is referred to [1].

1.4. Approach

The experiment will entail a road crossing scenario as this is a routine situation in urban environments, a situation where the majority of interaction between pedestrians and vehicles occurs, and a situations that is a common subject in previous research. As the experiment is conducted in The Netherlands, a Dutch/European road layout will be used. Furthermore, no crossing facilities are present at the location, as this might suggest that the situation is safe to cross at all times [34]. Finally, the automation of the AV is assumed to be correct in this experiment, so no flawed, incorrect or conflicting information is to be provided via the eHMI. In order to clarify differences due to individual factors within the participants, general demographic questions, a trust in automation scale [47] and a brief sensation seeking scale (BSSS) [48] will be provided and speed and distance estimation tasks will be performed, as a different perception of speeds and distances might also result in individual differences in crossing behaviour. Finally, only participants that are familiar with the local traffic environment will be allowed to participate to avoid unfamiliarity with the road environment. The subjective experience in each test environment will be evaluated by means of a presence assessment. In addition, the extent to which participants suffered from simulator sickness will be examined.

A visual eHMI has been developed, using a combination of a text message and the colours red and green. Two types of information are implemented: One text message is provided from an egocentric perspective, i.e. it instructs the pedestrian what he or she should do, and the second message is provided from an allocentric perspective; it informs the pedestrian about the intent of the vehicle. To evaluate the effect of this difference in the type of information, and to avoid any other influences, both messages are presented with similar size, brightness and font. Both messages have two states: one for a yielding vehicle (red) and one for a nonyielding vehicle (green). An overview of the eHMI design is depicted in appendix A, were the four text messages are shown. One might argue that colours as green and red might interfere with current traffic rules [49], which is a reason for some to adapt their eHMI design [50]. However, it was deliberately chosen to evaluate the influence of an eHMI on behaviour, which is a fundamental research question. For this, the colours are based on previous scientific consensus rather then current traffic law. The eHMI has been build using a $12 * 60$ SMD5050 LED Array, as these LEDs have a relatively high luminance ($L > 100$mcd/LED [51], see table 2.4 for technical details), which is important for an adequate response time [52].

2
Method

An experiment was conducted to test the interaction between pedestrians and autonomous vehicles using three different environments: a controlled field test on a public road (FT), a replication of the test in an animated virtual reality (VR) simulation and a third repetition using a 360° video recording of the same location (360 Vi), as shown in Fig. 2.1. Using a within-subjects design, participants performed the same experimental tasks in each environment, divided over two sessions. Written informed consent was provided before conducting the study. The research was approved by the Human Research Ethics Committee of TU Delft.

2.0.1. Participants

Thirty participants (7 female and 23 male) with a mean age of 25 years (SD = 2.4 years) participated in the study. Out of these, 28 participants completed both the first and second session (see table 2.1). The participants had 7 different nationalities: 18 Dutch, five Indian, three British, one French, one German, one Greek, and one Spanish; all of them were living in The Netherlands at the time of the experiment. Two participants reported to be colour-blind. All participants reported to travel by foot at least once a month and 27 of them at least once a week, of which 15 on a daily basis.

Table 2.1: Number of Participants who completed all tasks in each Environment

Field Test *FT*	30
360° video *Vi*	28
Virtual Reality *VR*	28

2.1. Experimental Design

The participants performed three tasks, which were all presented in each of the three environments. In each environment, the participant was standing on a fixed location on the (real or virtual) pavement, next to a two-lane urban road in Delft (see Fig. 2.1). The sequence of the tasks performed by the participants was kept the same in each environment (table 2.2). Participants completed the distance estimation (DE) task first, followed by speed estimation (SE) and gap acceptance (GA) tasks. The presentation order of the environments was varied among the participants. An overview of the task sequence and an example can be found in Fig. 2.2 and Fig. 2.8, respectively. A detailed explanation of the procedure will follow in section 2.3.

The order of the trials within a task was varied using a latin squares design. In total, participants completed 48 trials (see Table 2.2 for an overview of the trials in each environment). An explanation of the tasks will follow in the next sections.

Table 2.2: Tasks and Independent Variables in each of the three Environments

Order	Task	Independent Variable	Trials
1: DE	Distance Estimation	vehicle position s	6
2: SE	Speed Estimation	vehicle speed v	4
3: GA	Gap Acceptance	yielding behaviour ψ eHMI information type η	6

Figure 2.1: The participant's view in different environments. *From top to bottom*: the real location, the 360° video, and the animated virtual reality environment.

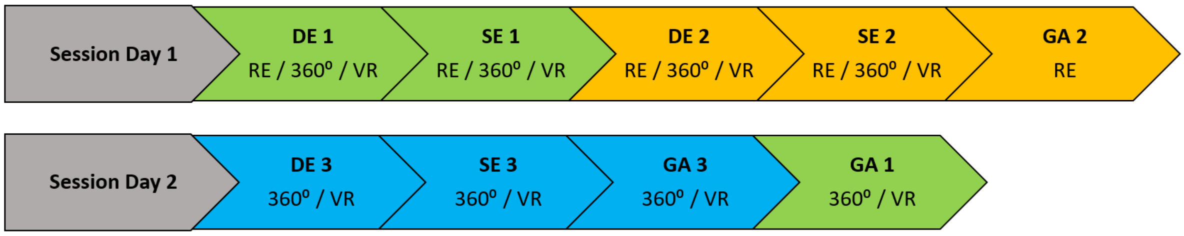


Figure 2.2: The sequence of the tasks as followed by all participants during the first and second session. Experimental tasks: Distance Estimation (DE), Speed Estimation (SE) and Gap Acceptance (GA). A number corresponds to a certain environment. The order of the environments was varied, with the possibilities shown as follows: Real Environment (RE), 360-degree video (360°) and Virtual Reality (VR). The colours indicate an example of a participant that participated in two 360° tasks first (green), then performed all RE tasks (orange) in the first session, and then completed the VR tasks (green) and the remaining 360° GA task in the second session.

2.1.1. Distance Estimation

To compare human distance perception in animated VR and 360-degree video with real life, a distance estimation task was performed. Each participant was asked to estimate six distances from an egocentric point of view. For each trial, a vehicle was parked at a certain distance from the participant (see Fig. 2.3 (top)) for ten seconds. In the 360° video and VR environment, a video clip of a parked vehicle was shown to the participant. Participants were asked to estimate the distance s from their position to the front of the vehicle verbally. To study differences in pedestrians' perception of distances, a range of vehicle positions from 10 m to 100 m was evaluated. The distances increased logarithmically (see Table 2.3) and their sequence was varied using latin squares with $n = 6$.

2.1.2. Speed Estimation

After estimating six distances, the speed estimation task was performed. While the vehicle approached the participant with constant velocity v, participants estimated it's speed in km/h. For this, the participants were provided with the audio instruction "estimate now", when the vehicle reached a distance s of 50 m (see Fig. 2.3 (bottom)). Participants were asked to immediately state their estimate verbally. The audio instruction was provided by the experimenter in the real environment, or by a computer voice in the VR and 360° video environment. Four different speeds were presented (see Table 2.3), using the same setup as used in the DE task. Their order was varied using latin squares with $n = 4$.

Table 2.3: Trial Conditions for the DE SE and GA Tasks

Position s **[m]**	10, 16, 25, 40, 63, 100
Speed v **[km/h]**	20, 30, 40, 50
Yielding ψ	0: No, 1: Yes
eHMI type η	NO: None, WW: Egocentric, DB: Allocentric

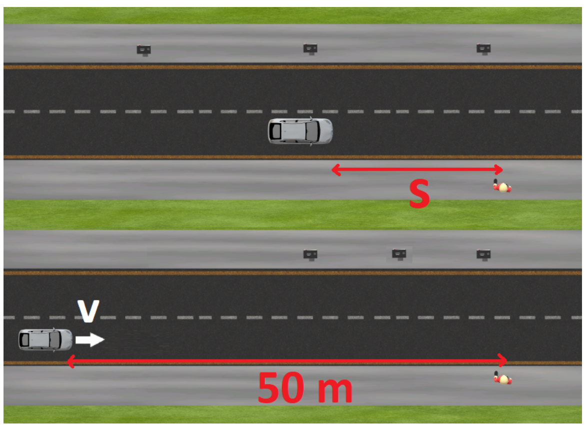


Figure 2.3: The distance and speed estimation tasks as seen from above. Top: Estimation of vehicle distance to the pedestrian s at zero speed. Bottom: Estimation of vehicle speed v, with audible "estimate now" cue provided at $s = 50$ m.

2.1.3. Gap Acceptance

The effects of eHMI information and type of environment on the decisions of participants in a road crossing scenario were measured through a gap acceptance task. During this task, the vehicle would drive at a constant speed of $v = 30$ km/h, while it showed a certain yielding behaviour ψ and type of information η. The participants were standing on the same marked position on the pavement as in the DE and SE tasks and observed the oncoming vehicle. Participants had to indicate continuously whether they felt safe to cross the road through pressing the button on a handheld remote. The following instructions were given to the participants before the task started:

1. *Press the button each time you feel safe to cross the road.*
2. *Keep pressing as long as you feel safe to cross.*
3. *Release when you do not feel safe to cross anymore.*
4. *Press the button again when you would cross again.*
5. *You can press and release the button multiple times during a trial, so that it reflects your feeling of safety at all times.*
6. *Please start performing the task when you hear the instruction to "press now".*
7. *Continue performing the task until you hear the instruction to "release now".*

The instructions were repeated in each environment prior to the GA task. Participants practised pressing the button once before performing the task. Six trials were performed in each environment, while the yielding behaviour (ψ) and eHMI type (η) were varied. In three trials ($\psi = 0$), the vehicle did not yield for the pedestrian and drove by at a constant speed. In three other trials ($\psi = 1$), the vehicle would start decelerating at 2.5 ± 1 m/s^2 from a distance $s = 25 \pm 5$ m, and finally come to a full stop at $s = 4.5 \pm 2$ m from the participant. In VR, the deceleration was kept at a fixed rate of 2.5 m/s^2 from $s = 20$ m, resulting in a fixed distance of $s = 6$ m at standstill. After six seconds, the vehicle would accelerate again and would drive past the participant (see Fig. 2.4). No other vehicles shared the road.

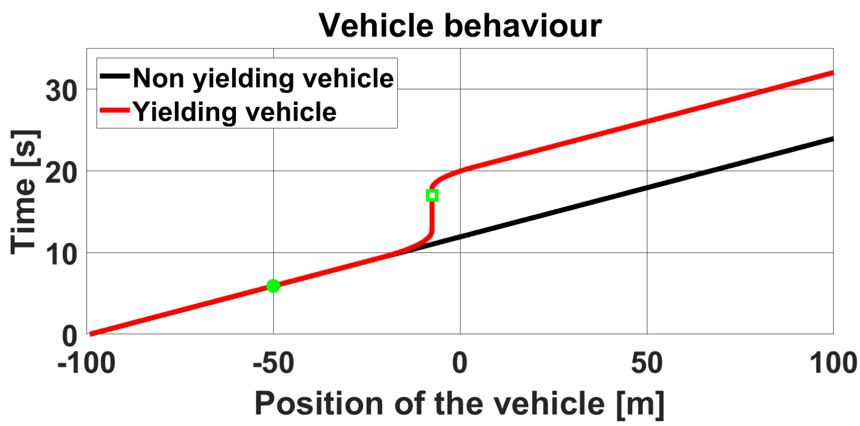


Figure 2.4: The distance of the vehicle to the pedestrian as a function of time as observed during a nonyielding condition (black) and a yielding condition (red). The green markers indicate when the eHMI switched to its yielding state (circle) and back to its nonyielding state (square).

The second independent variable that was changed during the trials was type of information that was conveyed by the vehicle. An external Human-Machine Interface (eHMI), which consisted of a LED screen, was implemented in front of the vehicle (see Fig. 2.5). Three conditions η were evaluated: (1) $\eta = NO$, in which the eHMI did not show any information., (2) $\eta = WW$ in which an egocentric advice (WAIT or WALK) was displayed, and (3) $\eta = DB$ in which allocentric information about the intent of the vehicle (DRIVE or BRAKE) was shown. The contrast and sizes of the text messages were kept constant across the conditions. In the DB and WW conditions, separate non-yielding and yielding states of the message can be observed. The non-yielding state was shown in red and the yielding state was shown in green in all environments (see Fig. 2.5). In all trials, the vehicle started driving with the eHMI in the non-yielding state. In the trials with yielding ($\psi = 1$), the eHMI would change to its yielding state at a fixed distance $s = 50$ m from the pedestrian and it remained in this state when the vehicle stopped. Two seconds before the vehicle would accelerate again, the eHMI would switch back to the non-yielding state to indicate the vehicle's intention to the pedestrian (see Fig. 2.4). The eHMI did never change state in nonyielding trials.

Figure 2.5: Information type η as shown on the eHMI in the real environment, with non-yielding state (*left*) and yielding state (*right*). From top to bottom: (1) None: Baseline condition, no information displayed, (2) WAIT/WALK: Egocentric, advisory information, (3) DRIVE/BRAKE: Allocentric, vehicle-based information.

2.2. Materials and Equipment

The three different environments of the experiment were the main variable influencing the required equipment. Therefore, each environment will be discussed separately in this section.

2.2.1. Real Environment

These tasks were performed at the Heertjeslaan in Delft, The Netherlands. This location was chosen as it offered a 225 m stretch of straight two-lane public road that could be temporarily closed down for other traffic. A sidewalk was present on one side of the road, and no pedestrian crossing facilities were available (see Fig. **??** and Fig. B.3). Road blockages were created at the beginning and ending of the road stretch for the duration of experiments, and traffic controllers were present to guide oncoming traffic. Three Logitech C930e cameras recorded the participants position and approximately 50 m of road stretch during the experiment. Their system times were synchronised with the NetTime 3.2.4.220 Network Time Synchronisation Tool. Traffic cones placed alongside the road were used as a distance reference for the experimenters. Six traffic cones were placed at the distances as mentioned in Table 2.3. One extra traffic cone was placed at s = 50 m for the SE and GA tasks. A van was parked on the sidewalk behind the participants, which served as a mobile lab for conducting the VR and video experiments (see Fig B.1. It also offered the participants a seat and some shelter while filling in the questionnaires.

Table 2.4: Specifications of the eHMI

Strip type	WS2813D, SMD-5050 60 LEDs m^{-1}
Power supply	Mean Well RS-150-5 DC 26A
Matrix size	$(w+2t)*12h = (0.8+2*0.1)*12*0.1\ m = 1.2\ m^2$
Total strip length	$12*L = 12*(w+2t) = 12$ m
Luminosity for red, green, blue, white	100, 420, 110, 630 mcd / LED

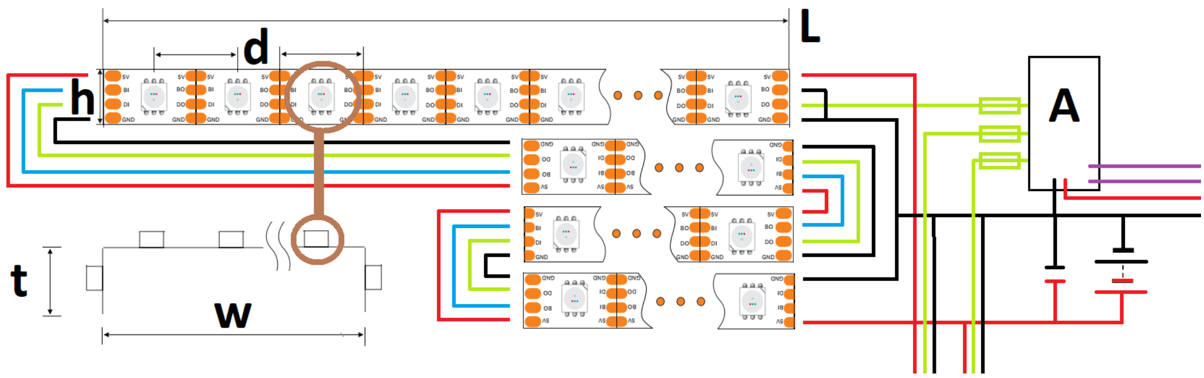


Figure 2.6: A schematic overview of the eHMI circuitry and it's dimensions. One out of three LED strips is shown partially. Each strip has been aligned in four horizontal strokes with height $h = 0.1$ m and length $L = 1$ m, which are folded around an U shape with a frontal width $w = 0.8$ m and two sides with thickness $t = 0.1$ m. The distance between the LED pixels on a strip is $d = 0.165$ m. The eHMI is powered by a 5V power supply (*red*), which shares a ground connection (*black*) with Arduino controller *A*. An USB control signal is coming in from a computer in the vehicle (from outside this figure) on the right (*purple*). The Arduino *A* calculates a PWM signal that is sent to the LED chips (*green*). Each LED chip also forwards the received PWM signal to the next chip as a backup feature (*blue*) to prevent data loss in case one LED chip fails. A 1000 μF capacitor is added in the power line and three 220 Ω resistors are added in the signal lines to protect the circuitry against inrush currents. The six lines at the bottom of this figure continue to the other two LED strips that are not shown in this figure and have an identical configuration.

A Toyota Prius was used to conduct the field tests. The vehicle was driven manually. The driver was paying attention to the road and did not make eye contact or convey any other signals to the participants. The steering wheel was held from the bottom, in such a way that this was not visible from the participants' point of view. A visual eHMI had been built, as described in the introduction section (see Fig. 2.6 and Table 2.4). It was fixed to the front of the vehicle by screwing it to the attachment points for a towing eye. The eHMI is connected to a computer with Matlab R2017b software via an Arduino Mega 2560 microcontroller. The state of the eHMI was controlled by a technician inside the vehicle. A Garmin Dash Cam 20 inside the vehicle recorded the driver's view, the current eHMI state and 1 Hz GPS data. In the pilot study, it was found that this output rate was insufficient to accurately determine the position of the vehicle. Therefore, a 10 Hz GPS sensor has been developed, based on an uBlox Neo-6M GPS receiver (see appendix A for specifications). This GPS sensor was connected to the same computer as the eHMI via USB and logged the vehicle's position and speed at a 10 Hz sampling rate using RealTerm 2.0.0.70 software.

A Logitech R400 presenter was used as wireless button for the GA task and a computer was placed behind the participant to record the button data. Walkie Talkies were used for communication between the traffic controllers, technicians, and experimenters. The complete site layout is depicted in Fig. 2.7.

2.2.2. The 360°-Video Environment

For each trial, a monoscopic 360-degree video was recorded beforehand on the same test location, from the participants' position at a height of 180 cm. The videos and sounds were recorded using a Nikon KeyMission 360 4K camera. The videos were combined in a specific sequence using Adobe Premier Pro CC software, to create a single video clip for each task and for each participant. The 360° video clips for the tasks are available online for the DE and SE [53] and GA tasks [54], respectively.

The participants were exposed to the 360° video through a Samsung Galaxy S7 phone in a Samsung Gear VR head mounted display (see Table 2.5), and sounds were provided via Pulsar Bluetooth headphones. Participants were asked maintain a standing position while performing the tasks. The tasks for the 360° video and animated VR environments were performed inside the van during the first session, and inside the lab during the second session to minimise the difference in circumstances. Furthermore, in all three environments, the same button has been used for the GA task.

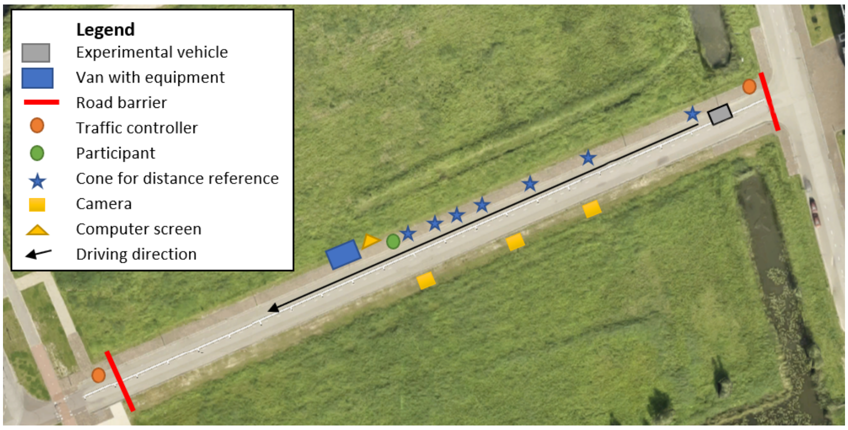


Figure 2.7: The site layout in the real environment, as depicted on a satellite image of the road stretch used in the experiment (Heertjeslaan, Delft). The vehicle is driving from the right towards the left end of the road in all tasks, as indicated by the arrow.

Table 2.5: Specifications of The Gear VR HMD

Resolution	2560 x 1440 pixel
Pixel Density	577 ppi
Screen Type	Super AMOLED
Refresh Rate	60 Hz
Field of View	96°
Connectivity	Micro-USB connection to Galaxy S7
Sensors	Accelerator, Gyro-meter, Geomagnetic, Proximity

2.2.3. Animated Virtual Reality Environment

An animated virtual environment was rendered using Unity software version 2018.3.9f1. An Oculus Rift head mounted display (HMD) with stereo vision, integrated headphones and two infrared tracking cameras were used to expose the participants to the animated virtual environment (see Table 2.6). The environment was designed to closely represent the real test location and the same length and width of the road and sidewalk were applied to the virtual environment for accurate replication. Unity assets representing the test vehicle, the van, cameras, cones, and the surrounding environment were incorporated. Vehicle speed, yielding behaviour and eHMI messages were programmed in C# through Microsoft Visual Studio 2016, and attached to the corresponding assets. An image of the eHMI in the VR environment can be found in appendix A. Background noise and driving sounds were implemented. For the DE and SE task, the sounds exactly replicated the sounds as in the 360° video. In the GA task, software-generated sounds were used that were the same for each vehicle and depended on the distance and velocity of the vehicle. A video of the VR environment as presented to the participants is available online through [55] for the DE and SE and [56] for the GA tasks, respectively.

Table 2.6: Specifications of the Oculus Rift HMD

Resolution	2160 x 1200 (1080 x 1200 per eye)
Pixel Density	456 ppi
Screen Type	Pentile AMOLED
Refresh Rate	90 Hz
Field of View	110°
Connectivity	HDMI 1.3, USB 3.0 (4-meter headset), USB 2.0
Sensors	Accelerometer, Gyroscope, Magnetometer Built-in audio and microphone

2.3. Procedure

Before conducting the experiment, participants signed an informed consent form. The participants performed the tasks in two sessions. An overview of the task sequence for both sessions can be seen in Fig. 2.8. A detailed overview of steps for conducting the experiments can be seen in appendix III. A booklet containing informed consent form, questionnaires and input table was printed for each participant and can be seen in appendix V.

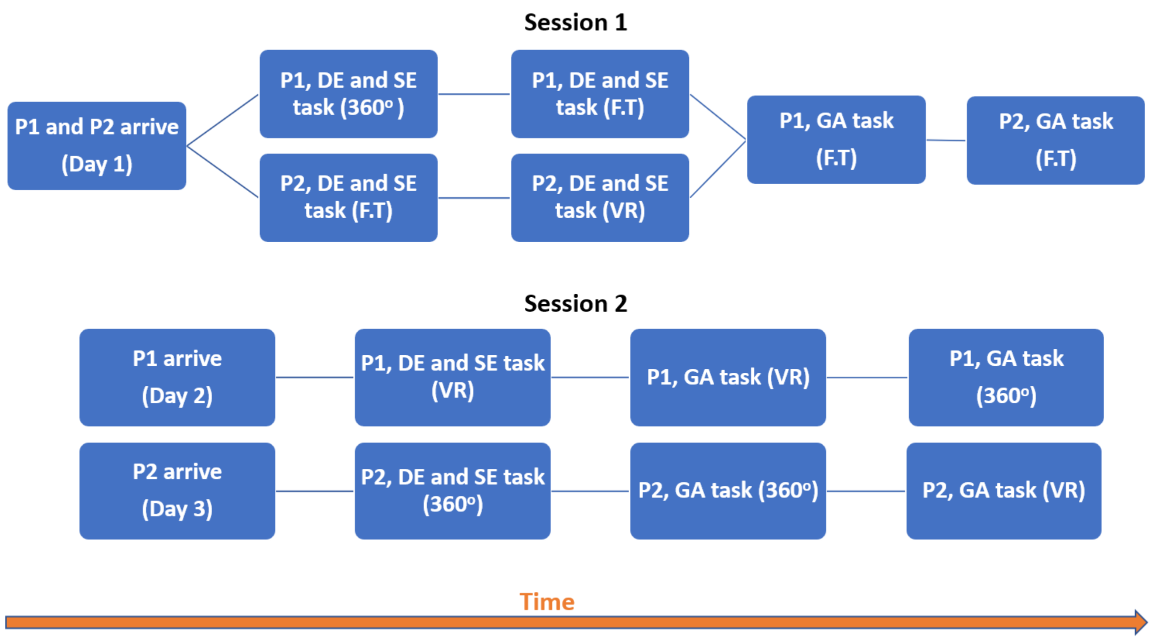


Figure 2.8: An Example of the task sequence for participants P1 and P2 during the first and second session. The first session included Distance Estimation (DE) and Speed Estimation (SE) in two environments, and Gap Acceptance (GA) in the real environment (Field Test, FT) only. IN the second session, the DE and SE estimation tasks were performed in the remaining environment and the Gap Acceptance GA in the 360-degree video (360°) and Virtual Reality (VR) environments.

2.3.1. First Session

The first session was conducted on three days: 19-02-2019 to 21-02-2019, from 09:45 to 15:30 each day. Day planning of the first session can be seen in appendix IV. Two participants were invited at the test location at the same time. The total experimental session lasted for 45 minutes for both participants combined. Upon arrival, participants were briefed about the experimental setup and the three tasks that had to be performed. After reading and signing the consent form, a general questionnaire with demographic questions and a Brief Sensation Seeking Scale (BSSS) [48] were administered. Following this, both participants were assigned an environment for the first two estimation tasks (DE 1 and SE 1 in Fig. 2.8), which determined the further procedure:

- *Real Environment:* The participant was invited at the marked position at the sidewalk. Participants were instructed clearly to not cross the road in any condition. The tasks were explained again briefly, and after confirmation from both the participant and the driver of the vehicle, the experiment started. First, the DE task was conducted. The experimenter asked the participant to estimate vehicle distance when the vehicle had moved into position. Then, the SE task was performed. The participant were asked to estimate vehicle speed when the vehicle passed the 50 m cone. Participants could see the cones but were not made aware of their distances.
- *VR or 360°-Video:* The participant was invited to stand in the back cabin of the van as shown in Fig B.1. (The van's height of 2.1 m was sufficient to accommodate every participant.) The experimenter repeated the task explanation and assisted the participants to wear the HMD comfortably. A 360°-Video or animated VR environment was shown, consisting of a sequence of 6 distances and 4 speeds, with a 10 second countdown before each trial. Through the headphones, a computer voice asked the participant to estimate when the vehicle had moved into position (DE) or passed the 50 m cone (SE).

In the estimation tasks, the participants verbally provided their estimates, which were noted down by the experimenter. Following the completion of the DE 1 and SE 1 tasks, a new environment was assigned to the participant and the DE 2 and SE 2 tasks were performed (see Fig. 2.8) in that environment. Afterwards, a 2-5 minute break was provided and participants were instructed about the gap acceptance task. During the first session, this task was performed in the real environment only. One participant was invited at the marked location on the sidewalk, provided with the wireless button, and received the instruction as described in the Experiment Design section. The button was tested once, after which the task was performed. The experimenter instructed the participant to start pressing the button when the vehicle started driving, and to release the button when the vehicle had passed the participant and had come to a standstill. Open questions and an acceptance scale [57] were provided for each interface to measure effects on usefulness and satisfaction. Participants were asked an open question if they had any comments about the interface, and if they perceived the vehicle as autonomous or not. A presence questionnaire was also provided to assess the subjective fidelity of the experimental environment [58]. Furthermore, long exposure to certain environments can result in virtual reality sickness which can degrade human performance. Therefore, participants filled in a virtual reality sickness questionnaire [59] after completing all the tasks. All questionnaires used in the experiment can be found in Appendix F.

2.3.2. Second Session

The second session took place in the Cognitive Robotics Lab at the TU Delft Faculty of Mechanical, Maritime and Materials Engineering, between 28-02-2019 and 08-03-2019. Only one participant was invited at a time and the total experimental session lasted approximately 40 minutes. Only VR and 360°-Video experiments were conducted, as shown in Fig 2.8. Upon arrival, participants were presented with the consent form again and verbally reconfirmed their consent, after which the experimenter explained the tasks that had to be performed that session. The participants first performed the DE 3 and SE 3 tasks in the remaining environment (VR or 360°-video), using the same approach as in the first session. Following the estimation tasks, participants performed a gap acceptance task in the same environment (GA 3). Then the acceptance, presence and virtual reality sickness scales were provided, after which participants could take a 2-5 minute break. Finally, the last gap acceptance task was performed in the environment that was left from the first session (VR or 360°-video), using the same procedure.

In the 360°-video environment, a training task for checking button press input and noting the start point of the video was conducted before each gap acceptance trial. This was necessary as the Gear VR HMD used in this environment is not equipped with a wired connection to the computer that recorded the button input. During the training task, participants had to press and hold the button for as long as they were instructed to on screen. The button press and release text was shown alternately for five seconds each, after which a five second countdown indicated the start of the next trial. For the animated VR environment, the Oculus Rift HMD was used, which was connected to the desktop PC and button data were logged directly using a Unity C# script. Here, a test scenario was played once in which the button could be tested. The same computer voice instructed the participant in both environments to start pressing the button when the vehicle started driving, and to release the button when the vehicle had passed the participant and had come to a standstill. After performing one GA task, an acceptance scale was filled in for each eHMI interface, while screenshots of each interface in each state were provided. Additionally, participants were provided with a presence and a virtual reality sickness questionnaire to monitor fidelity and simulator discomfort. All questionnaires used in the experiment can be found in Appendix F.

2.4. Dependent Measures

During the experiments, the vehicle's position was logged at a rate of 10 Hz (for the field test and the video environment), or a variable rate of 30-40 Hz (for the virtual reality environment). Button press data were logged at the same variable rate for VR, and with 100 Hz for the other two environments. The variables were further analysed using custom written Matlab scripts. To check the validity of the Field Test analysis, the start and end times of the trials and correct state of the eHMI states were checked manually by reviewing the three days of video recordings. The checked start and end times for each were noted in an Excel file, which serves as an input for the Matlab script. For the 360°-video, the video clip was matched to the GPS data log by assigning the start of the GPS log to the first frame of the video containing movement. As the virtual reality data are captured with a variable rate, the vehicle speed in VR was filtered using a moving average filter with a window length of 20 before further post-processing. Then, all vehicle data was interpolated between $s = 75$ m (before the onset of the eHMI) and $s = 0$ m (the position of the pedestrian) and data was calculated with a 0.5 m resolution in each environment. The dependent measures required to evaluate the hypotheses were derived from these data. They are operationalised as follows:

- *Decision Efficiency*: First, descriptive plots of the button press versus vehicle speed and distance were created, which allows to understand when participants feel safe to cross the road [34]. Then, the "feel safe" percentage of participants was calculated for every vehicle position in the trial. This provides an percentage of the distance that the participant was safe to cross, which is not influenced by deviations in vehicle speed in the field test. To incorporate the effect of vehicle speed, a time-base comparison is performed as well. The temporal button press ratio is defined as the total time that the button was pressed divided by duration of the trial, as calculated over the same distance interval from $s = 75$ m to $s = 0$ m.

- *Gap Acceptance*: The above two measures are calculated over the whole distance interval and therefore reflect the continuity of the driving task. In most other research, however, the safety perception of the pedestrian is evaluated by means of the accepted spatial gap, which is defined as the minimum the distance to the vehicle that is required by the pedestrian in order to cross the road. For this, the distance at the moment the button is released for the first time in a trial has been calculated (spatial gap) and combined with speed data to calculate a hypothetical time to collision (TTC).
- *Decision Certainty*: As the road crossing decision can be changed at any moment in time, the number of changes in the decision reflects how clearly the car's behaviour had been interpreted. A button reversal rate could thus be regarded as a measure the pedestrian's activity required to understand the vehicle's intentions (similar to the steering reversal rate, which is used as a measure of control activity in a vehicle simulator). As a higher activity means less clarity - and vice versa - it is proposed that this metric could indicate the certainty in the crossing decision. The decision reversal rate is defined as the number of button state reversals while the vehicle distance s is within the $s = 75$ m to $s = 0$ interval.
- *Subjective Acceptance*: Pedestrian acceptance is determined subjectively using a Van der Laan acceptance questionnaire. This a simple 9-item survey that assesses system acceptance on two dimensions: a usefulness scale and an affective satisfying scale. Usefulness is calculated by averaging the scores of questions 1, 3, 5, 7 and 9, and satisfying is obtained by the sum of items 2, 4, 6 and 8, divided by 4. Additionally, participants are asked to provide their impression of the automation mode of the vehicle. For statistical analyses, the ratings were converted to numerical values, ranging from 1 (fully manual) to 4 (fully automated). Finally, an open question was provided for all comments that participants might have had about the interface.

2.5. Statistical Analysis

All dependent measures have been analysed for the effects of eHMI information type using a repeated measures analysis of variance (ANOVA with three repetitions per condition). Effects of combinations of eHMI and environment were evaluated using a two-way repeated measures analysis of variance (ANOVA with one repetition per condition in each environment). Before performing statistical analyses, measures were checked for sphericity using Mauchly's test. When the sphericity assumption was violated, Greenhouse-Geisser correction has been applied. If the ANOVA indicated statistically significant differences, a post-hoc pairwise comparison on the eHMI type was performed, using Bonferroni adjustment to compensate for multiple comparisons. To investigate the effect of the decision reversal rate and gap acceptance on the decision efficiency, a Pearson correlation analysis was conducted. Additionally, an exploratory correlation analysis was performed among individual participant characteristics, demographic factors and the dependent measures.

3 Results

In this chapter, the experimental results will be presented, according to the dependent as described in the method section. The input for all objective metrics is based on the vehicle's trajectory and button data from the participants. In total, an amount of $30*6+28*6+28*6 = 516$ trials has been conducted. For six trials in the 360° video, the button data were incomplete. For eight trials in the real environment, the GPS was not functioning properly and no 10 Hz data are available. In principle, interpolated 1 Hz backup GPS data could be used to overcome this, however, to ensure equality of all data, these trials have been omitted from further analysis. Thus, the results in the coming sections are based on a total of 502 trials (172 Field Test (FT) , 162 Video (Vi) and 168 Virtual Reality (VR)).

3.1. Presence and Sickness

The virtual reality sickness questionnaire [59] responses indicate that overall discomfort was low or absent for most participants, see Fig 3.1. For VR, three participants reported moderate discomfort for one or more criteria. For 360° video, also three participants reported moderate and one reported maximum discomfort on fatigue, difficulty focusing and eye strain. Remarkably, two participants reported the highest level of discomfort for eye strain, difficulty focusing, and blurred vision after completion of the field test (see appendix C.5 for all responses). A detailed comparison between the test environments is part of the work of the work done by Agarwal [1], and would therefore be beyond the scope as lined out in this research. All participants completed the experiments.

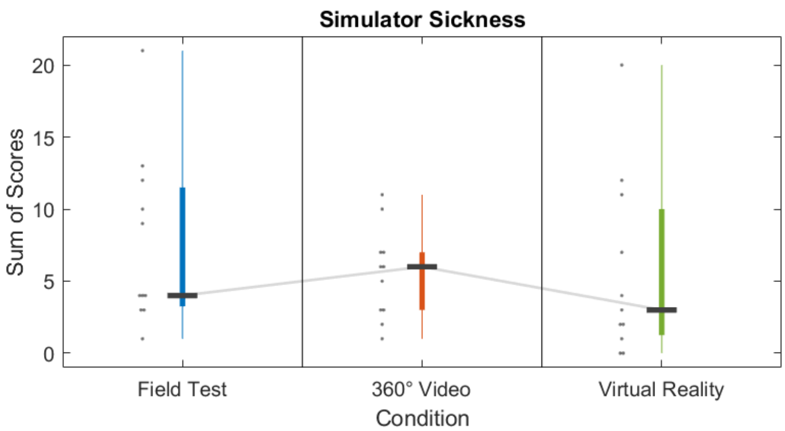


Figure 3.1: Aggregate simulator sickness scores on a 0-33 scale. The ratings are calculated by a summation of the participants' scores for individual symptoms as in appendix C.5. Eleven symptoms are indicated, each one 0-3 range. The aggregate score for a participant is indicated by a dot and the median is represented through a horizontal line.

The presence in the three test environments has been evaluated using a presence questionnaire (based on [58]). Aggregate presence ratings have been calculated by a summation of the answers for each environment for each participant. Results seem to indicate that presence in the field test and 360° video environment is similar and in animated VR, presence i rated lower (see Fig. 3.2).

However, in general, it is difficult to compare presence in different environments [58] and no significant differences between the aggregate ratings of the three environments have been found. For reference, the means of the individual answers to the presence questions are shown individually in table C.3 in appendix C.1.

In accordance with the presence scores, the distance estimation results do not show any significant differences between the test environments. For speed perception, one significant difference has been found between the video and VR environments for v = 30 km/h ($F(2,54)$ = 5.26, p = .011) [1]. The perceived speed and distance estimates are presented in C.2 and C.3, respectively. For an in-depth comparison between the test environments, the reader is referred to the work by Agarwal et al. [1].

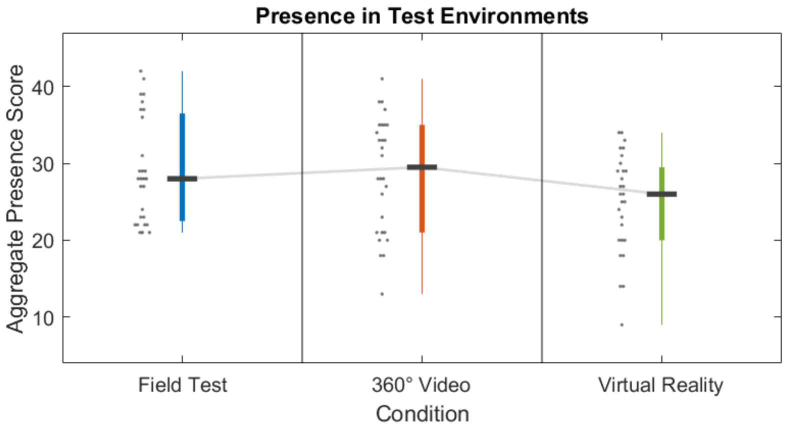


Figure 3.2: Aggregate presence scores on a 0-42 scale. The values are composite scores, calculated by summation of the participants' presence scores for 6 questions ranging from 0, (not feeling present at all) to 7 (feeling very much present), as in [1].

3.2. Decision Efficiency

As all objective metrics are derived from the vehicle's trajectory during the gap acceptance task, an example of the characteristic interaction between the vehicle and pedestrian is provided in Fig 3.3. The colour of the lines is based on the input of the participant: when feeling safe to cross, the line is coloured red. The distances are corrected for the measurement location of the GPS in the car. To avoid overlap in the figure, a cumulative 1/32 km/h speed increase has been added to the ground truth speed values with each participant. However, as may be expected, the spread in vehicle speed data is larger in the field test then in the other environments, which had identical trajectories for each participant. Note that some noise is visible in the VR speed data due to the variable sampling rate in that environment. By visualisation of the results in this way the difference in gap acceptance between a yielding and nonyielding vehicle can be clearly observed: In the yielding case, more participants seem to feel safe to cross the road at smaller distances then in the nonyielding conditions.

At a distance s = 75 m, approximately 90% of the participants feel safe to cross. This percentage decreases when the vehicle is approaching, see Fig. 3.4. Around 20 m distance, none of the participants feels safe to cross any more in the nonyielding scenario, whereas approximately 20% of them still feel safe to cross after noticing deceleration of the vehicle. When the eHMI is providing information, the perceived safety drop is lower in the yielding scenario. A version of this graph is provided for each environment separately in appendix C.6. As the information from the eHMI yielded higher feel safe percentages in yielding scenarios and lower percentages in nonyielding cases, both differences were in the expected direction. Following a two-way repeated-measures ANOVA in yielding cases, the effect of eHMI type was significant, $F(2,52) = 9.62$, $p < .001$, and the environment had no significant effect $F(2,52) = 1.667$, $p = .202$. No statistically significant eHMI x environment interaction was observed, $F(4,104) = 0.296$, $p = .880$.

For nonyielding cases, the results also show a significant effect of eHMI type, $F(2,52) = 8.23$, $p < .001$. The environment had no significant effect $F(2,52) = 2.61$, $p = .085$, and no statistically significant eHMI x environment interaction had been found, $F(4,104) = 0.501$, $p = .7111$. Pairwise comparisons show a significant difference between the Wait/Walk eHMI and No Information, both for yielding and nonyielding scenarios ($p = .002$), a significant effect between Drive/Brake and No Information ($p = .012$, yielding only), and between Wait/Walk and Drive/Brake ($p = .029$, nonyielding only). An overview of all dependent metrics is provided in Table 3.2.

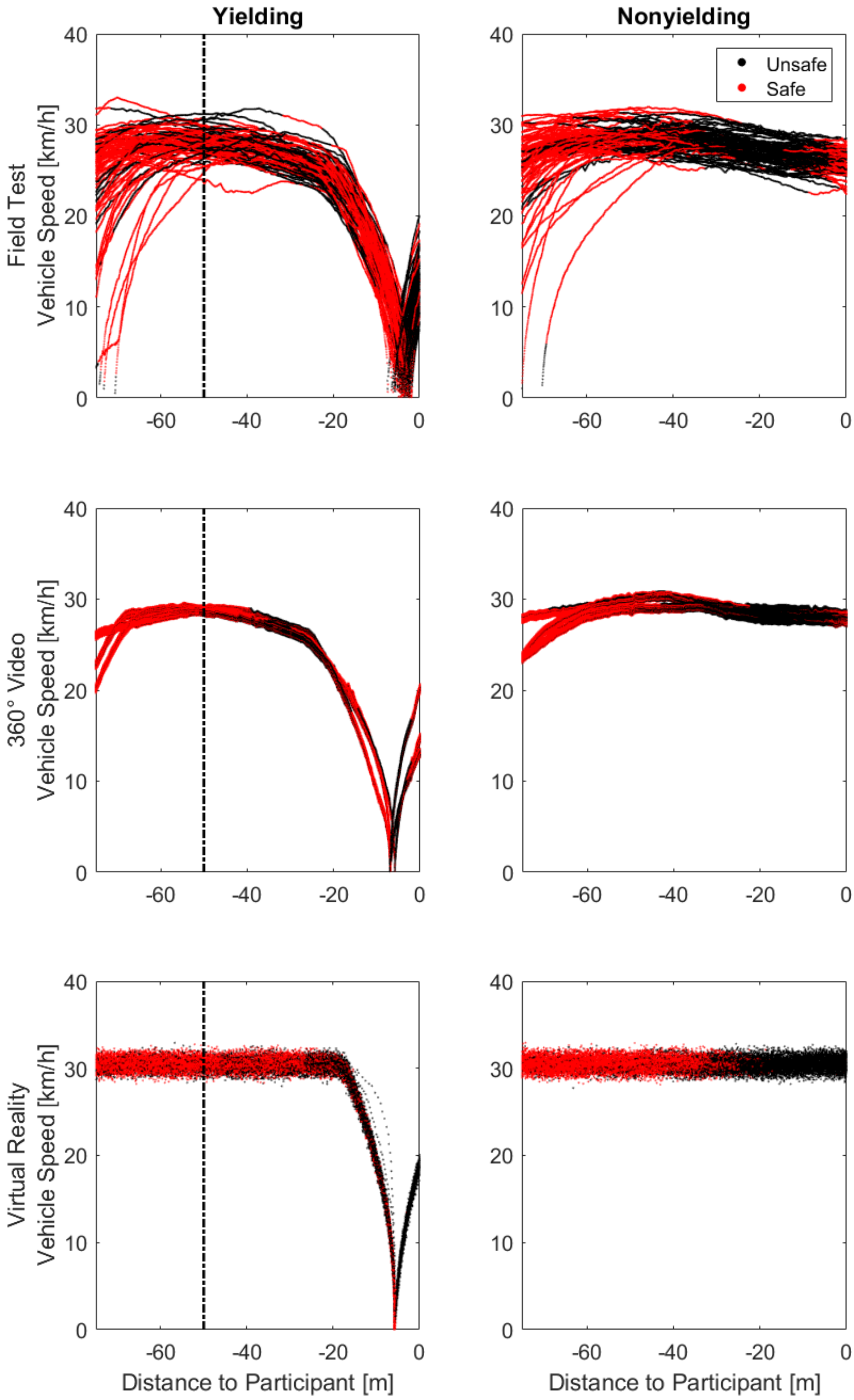


Figure 3.3: Combined figure showing vehicle speed during the trial for all participants. Distances have been corrected to represent the distance between the participant and the front of the vehicle. Please note that a cumulative 1/32 km/h speed increase has been added with each participant, and that the environments are separated in the figures for clarity. The dashed-dotted line represents the moment the eHMI changed state from nonyielding to yielding.

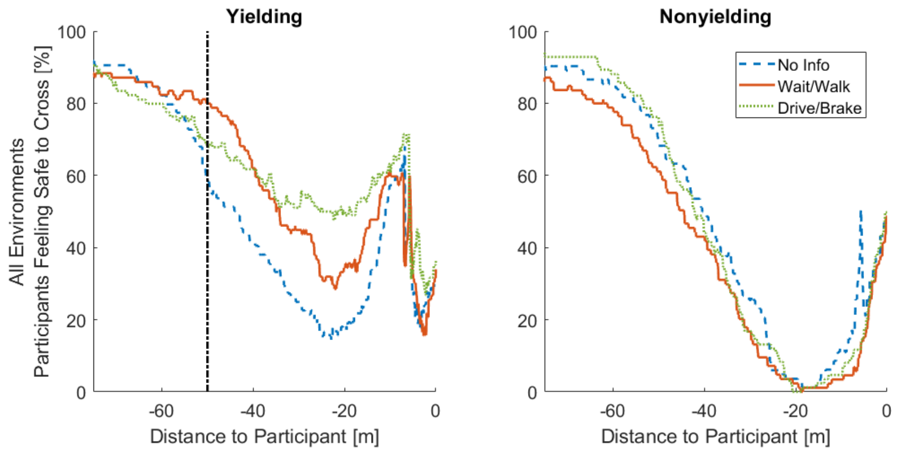


Figure 3.4: The percentage of participants feeling safe to cross as a function of distance *s* for a yielding (left) and nonyielding vehicle (right), obtained with the data from the three environments combined. The black dotted line represents when the eHMI switched from it's nonyielding to yielding state. During the nonyielding scenario, the eHMI did not change.

For each participant, the previous graph can be reduced to one time-based ratio. This time-based button press ratio is defined as the total time that the button was pressed divided by duration of the trial, in accordance with previous research [34]. The ratio has been calculated over the same distance interval from $s = 75$ m to $s = 0$ m, see Fig. 3.5. A larger percentage indicates that the pedestrian felt safe to cross the road for a longer part of the trial.

The figure indicates that the Wait/Walk eHMI resulted in a lower time percentage in nonyielding scenarios, and thus an increased safety as the participants do not to cross the road while the vehicle is not yielding. A repeated measures ANOVA did confirm significant effects for eHMI, $F(2,52) = 9.489$, $p < .001$. A post-hoc analysis shows that the results differ between Drive/Brake and Wait/Walk ($p = .020$), and between Wait/Walk and No Information ($p < .001$) in nonyielding scenarios. However, in yielding scenarios, no effect has been found for eHMI type $F(2,52) = 2.16$, $p = .135$, although the results were differing significantly with environment type, $F(2,52) = 16.05$, $p < .001$ and eHMI x environment interaction, $F(4,104) = 4.319$, $p = .002$. A pairwise comparison shows significant differences in the video environment between the Drive/Brake and No Information eHMI ($p = .002$) and between Wait/Walk and No Information ($p < .001$). These differences can be distinguished more clearly when observing the results from the one environment in more detail (Fig. C.6 or Table C.5).

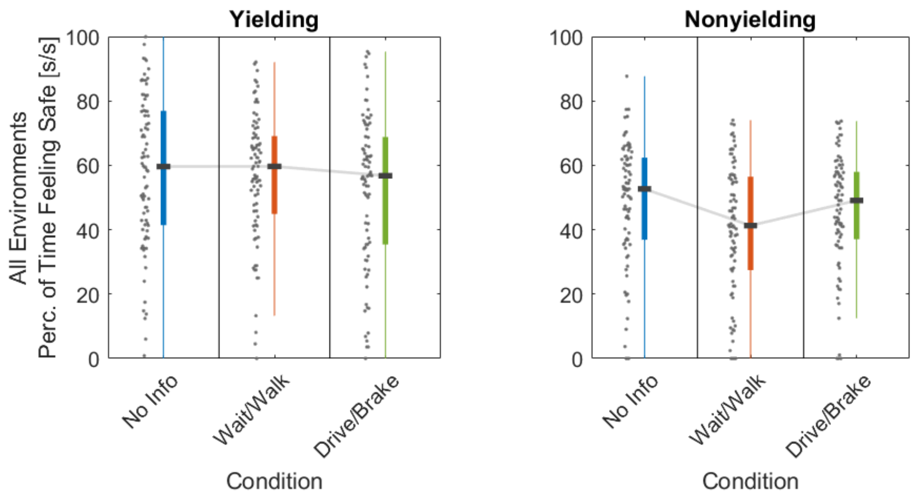


Figure 3.5: The time percentage a participant is feeling safe to cross the road. The percentages were calculated across 502 in total.

3.3. Gap Acceptance

To provide insight in the working mechanism of the eHMI, the distance range in which pedestrians change their decision is evaluated. The accepted spatial gap is defined as the minimum distance to the vehicle that the pedestrian considers as safe to cross the road. For this, the distance at the moment the button is released has been shown in Fig. 3.6. This metric represents the critical moment in which the pedestrian decides that it is not safe to cross the road any more. Note that the accepted spatial gap reflects the initial perception of the pedestrian. Therefore, any later changes in the decision to cross the road, for example when the yielding vehicle has come to a standstill, are not taken into account.

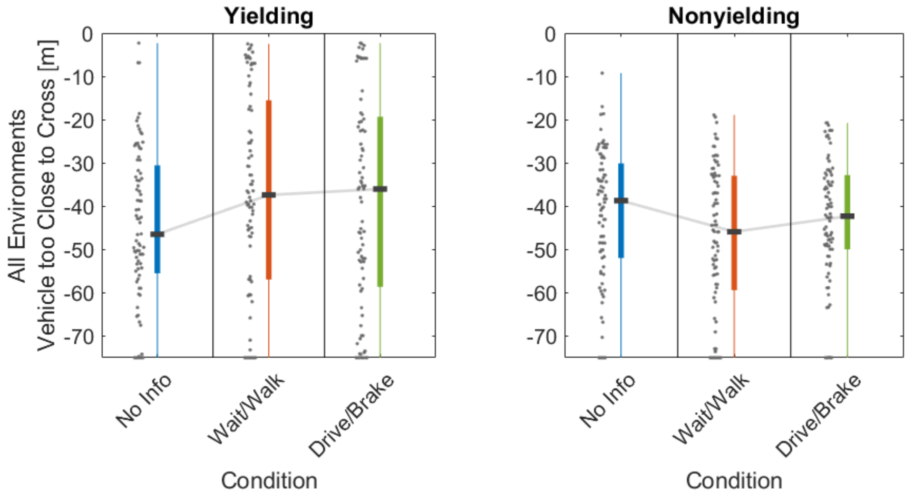


Figure 3.6: The vehicle distance The time percentage a participant is feeling safe in the field test. The percentages were calculated across 502 trials in total.

The results for yielding gap acceptance indicate significant differences for eHMI type $F(2,52) = 3.827$, $p = .032$. A pairwise comparison shows a difference for No Information and Wait/Walk ($p < .046$). In the nonyielding scenarios, a significant effect has been found for eHMI type, $F(2,52) = 5.22$, $p = .009$, and type of test environment, $F(2,52) = 11.846$, $p < 0.001$., but not for eHMI x environment interaction. Pairwise differences have been found for No Information-Wait/Walk ($p = .023$). The effects are shown for each environment separately in appendix C.9.

By combining the pedestrian's gap acceptance with the vehicle's speed data, a virtual time-to-collision (TTC) can be calculated. As visible in Fig. 3.7, the TTC for yielding scenarios is considerably larger, which is expected as the deceleration of the vehicle equals a time increase. Furthermore, Wait/Walk or Drive/Brake information from the vehicle seems to lower the accepted TTC in yielding cases.

A post-hoc comparison confirms significance for eHMI type, $F(2,52) = 9.632$, $p < .001$ and environment, $F(2,52) = 15.529$, $p < .001$, but not for eHMI x environment interaction. Significant differences have been found between No Information and Drive/Brake ($p = 0.011$) and between No Information and Wait/Walk ($p = 0.001$). In nonyielding cases, an opposite effect has been found: the eHMI appears to increase the TTC significantly, $F(2,52) = 4.530$, $p = .016$. The results show pairwise differences between No Information and Wait/Walk ($p = 0.045$). The data differ significantly with environment $F(2,52) = 23.182$, $p < .001$, thus the environment-specific TTC data are presented in C.10 for further reference.

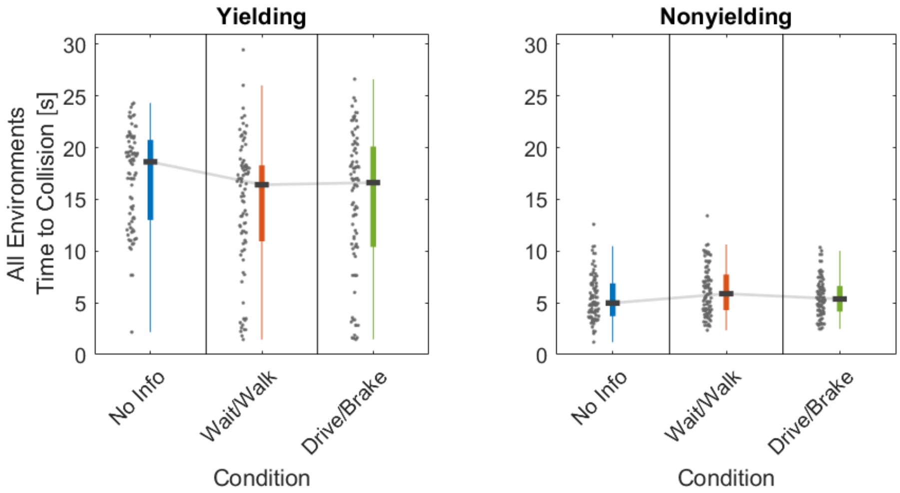


Figure 3.7: Virtual time-to-collision at the moment the pedestrian decides not to cross the road any more. The TTC was calculated across 502 trials in total.

3.4. Decision Certainty

The decision reversal rate is defined as the number of button state reversals on the $s = 75$ m to $s = 0$ interval. For nonyielding vehicles, significant differences have been found for test environment, $F(2,50) = 32.677$, $p < .001$, but not for eHMI type, $F(2,50) = 0.926$, $p = .394$. For yielding vehicles, significance was indicated for eHMI type, $F(2,46) = 15.719$, $p < .001$, environment, $F(2,46) = 21.687$, $p < .001$ and eHMI x environment interaction, $F(4,92) = 6.419$, $p < .001$. Pairwise comparison shows that the Drive/Brake and Wait/Walk eHMI provided extra certainty here, with significantly less decision reversals for Drive/Brake compared to No Information, ($p < .001$), and Wait/Walk compared to No Information ($p < .001$). The results are shown in Fig. 3.8.

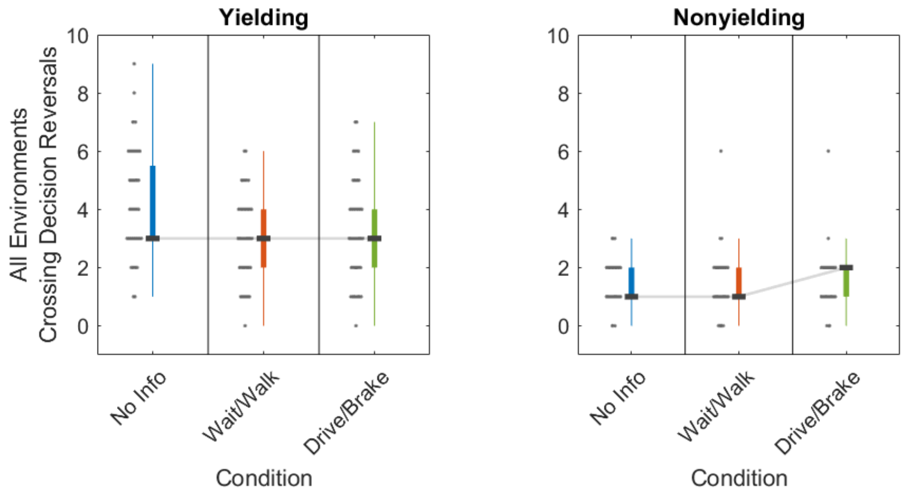


Figure 3.8: The number of button state changes during a trial while the vehicle is approaching within the $s = 75$ m to $s = 0$ distance interval in all test environments.

3.5. Subjective Acceptance

Pedestrian acceptance has been measured using the Van der Laan questionnaire. This survey assesses system acceptance on two dimensions: Usefulness is calculated by averaging the scores of questions 1, 3, 5, 7 and 9, and satisfying is obtained by the sum of items 2, 4, 6 and 8, divided by 4. Each eHMI has been rated in each environment. An overview of the results is depicted in Fig. 3.9, clearly indicating the difference between No Information and the other conditions. Participants were able to provide comments to clarify their rating; some examples are shown in Table 3.1.

A repeated measures ANOVA of the acceptance results has been performed and overall significant effects for eHMI type have been found, both for *satisfying* $F(2,54) = 17.067$, $p < .001$ and for *usefulness* $F(2,27) = 115.249$, $p < .001$, with pairwise differences for No Information-Drive/Brake ($p < .001$) and No Information-Wait/Walk ($p < .001$) on both metrics. No significant effects between the type of environment have been observed.

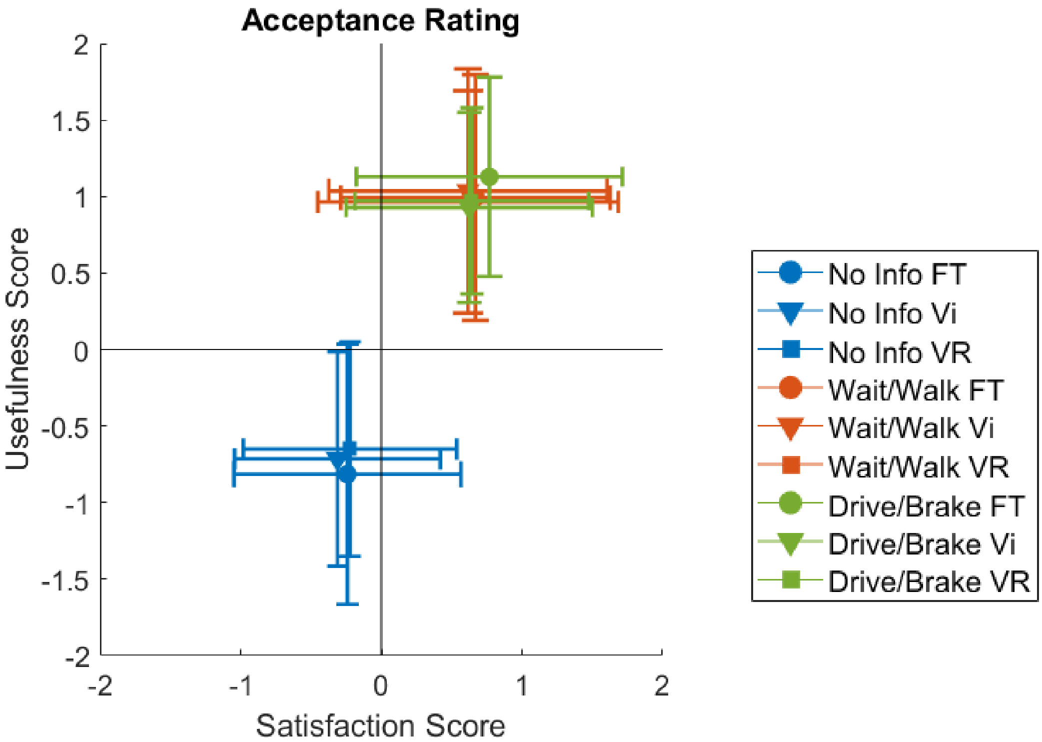


Figure 3.9: VdL Acceptance ratings as indicated by error bars for standard deviation. The intersection of the bars mark the mean acceptance rating, with a shape indicating the environment: *circle*: field test (FT), *triangle*: 360° video (Vi), *square*: virtual reality (VR). The colour indicates eHMI type: *blue*: No Information, *orange*: Wait/Walk, *green* Drive/Brake. A significant difference has been found for the η = No information provided compared to Wait/Walk or Drive/Brake information.

Table 3.1: Examples of answers to the question *"Do you have any comments about the interface?"*

Baseline (No Info)	**Egocentric (Wait/Walk)**	**Allocentric (Drive/Brake)**
If not switched on, it makes me hesitate about the performance of the car	Feels unnatural that the car tells you what to do.	Very clear, completely trusted
I noticed that when the screen was not used, I would also feel myself more encouraged to cross as I did not see the red, bright light.	Better due to power relationship (car stronger then trespasser) pedestrian	Not as good as previous display as I didn't really trust the intent of the car (less processed than previous display)
It raises alertness	I find it hard to trust the vehicle or driver with the responsibility of whether I can walk or not. I rather decide that for myself	The interface made it clear what the car was going to do, so I could adjust my decisions accordingly.

Table 3.1: Examples of answers to the question *"Do you have any comments about the interface?"*

Baseline (No Info)	**Egocentric (Wait/Walk)**	**Allocentric (Drive/Brake)**
It didn't strike me it was there	The instructions were clear and it made it easier for me to notice the cars intentions. I still waited to notice a deceleration though.	Brake/Drive is useful since it confirmed my intuition that the vehicle is brake/speeding up. It is like a second check on your initial intuition so it is useful and allows you to build more trust in the machine without putting full trust in it
The display created the feeling of distrust, you are not sure if it is going to show something or not	Unsafe, prone to ignoring the advice. It's not personal, does not give a clear indication whether the message is meant for you	Focused on both display and vehicle's speed and distance
Make it more aerodynamic/ Make invisible when not used	I don't trust that the vehicle knows when it is safe for me to walk. What if there are more vehicles? Then it wouldn't be safe to cross	Confusing information (drive, brake)
Contact with driver expected	Wait/Walk better than Drive/Brake, since that provides me with clear instructions	Brake is useful, drive is not

3.6. Subjective Perception

Using an open question after each GA task, participants were asked to indicate how they thought that the vehicle was operating. A significant difference has been found for the type of environment, $F(2,54) = 4.523$, $p = .018$ and eHMI, $F(2,54) = 7.909$, $p = .002$. A larger number of participants think the vehicle is automated when the eHMI is providing information (see Fig 3.10 and Table 3.2), compared to the η = No Information baseline. Pairwise analysis shows a significant difference between No Information-Drive/Brake ($p = .008$) and No Information-Wait/Walk ($p = .003$), but not between Wait/Walk and Drive/Brake.

3.7. Correlational Analysis

An exploratory correlational analysis has been performed among the demographic factors and the dependent variables. Since distance and time representations of the variables are inherently correlated, only the latter are evaluated. Strong, statistically significant correlations ($r \geq 0.70, p < 0.05, N = 28$) are shown in boldface type. As can be seen in the table, the demographic factors do not correlate substantially with other metrics. However, the safe to cross percentages for Wait/Walk and Drive/Brake are strongly correlated with the percentage for No Information in the nonyielding scenario ($r = 0.78, p < 0.01, N = 28$ and $r = 0.85, p < 0.01, N = 28$, respectively). The same effect can be observed in the yielding scenario, although only statistically significant for the Wait/Walk eHMI ($r = 0.75, p < 0.01, N = 28$). Additionally, all time to collision values in the nonyielding scenario are strongly correlated with each other, while the correlation is less significant in the yielding scenario. However, each time to collision value in a yielding scenario correlates with it's nonyielding value for the same eHMI. Furthermore, a strong significant correlation has been found among the time to collision and decision efficiency in the nonyielding, Drive/Brake scenario ($r = 0.75, p < 0.05, N = 28$). Finally, the number of decision reversals seems to correlate strongly with both the efficiency ratio and the time to collision.

The usefulness and satisfying components of the Acceptance scale are strongly correlated with each other, but not with other variables. The correlations between the Van der Laan components are shown separately in Table C.4.

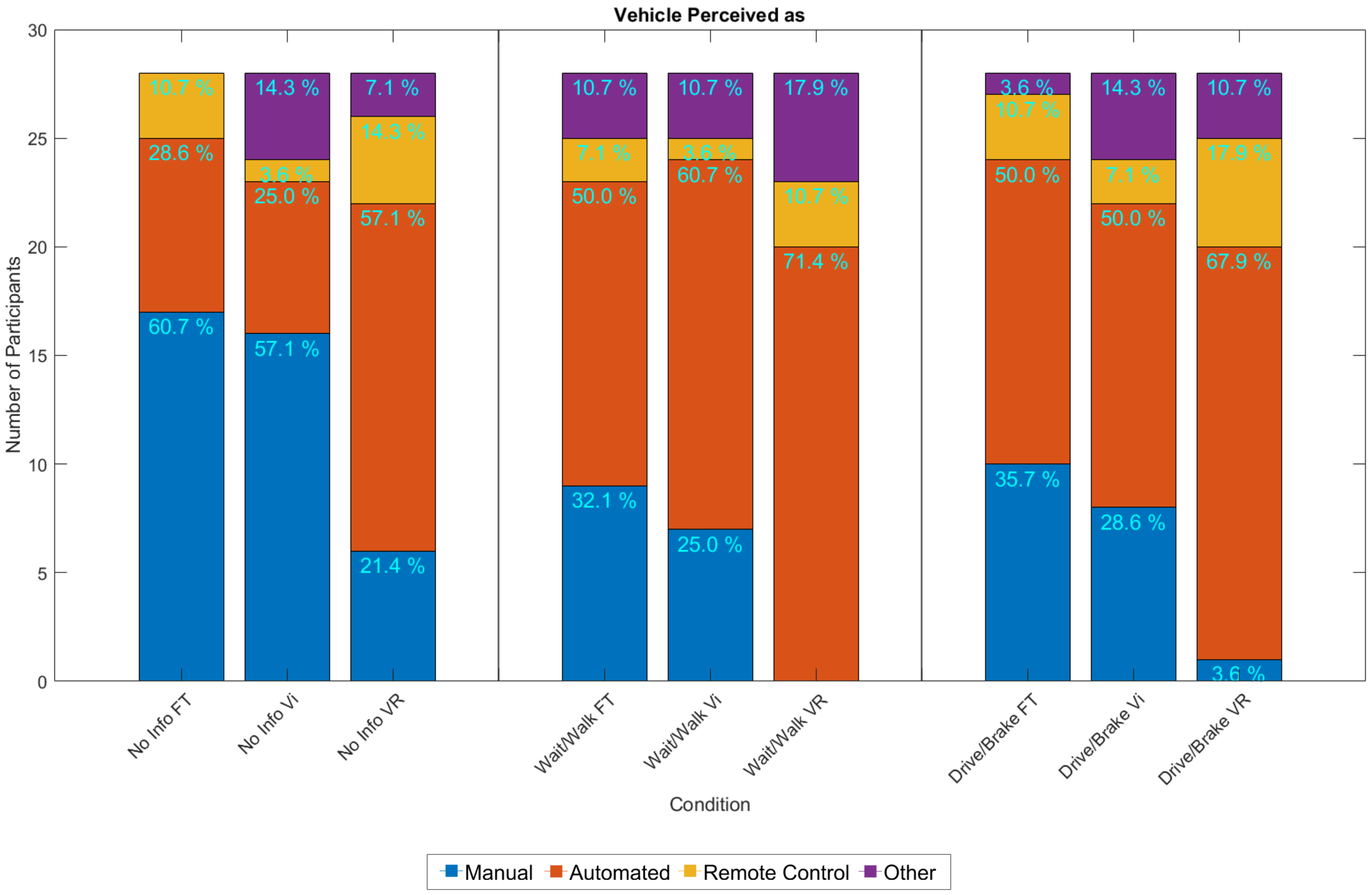


Figure 3.10: Histogram of the responses to the question *How do you think the vehicle was driving (e.g. autonomously, steering wheel, remote controlled)?* The responses are shown separately for eHMI type η: No Information, Wait/Walk and Drive/Brake. In each group the first bar represents the field test (FT), the second 360° video (Vi), and the last bar shows virtual reality (VR).

Table 3.2: Means and standard deviations for dependent metrics, including statistical tests.
The p-values in the table only represent the significance of the effect of the eHMI. If Mauchly's test resulted in $p > 0.05$, the assumption of sphericity was confirmed. Values were corrected using Greenhouse-Geisser estimates when the assumption was violated. The subjective metrics were evaluated once for each eHMI and do not have separate entries for the Yielding (Y) and Nonyielding (NY) states. Note that the perception ratings were converted into numerical values for statistical analyses.

		No Info (NO)		**Wait/Walk (WW)**		**Drive/Brake (DB)**				**Pairwise Comparison**		
Metric	Yielding ψ	mean	SD	mean	SD	mean	SD	sphericity	p	NO-DB	DB-WW	NO-WW
Distance Feeling Safe [%]	Yielding	50.444	22.171	63.641	27.843	62.684	28.548	corrected	0.001	0.01	-	0.002
	Nonyielding	48.366	19.319	40.219	20.871	45.999	17.926	confirmed	0.001	-	0.03	0.002
Time-Based Button Press Ratio [%]	Yielding	58.287	24.539	56.555	19.895	52.674	23.543	corrected	0.135	-	-	-
	Nonyielding	48.620	19.216	40.155	20.663	46.171	17.730	confirmed	0.000	-	0.02	0.001
Accepted gap in distance [m]	Yielding	44.582	17.715	37.305	23.794	38.783	24.256	corrected	0.03	-	-	0.05
	Nonyielding	42.221	15.691	47.750	16.986	43.130	14.088	confirmed	0.01	-	-	0.02
Time To Collision [s]	Yielding	17.03	4.623	14.537	6.352	14.783	6.815	corrected	0.000	0.011	-	0.001
	Nonyielding	5.47	2.230	6.181	2.354	5.542	1.862	corrected	0.02	-	-	0.05
Decision Reversals	Yielding	4.083	1.622	3.048	1.258	3.148	1.534	corrected	0.000	0.001	-	0.000
	Nonyielding	1.48	0.635	1.440	0.812	1.536	0.768	corrected	0.394	-	-	-
Satisfaction [-2 2]	-	-0.259	0.758	0.634	0.994	0.679	0.877	corrected	0.000	0.000	-	0.002
Usefulness [-2 2]	-	-0.726	0.748	0.998	0.768	1.010	0.625	corrected	0.000	0.000	-	0.000
Perceived as [1-4]	-	2.345	1.384	3.155	1.197	2.988	1.266	corrected	0.001	0.008	-	0.003

Table 3.3: Pearson Correlation Matrix for dependent metrics and demographic factors, with strong correlations that are statistically significant in **bold**. N = 28..

	Metric	1	2	3	4	5	6	7	8	9	10	11	12
1	Age (years)												
2	Gender (1: female, 2: male)	0.08											
3	Driver's License (1: no, 2: yes)	-0.21	-0.08										
4	Travel by car, normalised (0: never, 1: daily)	-0.31	-0.13	0.33									
5	Yearly driving distance (10.000 km)	-0.28	-0.03	0.34	**0.84**								
6	Travel by foot, normalised (0: never, 1: daily)	-0.22	0.07	0.07	0.03	0.02							
7	Wearing glasses (1: no, 2: lenses, 3: yes)	-0.02	0.10	-0.30	-0.43	-0.36	0.01						
8	Colour blindness (1:no, 2: yes)	-0.17	0.13	0.15	0.23	0.15	0.23	-0.20					
9	Video game playing, normalised (0: none, 1: weekly or more)	0.14	0.41	0.20	-0.16	-0.11	-0.09	0.14	-0.10				
10	VR experience, normalised (0: none, 1: multiple times)	0.18	-0.19	-0.15	0.18	0.14	0.05	-0.20	0.10	-0.18			
11	Sensation seeking score [%]	-0.09	0.17	0.11	0.36	0.36	0.08	-0.40	0.37	-0.24	0.27		
12	Trust in automation score [%]	-0.32	-0.10	0.13	-0.03	0.07	-0.24	0.06	0.07	0.16	-0.12	0.10	
	Time-Based Button Press Ratio [s/s] (Decision Efficiency)												
13	- Nonyielding, No Information [%]	0.43	0.21	0.21	0.05	-0.03	-0.21	-0.23	0.11	0.00	0.21	0.27	-0.24
14	- Nonyielding, Wait/Walk [%]	0.22	0.25	0.13	0.01	-0.09	-0.24	-0.21	0.22	0.07	0.23	0.17	-0.16
15	- Nonyielding, Drive/Brake [%]	0.32	0.26	0.12	0.15	0.04	-0,25	-0,21	0.10	0.19	0	0.15	-0,19
16	- Yielding, No Information [%]	0.17	0.05	0.08	0.10	-0,01	-0,20	-0,15	-0,11	-0,04	0.28	-0,07	-0,51
17	- Yielding, Wait/Walk [%]	0.24	0.25	-0,04	-0,19	-0,20	-0,14	-0,05	-0,04	0.05	0.03	-0,14	-0,35
18	- Yielding, Drive/Brake [%]	0.13	0.29	0	-0,15	-0,23	0.04	-0,08	-0,01	0.24	-0,11	-0,20	-0,31
	Time to Collision (Gap Acceptance)												
19.	- Nonyielding, No Information [s]	0,13	0.030	-0,09	0.18	0.030	0	-0,19	0.11	-0,20	-0,02	-0,01	-0,47
20	- Nonyielding, Wait/Walk [s]	0.24	-0,04	0.07	0.20	0.07	0.07	-0,16	-0,01	-0,03	-0,01	0.01	-0,40
21	- Nonyielding, Drive/Brake [s]	0.15	-0,01	0.04	0.07	-0,09	-0,01	-0,09	0.06	-0,20	0.12	0.05	-0,42
22	- Yielding, No Information [s]	0.24	0.07	0.04	0.03	-0,12	-0,07	-0,16	0.12	-0,05	-0,04	0.03	-0,33
23	- Yielding, Wait/Walk [s]	0.32	0.10	0.12	0.13	0.04	0.07	-0,25	0.22	-0,03	0.08	0.23	-0,40
24	- Yielding, Drive/Brake[s]	0.33	-0,04	0.13	0.11	-0,08	-0,03	-0,14	0.19	-0,09	0.17	0.16	-0,23
	Decision Reversals (Decision Certainty)												
25	- Nonyielding, No Information	0.18	0.20	0.03	-0,04	-0,18	-0,07	0.02	0.11	-0,03	0.06	0.17	-0,24
26	- Nonyielding, Wait/Walk	0,30	0.25	0.08	0.12	0.04	-0,30	0	0.06	-0,01	0.11	0.37	-0,11
27	- Nonyielding, Drive/Brake	0.40	0.18	-0,10	0.10	-0,01	-0,21	0.03	0.06	0.06	0.10	0.15	-0,24
28	- Yielding,No Information	0,26	0.13	-0,07	0.02	-0,06	-0,09	-0,04	0.02	-0,05	0.02	-0,05	-0,35
29	- Yielding Wait/Walk	0.42	0.04	0.12	-0,04	-0,08	0.00	-0,15	0.06	-0,16	0.09	0.03	-0,52
30	- Yielding, Drive/Brake	0.47	0.15	0	0.030	-0.15	0.08	-0.11	0.21	-0.01	0.07	0.07	-0.35
	Mean	25.1	1.8	1.8	0.41	0.33	0.83	1.7	1.1	0.42	0.74	59.0	49.9
	Standard Deviation	2.49	0.41	0.43	0.35	0.36	0.21	0.88	0.25	0.25	0.24	17.0	8.44

Pearson correlation matrix for dependent meatrics and demographic factors (continued)

		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	Time-Based Button Press Ratio [s/s] (Decision Efficiency)																	
14	- Nonyielding, Wait/Walk [%]	**0.78**																
15	- Nonyielding, Drive/Brake [%]	**0.85**	**0.81**															
16	- Yielding, No Information [%]	0.66	0.59	0.54														
17	- Yielding, Wait/Walk [%]	0.70	0.66	0.62	**0.75**													
18	- Yielding, Drive/Brake[%]	0.57	0.64	0.69	0.70	**0.81**												
	Time to Collision (Gap Acceptance)																	
19	- Nonyielding, No Information [s]	0,37	0.35	0.45	0.66	0.60	0.66											
20	- Nonyielding, Wait/Walk [s]	0.49	0.21	0.46	0.66	0.55	0.61	**0.83**										
21	- Nonyielding, Drive/Brake [s]	0.44	0.33	0.34	**0.75**	0.57	0.59	**0.88**	**0.84**									
22	- Yielding, No Information [s]	0.58	0.46	0.57	0.71	0.70	0.74	**0.90**	**0.90**	**0.91**								
23	- Yielding, Wait/Walk [s]	0.53	0.34	0.48	0.61	0.39	0.54	0.72	**0.83**	0.79	0.84							
24	- Yielding, Drive/Brake [s]	0,55	0.28	0.40	0.52	0.33	0.36	0.62	0.77	**0.78**	0.78	0.80						
	Decision Reversals (Decision Certainty)																	
25	- Nonyielding, No Information	0.64	0.64	0.59	0.59	0.65	0.64	0.60	0.59	0.71	0.76	0.60	0.59					
26	- Nonyielding, Wait/Walk	**0.74**	0.66	**0.70**	0.52	0.46	0.47	0.49	0.50	0.56	0.61	0.56	0.56	0.68				
27	- Nonyielding, Drive/Brake	0.67	0.51	0.69	0.49	0.52	0.47	0.49	0.63	0.49	0.61	0.53	0.50	0.64	0.68			
28	- Yielding, No Information	0.58	0.47	0.56	**0.71**	0.69	0.67	**0.82**	**0.83**	**0.85**	**0.89**	0.73	0.74	**0.77**	0.62	0.66		
29	- Yielding, Wait/Walk	0.68	0.50	0.56	**0.75**	**0.73**	0.65	**0.78**	**0.80**	**0.82**	**0.86**	0.79	0.67	0.68	0.53	0.59	**0.78**	
30	- Yielding, Drive/Brake	0.64	0.45	0.57	0.46	0.48	0.46	0.59	0.69	0.63	0.70	0.63	0.79	0.58	0.59	0.66	**0.77**	0.63
	Mean	48.6	40.2	46.2	58.3	56.6	52.7	5.47	6.18	5.54	17.0	14.5	14.8	1.48	1.44	1.54	4.08	3.05
	Standard Deviation	19.2	20.7	17.7	24.5	19.9	23.5	2.23	2.35	1.86	4.62	6.35	6.82	0.64	0.81	0.77	1.62	1.26

4 Discussion

The aim of this study was to investigate the effects of an eHMI providing allocentric and egocentric information on pedestrian crossing decisions, in terms of decision efficiency, initial gap acceptance, decision certainty and subjective acceptance. The objective metrics were measured continuously in three different experimental environments to reduce biases influenced by a specific test method, and to obtain heterogeneous test data that could potentially be generalised or compared compare with other research. The metrics have been elaborated in the previous section. Here, the results will be interpreted and related to the four hypotheses.

The results show that the amount of distance the participants feels safe to cross is significantly larger for both the Drive/Brake and Wait/Walk eHMI in the yielding scenario. Conversely, the amount of distance feeling safe is significantly lower in nonyielding scenarios. This shows that over the whole scenario, the pedestrian intention is more in line with the intentions of the vehicle, as the behaviour can be better predicted, which confirms the Decision Efficiency hypothesis. This effect has also been found in previous research [34]. In nonyielding scenarios, the egocentric Wait/Walk information has a significantly stronger effect than the allocentric message. In yielding scenarios, the effect is also larger for Wait/Walk but not significantly distinct, which could be due to the fact that participants rely mostly on the eHMI state change rather then the content of the message on larger distances. When the data is merged with the vehicle's speed to enable a comparison in the time domain, the effect is only present in the nonyielding scenario. In the yielding case, no significant effect can be observed. This could have been caused by slight differences in the speed profile between trials, as this metric is susceptible to changes in vehicle speed.

4.1. Gap Acceptance

Now it has been found that the presence of an eHMI does increase decision efficiency, it would be interesting to further investigate the underlying mechanism of this effect, which has not been investigated before. The higher efficiency may be contributed to one or multiple factors as found in literature: improved signalling [8][9]), better comprehension of others [2][10], or improved prediction of future events [7]). An exploratory investigation has been conducted, guided by the gap acceptance and decision certainty metrics. It has been argued that an improved initial signalling of vehicle behaviour would lead to earlier crossing decision. For this, the accepted initial gap has been evaluated by means of a hypothetical time to collision. Effects for the Wait/Walk eHMI have been found, with a lower TTC in yielding scenarios, and higher TTC in nonyielding scenarios. This indicates that the eHMI pedestrians tend to make their decision not to cross in an earlier stage due to the early signal of the eHMI. Furthermore, the signal that the vehicle would stop seems to have convinced participants to accept smaller safety margins in yielding scenarios. Thus, the first hypothesis is confirmed. This indicates that a significant portion of participants trusted the information from the eHMI to make a decision.

4.2. Decision Certainty

It is argued that any later changes in the pedestrian decision would be caused by better vehicle comprehension. For this, the changes in the crossing decision were counted to calculate a decision reversal rate; a binary statistic similar to the steering wheel reversal rate in driving simulators. It seems that the second hypothesis can be confirmed as the eHMI significantly lowers the amount of changes in the decision to cross the road in the yielding scenario. In the nonyielding scenario, the same trend can be observed, although it is not statistically significant. Interestingly, the Drive/Brake information has a slightly negative effect on decision reversals in nonyielding scenarios. It is assumed that this might be caused by the higher ambiguity of the allocentric information, as language appears to be processed from an egocentric perspective [35].

The number of decision reversals with eHMI is strongly correlated to the number of reversals without eHMI, especially for the yielding scenario. This might indicate that there are reliable individual differences, even though this metric is correlated with multiple other measures as well. The number of reversals is also strongly correlated with the decision efficiency metric, more so then the time to collision values. Thus, instead of early signalling of vehicle behaviour, the major improvement in decision efficiency could be attributed to the higher pedestrian certainty, as the eHMI appears to improve comprehension of vehicle behaviour. However, strong correlations with the time to collision value can be observed as well, so solid conclusions about the working mechanism of the eHMI cannot be drawn.

4.3. Subjective Acceptance

A better comprehension of vehicle behaviour seems to be related to higher subjective acceptance ratings. Both the usefulness and satisfying components of the Van der Laan scale [57] are significantly higher for an eHMI that is providing Wait/Walk or Drive/Brake information, compared to no information. Regarding this difference, it is pointed out that the eHMI was also attached to the vehicle when it was not providing any information. This might have resulted in a lower rating, as a vehicle with an empty screen or sign has an appearance different from a conventional vehicle. For example, at least 25% of participants indicate 'automated' as driving mode after interacting with the (manually driven) test vehicle, presumably because of this appearance. Interestingly, no differences had been found between conventional and automated appearances in some prior work [37][29], so more research is required to fully understand the extent to which vehicle appearance influences pedestrian behaviour.

Furthermore, the subjective assessment of the type of information seems to be subject to personal preference. On one hand, several participants indicate they prefer the egocentric Wait/Walk information as it this type of information is easy to follow and clear, and it reflects the power relationship between a pedestrian and a vehicle. On the other hand, some participants found Wait/Walk information confusing and prone to ignorance, as it was not clear for whom the message was meant. For these participants, Drive/Brake information was preferred as it was regarded as assisting, raising alertness or as providing an extra layer of confidence. As a conclusion, the presence of information improved pedestrian acceptance, so the second hypothesis has been confirmed, although no differences between the type of information have been observed.

4.4. Information Type

In the previous paragraphs, the effects of the eHMI were explained. It was expected that these effects would be more distinct for an eHMI that is clearer and less ambiguous. However, no significant effects between the two types of information were observed for most metrics. Only in the nonyielding scenario, the egocentric eHMI had the strongest effect on decision efficency. In the other scenarios and metrics, there appears to be a trend in the same direction. As such a trend is not significant, however, this hypothesis cannot be confirmed.

Furthermore, care should be taken in directing egocentric information as "There is also a risk that the AV will provide false or at least risky advice to other traffic participants, and it is also challenging to know which traffic participant is the target of such information." [36], which could be a reason to avoid egocentric information in certain cases [60][49][61][62]. One might also debate any legal implications of providing an egocentric message (if any, as it is common on traffic lights in certain parts of the globe). Finally, an allocentric message that simply shows the vehicle's state to the outside world could be simpler to develop [25].

A possible explanation for the small differences in subjective acceptance between the two types of information could be given by the difficulty to rate an eHMI that has two different states. For example, some participants reported that the display was useful for an early detection of deceleration, e.g. "Brake is useful, drive is not". However, the ratings were constrained to one rating per type of information. Secondly, the ratings for Drive/Brake and Wait/Walk might be similar, as the difference between the types of information is hard to notice at larger distances, especially when the lower resolution of the HMDs is taken into account. Some participants indicated that they relied mostly on the change of colour, rather than the exact wording on the display. Individual differences indicate that human perception and behaviour is different and can not be generalised. The a priori knowledge that is required to get trough traffic is regarded as being biologically encoded in our brain, learned, or based on previous experiences (thus somewhat context-dependent) [63]. Consequently, the crossing decision can vary significantly based on demographic factors and personal experiences [64], which is also evident from the considerable variances in the data.

4.5. Usability of Test Methods

As found in Agarwal et al. [1], the level of fidelity of the environments was sufficient for conducting experiments regarding interaction between pedestrians and automated vehicles. Small differences in the results have been found, which can be attributed to various factors, such as differences in fidelity, resolution or the low sample size. No significant differences in presence or sickness have been found, which could indicate that an HMD can be used.

4.6. Conclusion

The results of this study confirm that an eHMI attached to a vehicle increases decision efficiency, i.e. more participants feel safe to cross when it is safe to do so. This can be contributed to multiple underlying mechanisms: Differences in the accepted time to collision that might be related to better detection of vehicle cues at a larger distance range, as well differences in the amount of decision changes during the scenario, which could reflect the increased certainty due to better comprehension of vehicle behaviour. Decision efficiency seems to have a stronger correlation with the decision reversals then with the time to collision values, although more research is required to fully understand the working principles of an eHMI. Subjectively, more pedestrians tend to think the vehicle is automated when an eHMI is providing information. Overall, having one type of information significantly differs from having no information, but significant differences between allocentric and egocentric information have only been found for decision efficiency. This suggests that a final choice for a certain type of information could be made on the basis of other factors than pedestrian behaviour only. Finally, using this and other research, car makers might eventually find the optimal properties for a standardised and regulated eHMI design.

5 Limitations and Future Work

Based on the findings and limitations in this study, the following recommendations are made:

- The visibility of the eHMI in the Virtual Reality and Video environments was limited do to constraints in the equipment, which could have affected the results, as pedestrians indicated to rely on state change of the eHMI rather then the state itself. Equipment with higher resolution and larger field of view could improve this. Furthermore, no avatar was implemented in these environments (no feet or legs were shown) and no pedestrian movement was involved. Although no differences in presence have been found, and earlier work did not find differences [65], this could have affected fidelity.
- The absence of movement might have affected the safety perception of the pedestrian. While the usage of a remote button allowed for the continuous measurement of the crossing decision, actual behaviour was not evaluated, which might have resulted in different accepted gaps.
- The visibility of the eHMI in the field test could change with weather conditions and the time of the day. This might have influenced the results [66][67][68]. Repetition of this test in other climates and daylight conditions [69][70] would confirm continuity of pedestrian behaviour under such circumstances.
- Although all participants were residing in The Netherlands and familiar with the road layout, the sample size of this work is limited. In addition to the limited number, the group is homogeneous as all participants were students. A repetition with other age groups could improve generalisability of the findings.
- The reserach was conducted using a European road layout, in an unambiguous scenario. In other parts of the world, regulations and road layout could differ [71][72][73][74]. The scenario was quite simple and did not involve other traffic. The presence of multiple vehicles or pedestrians might lead to different results, as traffic conditions could influence pedestrian behaviour [75], especially at different speeds [10][76][77][78][79].
- As allocentric information is assumed to require more cognitive processing, this type of information could lead to different pedestrian response times. Reaction times were not evaluated in this work. By having a more precise setup (such as a differential GPS with a higher update rate), reaction times could be measured for different eHMIs as well.
- The effect of learning was not examined, as pedestrians encountered each eHMI for one time in each environment. By involving more repetitions in each environment, learning could have been evaluated. Learning effects could matter, as the ability to 'read the road' is gained with experience, and the eHMI is a relatvely new concept. Furthermore, the meaning of an eHMI that is currently not regarded as clear as a plain text could be trained or learned. A symbol, for example, is rated as more ambiguous, but has other advantages, as it removes the need to understand a language.
- In this work, the eHMI was assumed to provide correct information, in line with the (future) state of the vehicle. In a realistic scenario, this might not be the case (for example, when the system fails). The negative aspects of providing an incorrect message should be investigated and weighed against the positive effects of the eHMI.
- In this work, a visual text eHMI has been evaluated. The readability of such an interface is dependent on the size of the screen, and the clarity is language dependent. Implementation of a red colour in front of a vehicle might cause legal difficulties. A combination of multiple types of information and modalities, such as projections or sounds, might lead to other results, as different types of modalities are suited for different types of feedback.

A

Specification of Materials

GPS Module

A 10 Hz GPS module has been created, based on the uBlox Neo-6M GPS sensor connected to a computer via an Arduino and USB-B (see Fig A.1 (right) and Table A.1).

Table A.1: Specifications of the uBlox Neo-6M

Receiver type	50 Channels GPS L1 frequency, C/A Code SBAS: WAAS, EGNOS, MSAS
Maximum navigation update rate	10 Hz
Horizontal position accuracy	2.5 m
Velocity accuracy	0.1 ms^{-1}
Heading accuracy	0.5 degrees
Time pulse signal accuracy	RMS: 30 ns
Position	1.20 m from front

eHMI

The eHMI has been developed for this research. 12 m of LED strip is attached to an U profile that fits within the frontal lights of the test vehicle. The test equipment is located on the inside of the profile for protection. The frontal area of the LEDs is covered in transparent polycarbonate. The technical drawing for laser cutting the front of the LED display in polycarbonate has been included on the following page. A software-rendered example of the eHMI messages for different types of information and different states is shown in Fig. A.3. The assembled eHMI attached to the vehicle is shown in Fig. A.1 (left). For analysis in the virtual reality environment, photos from the real eHMI were imported into the animated VR environment using Unity software (see Fig A.2).

Figure A.1: *Left:* Example of the eHMI showing a WALK message. *Right:* The GPS module as packed in a small black box with the USB-B connector visible.

Figure A.2: Information type η as shown on the eHMI in the virtual reality environment, with non-yielding state (*left*) and yielding state (*right*). From top to bottom: (1) None: Baseline condition, no information displayed, (2) WAIT/WALK: Egocentric, advisory information, (3) DRIVE/BRAKE: Allocentric, vehicle-based information.

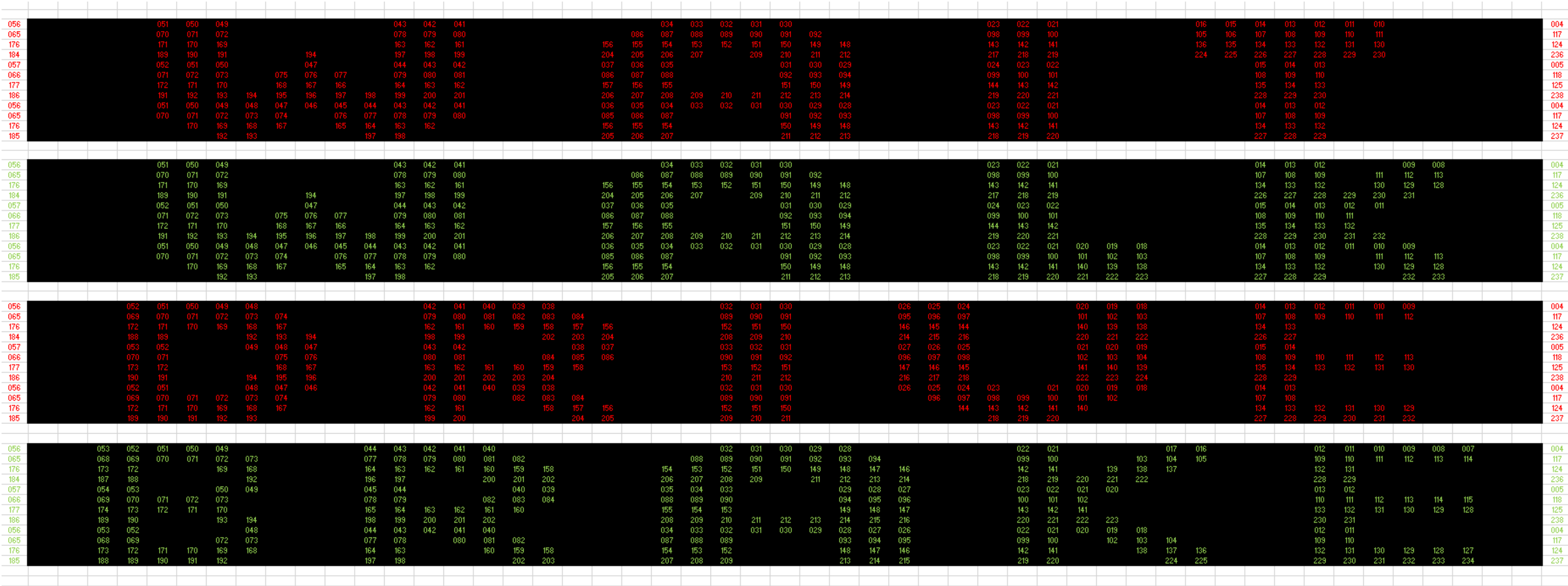
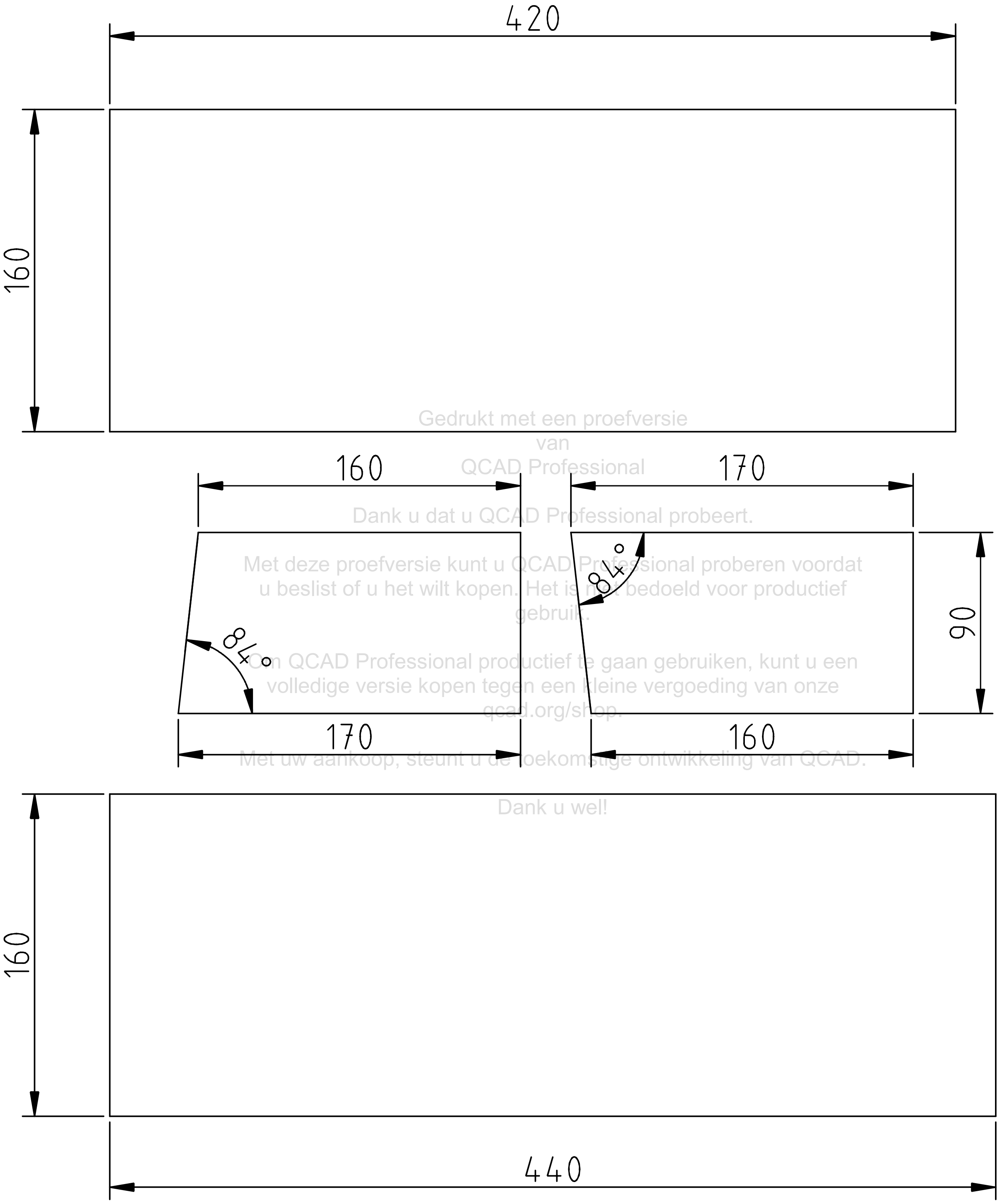


Figure A.3: Software Demo of eHMI texts. *From top to bottom:* Egocentric advisory information in the nonyielding state (WAIT) and in the yielding state (WALK), and allocentric vehicle state information for the nonyielding and yielding states (DRIVE and BRAKE, respectively).


420
160
160
170
84°
84°
90
170
160
160
440

Other Equipment

Table A.2: Specifications of the Nikon Keymission 360 Camera

Max Video Resolution	3840 x 2160
Camcorder Sensor Resolution	23.9 MP
Lens Aperture	f/2.0
Min Focal Length	1.6 mm
Max View Angle	360 degrees
Frame Rate (Max Resolution)	24 fps

Table A.3: Specifications of the Arduino Mega 2560

Microcontroller	ATmega2560
Flash Memory	256 KB (8 KB used by bootloader)
Clock Speed	16 MHz
SRAM	8 kB
EEPROM	4 kB
Connection	USB 2.0

Table A.4: Specifications of the Desktop for Simulations

Processor	Intel(R) Core i7-6700 CPU @ 3.4 GHz
RAM	16 GB Single Channel @ 1064 MHz
Operating system	Windows 10 Enterprise
Storage	500 GB Samsung SSD 850 EVO (SATA SSD) 1 TB Toshiba DT01ACA100 (SATA)
Graphics	NVIDIA GeForce GTX 1070 4GB

Table A.5: Specifications of the in-Vehicle Computer

Processor	Intel(R) Core i7-2630QM CPU @ 2.0 GHz
RAM	8 GB Dual Channel @ 665 MHz
Operating system	Windows 10 Education
Storage	238GB Samsung SSD 840 PRO (SATA SSD) 1 TB Hitachi HGST HTS721010 (SATA)
Graphics	NVIDIA Quadro 1000M 2GB

Table A.6: Specifications of the Logitech R400 button for the GA tasks

Dimensions	37.8 x 115.5 x 27.4 mm
Weight	57 g
Frequency	2.4 GHz
Range	15 m
Receiver	USB 2.0
USB VID_PID	VID_046D, PID_52D
Batteries	2x A-Force AAA Alkaline

Table A.7: Specifications of the Garmin 20 Dash cam

Dimensions	66 x 82.1 x 36.9 mm
Resolution	1080p (1920 x 1080)
Frame rate	30 Hz
Sensor	3 MP, 0.33" CMOS
Video format	AVI (H.264)
Memory	class 10 microSD

Table A.8: Specifications of the three Logitech C930e Cameras

Resolution	1080p (1920 x 1080)
Frame rate	Variable (13-15 Hz)
Field of view	30°
Video format	MP4 (H.264/SVC UVC 1.5)
Memory	PC with HDD via USB 2.0

B

Additional Illustrations

Figure B.1: The Toyota test vehicle with the eHMI mounted in front (*top*); The Iveco van used as a mobile lab for the VR or 360°-video environments during the first session (*bottom*).

Figure B.2: Participants performing the GA Task in the real environment during the first session (*left*) the same task in the VR environment during the second session (*right*).

Figure B.3: Panoramic image of the test location for the real environment.

Figure B.4: Image of the two HMDs used in the experiments: Samsung Gear VR (*left*) and Oculus Rift (*right*).

C
Additional Test Results

C.1. Presence Scores

Table C.1: Presence Questionnaire Results on a 1-7 scale for each question Q1 to Q6, with mean and standard deviation SD. The means have been compared using a one-way ANOVA. The *p* and *F* statistics are shown in the right columns.

	Environment							
Question	Field Test		360° Video		Virtual Reality			
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**p**	**F**
Q1	5.179	1.389	5.071	1.412	4.571	1.597	0.262	1.36
Q2	4.750	1.647	4.357	1.967	4.250	1.456	0.515	0.67
Q3	5.107	1.474	5.214	1.729	4.000	1.587	0.009	4.94
Q4	4.964	1.710	4.964	1.644	4.143	1.799	0.125	2.13
Q5	4.500	1.401	4.714	1.536	4.107	1.524	0.307	1.20
Q6	4.571	1.687	4.321	1.806	3.893	1.685	0.336	1.11

C.2. Distance Estimates

Table C.2: Mean, median and standard deviation in perceived distance, as estimated for six distances *s* [m], as presented in [1].

	Environment								
	Field Test			360° Video			Virtual Reality		
s [m]	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
10	9.48	10	3.49	10.59	10	5.95	9.36	09	6.08
16	15.82	13	9.30	18.50	15	11.85	15.46	15	10.31
25	24.14	23	12.58	31.40	25	20.67	27.21	20	15.50
40	40.29	35	19.23	45.54	43	22.54	45.96	40	31.91
63	62.43	58	34.01	70.29	70	31.21	75.07	60	49.44
100	103.75	95	52.52	105.71	95	50.07	110.36	95	78.90

C.3. Speed Estimates

Table C.3: Mean, median and standard deviation in perceived speed, as estimated for four speeds v [km/h], as presented in [1].

	Environment								
	Field Test			360° Video			Virtual Reality		
v [km/h]	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
20	15.32	15	6.29	18.21	20	8.18	16.79	15	8.92
30	26.43	25	9.01	28.93	30	10.57	24.82	20	9.95
40	33.57	35	11.12	39.04	40	13.75	35.36	30	11.78
50	45.07	50	10.08	50	50	11.14	46.96	50	13.97

C.4. Van der Laan Correlation

Table C.4: Pearson Correlation Matrix among Van der Laan Variables

	Measure	1	2	3	4	5	6
1	Usefulness No Information						
2	Usefulness Wait/Walk	-0,04					
3	Usefulness Drive/Brake	-0,16	0,76				
4	Satisfying No Information	0,77	-0,06	0,07			
5	Satisfying Wait/Walk	-0,04	0,83	0,53	-0,15		
6	Satisfying Drive/Brake	-0.09	0,60	0,76	0,12	0,64	

C.5. Simulator Sickness Scores

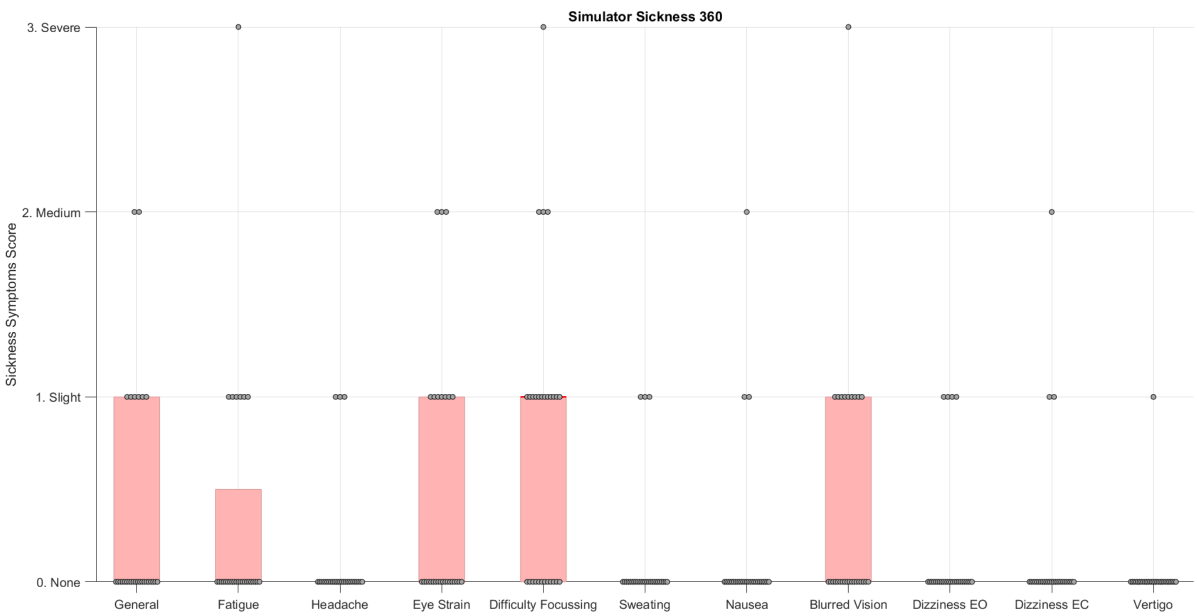


Figure C.1: Simulator Sickness results for the 360° video environment on a scale varying from 0 (no symptoms) to 3 (severe symptoms). *From left to right:* General Discomfort, Fatigue, Headache, Eye Strain, Difficulty Focusing, Sweating, Nausea, Blurred Vision, Dizziness with Eyes Open, Dizziness with Eyes Closed and Vertigo. Individual responses are marked with grey dots, a 95% confidence interval of the mean is shown in red (if available). Three participants reported moderate discomfort for one or more criteria. One participant reported severe discomfort for fatigue, difficulty focusing and eye strain.

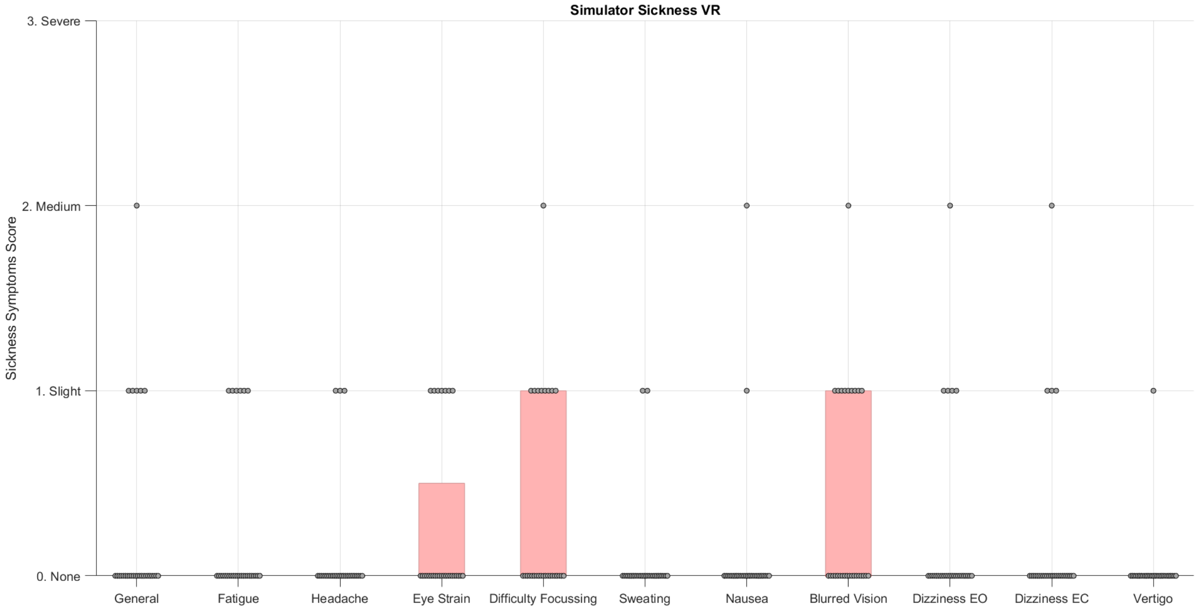


Figure C.2: Simulator Sickness results for the animated virtual reality environment on a scale varying from 0 (no symptoms) to 3 (severe symptoms). *From left to right:* General Discomfort, Fatigue, Headache, Eye Strain, Difficulty Focusing, Sweating, Nausea, Blurred Vision, Dizziness with Eyes Open, Dizziness with Eyes Closed and Vertigo. Individual responses are marked with grey dots, a 95% confidence interval of the mean is shown in red (if available). Three participants reported moderate discomfort for one or more criteria.

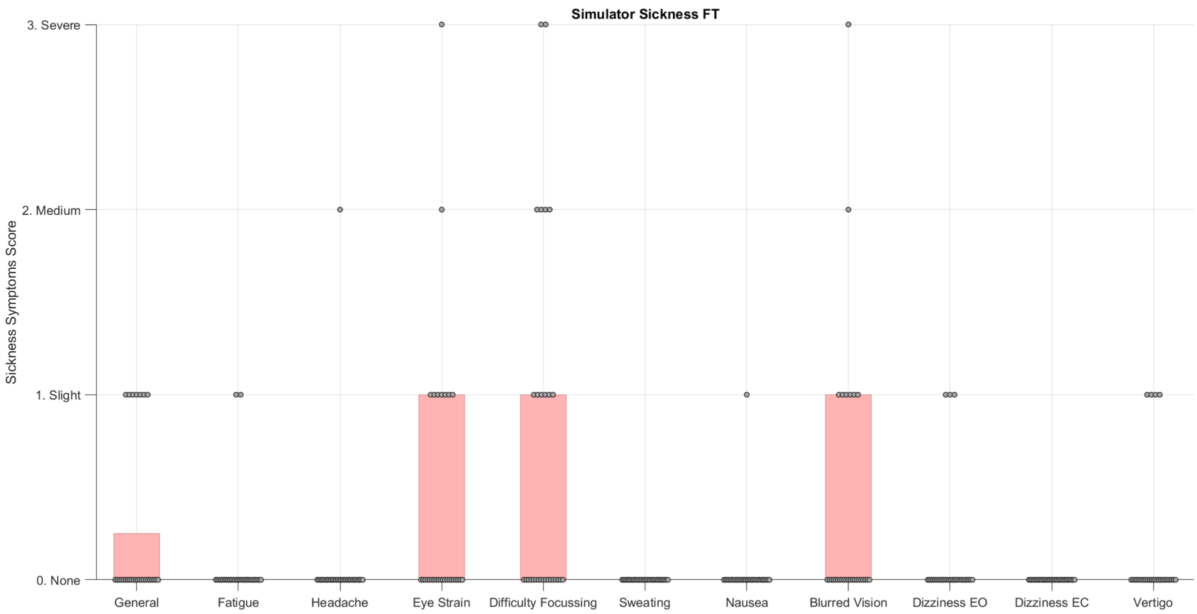


Figure C.3: Simulator Sickness results for the controlled field test environment on a scale varying from 0 (no symptoms) to 3 (severe symptoms). *From left to right:* General Discomfort, Fatigue, Headache, Eye Strain, Difficulty Focusing, Sweating, Nausea, Blurred Vision, Dizziness with Eyes Open, Dizziness with Eyes Closed and Vertigo. Individual responses are marked with grey dots, a 95% confidence interval of the mean is shown in red (if available). Four participants reported moderate discomfort for one or more criteria. Interestingly, two participants reported the highest level of discomfort for eye strain, difficulty focusing, and blurred vision in this environment, which might be attributed to residual effects of an earlier environment.

C.6. Feel Safe Percentages versus Vehicle Distance

The percentages as shown in Fig 3.4 are split out for each experimental environment in Fig. C.6 below.

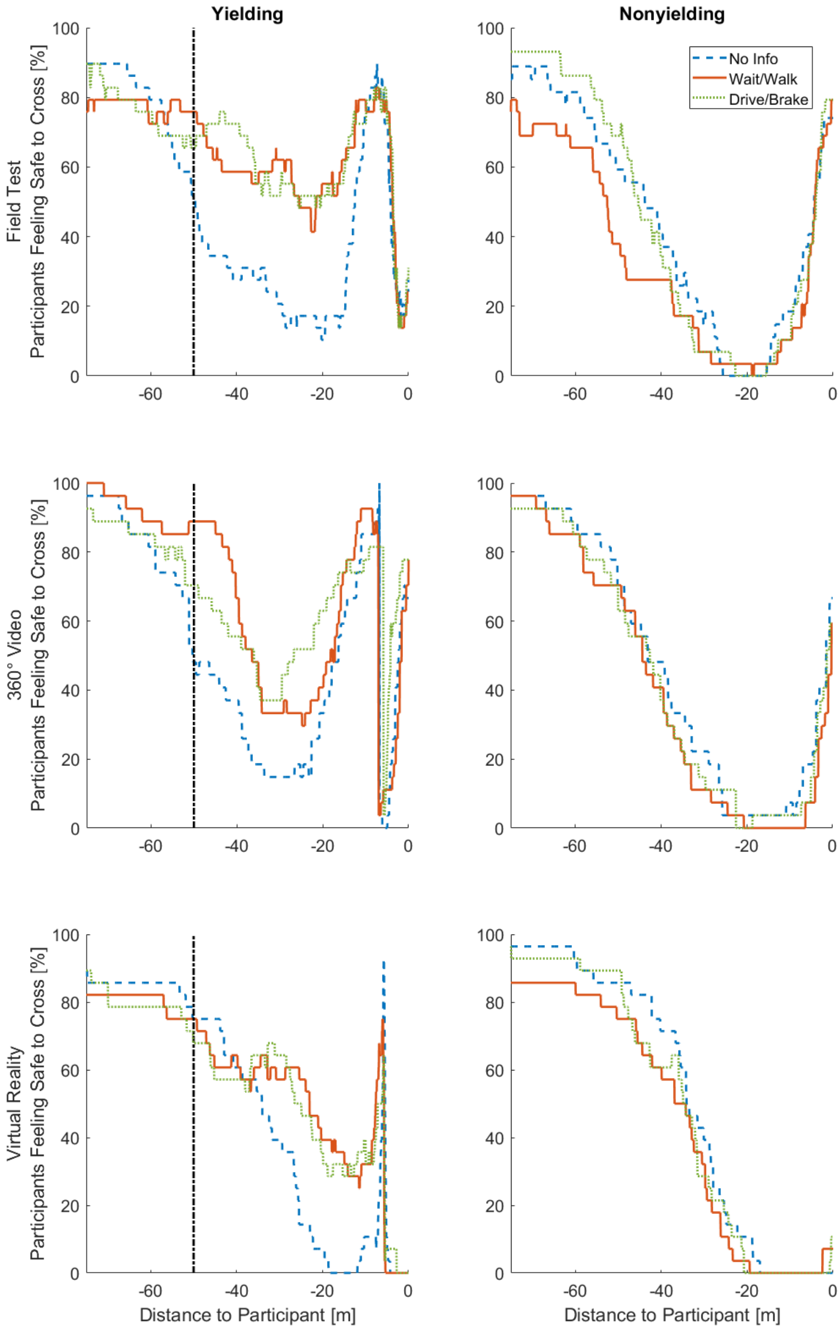


Figure C.4: The percentage of participants feeling safe to cross the road as a function of vehicle distance, for each environment. The percentage was calculated across 172 trials (Field Test), 162 (Video) and 168 (VR), respectively. The dashed blue line represents the baseline without eHMI information. The vertical dotted line shows the timing of the eHMI, i.e. when it switched from it's nonyielding to yielding state.

C.7. Spatial Feel Safe Percentages

The spatial feel safe percentages have been summarised in one boxplot for each environment for clarity.

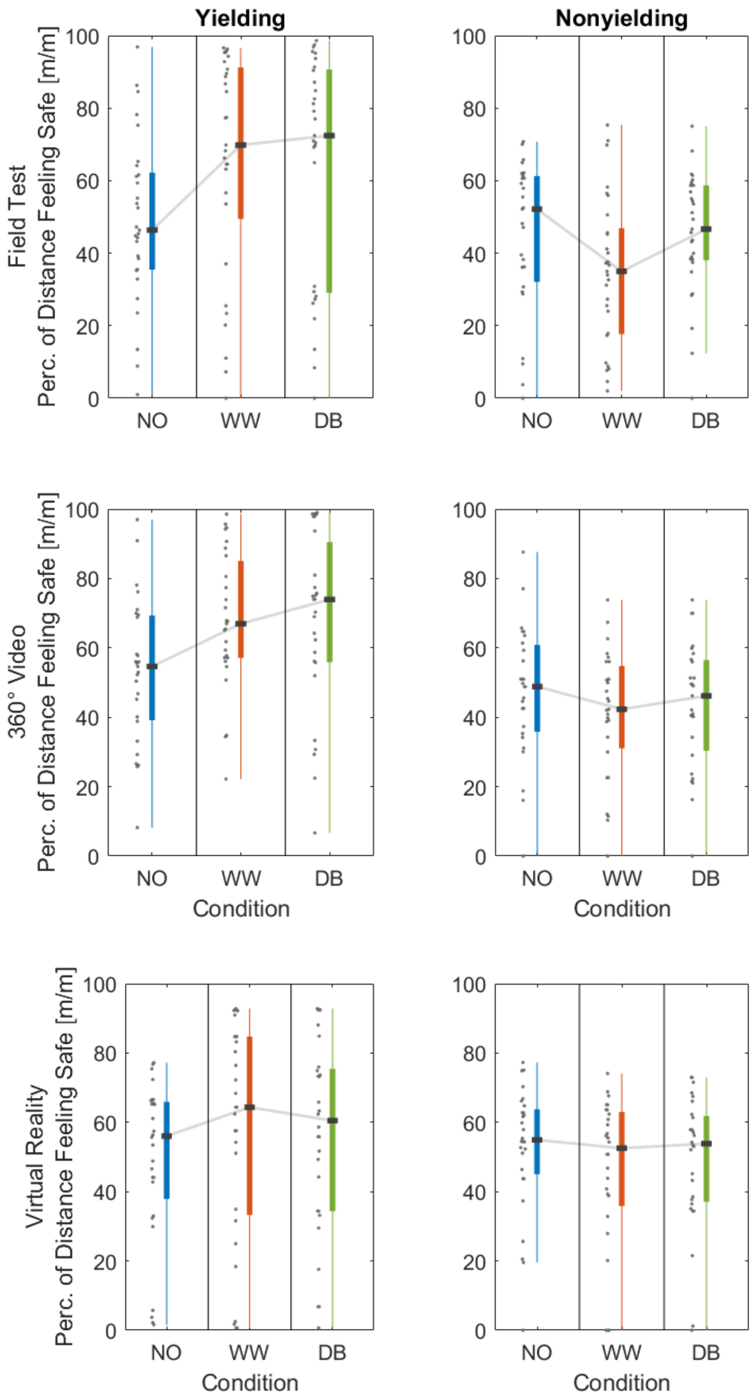


Figure C.5: The percentage of distance participants are feeling safe to cross the road, for each environment. The percentage was calculated across 172 trials (Field Test), 162 (Video) and 168 (VR), respectively. The conditions are: No information (NO), Wait/Walk (WW) and Drive/Brake (DB).

C.8. Time-based Feel Safe Percentages

The feel safe percentages are also calculated over time, in accordance with previous research. The findings have been summarised in one boxplot for each environment for clarity.

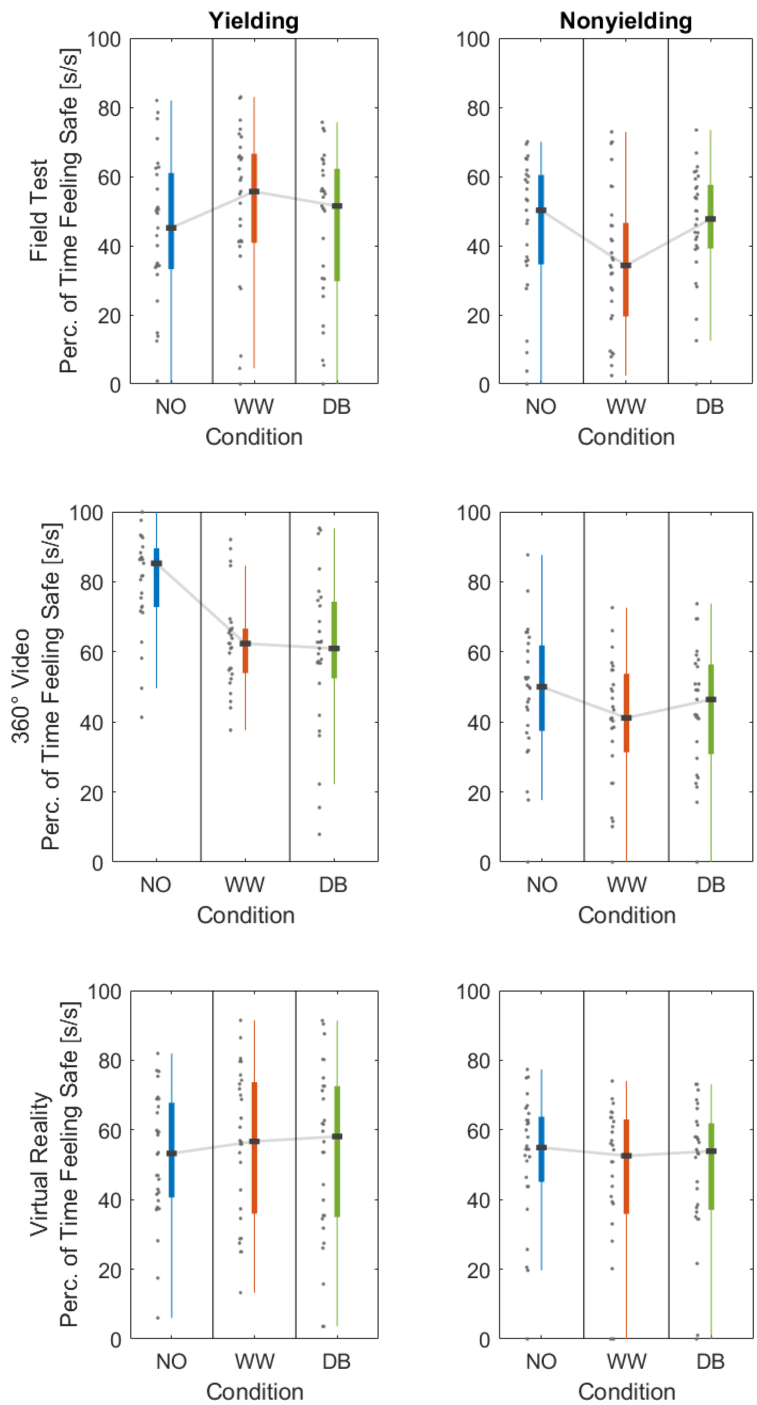


Figure C.6: The percentage of time participants are feeling safe to cross the road, for each environment. The conditions are: No information (NO), Wait/Walk (WW) and Drive/Brake (DB)

C.9. Spatial Gap Acceptance

The gap that is required by the pedestrian is defined as minimum distance the pedestrian requires before he or she does not feel safe to cross the road any more.

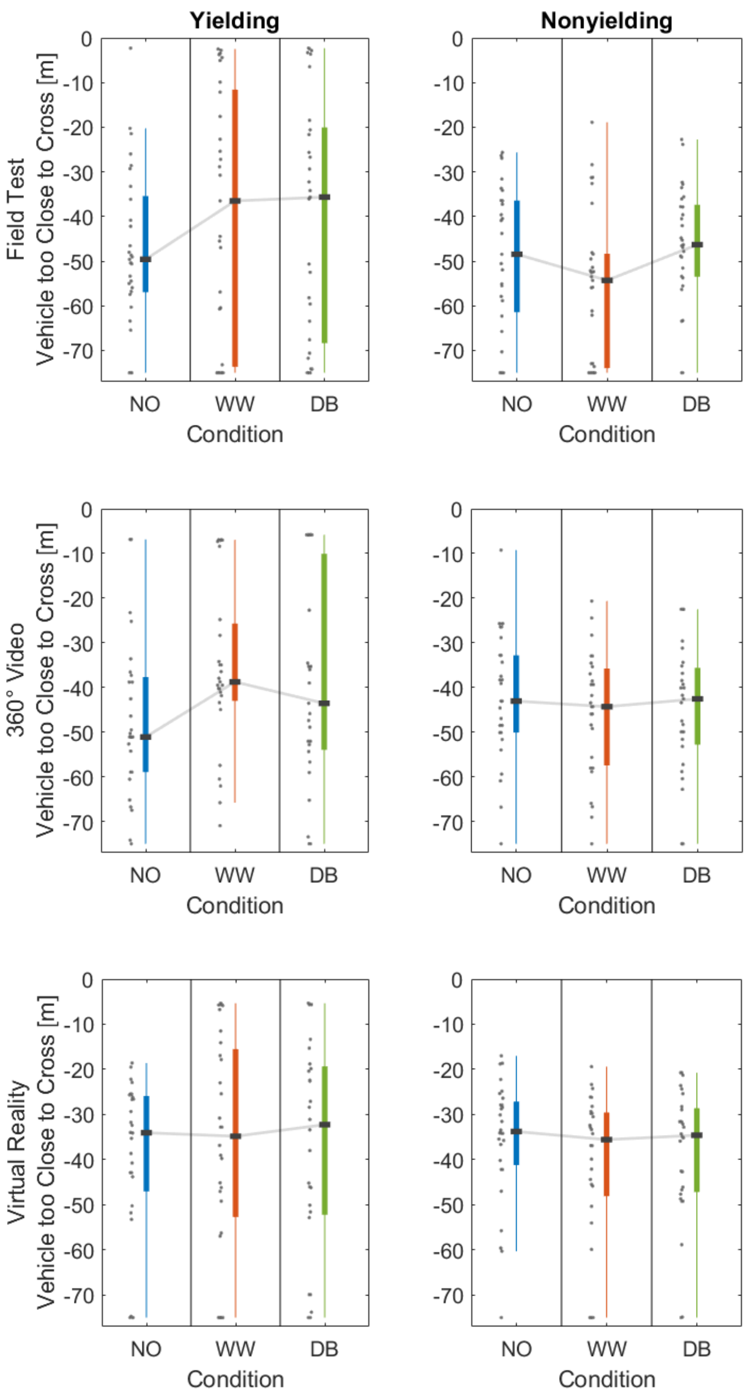


Figure C.7: Spatial gap acceptance for each environment. The conditions are: No information (NO), Wait/Walk (WW) and Drive/Brake (DB).

C.10. Time to Collision

When combining the required spatial gap with the vehicle's speed, it is possible to calculate a virtual time to collision.

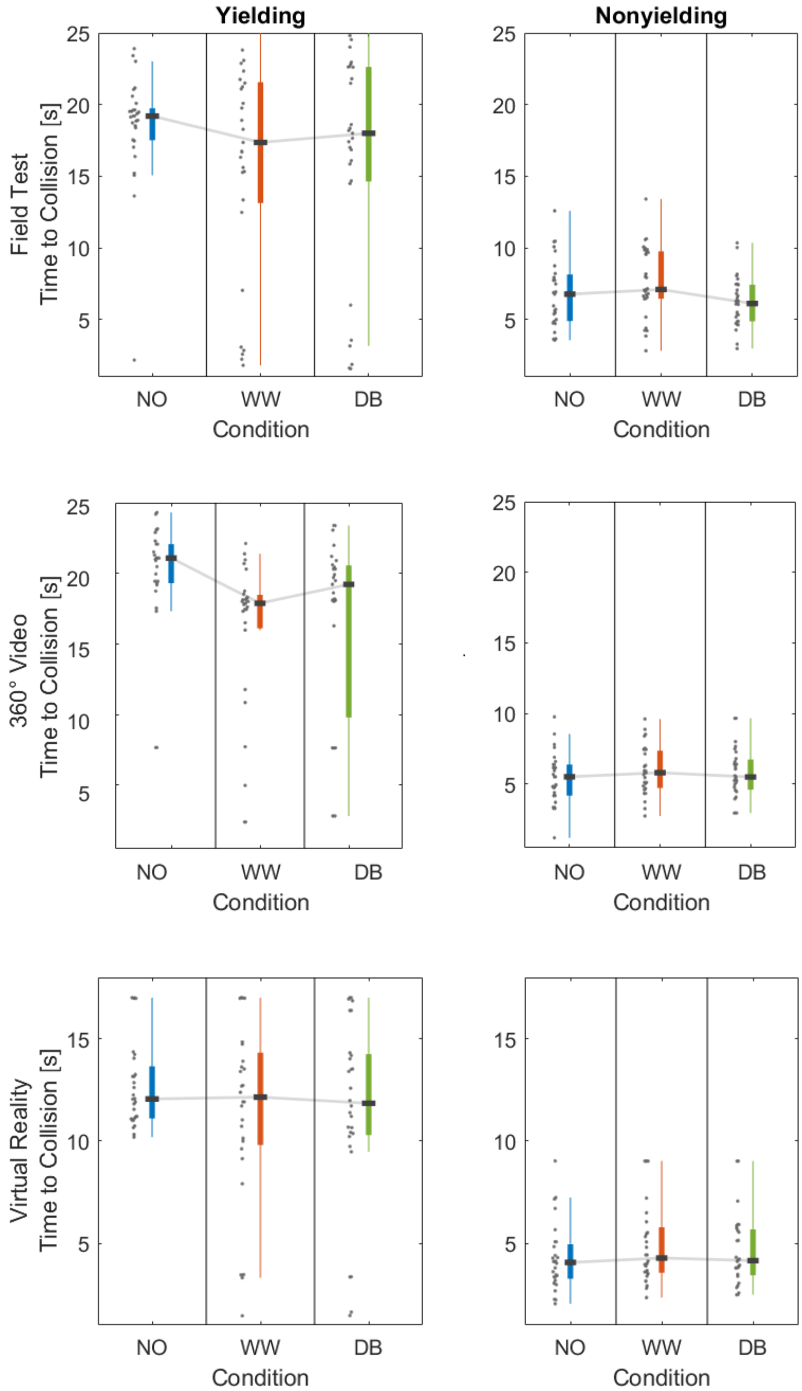


Figure C.8: Virtual Time to Collision for each environment. The conditions are: No information (NO), Wait/Walk (WW) and Drive/Brake (DB).

C.11. Decision Reversal Rate

The number of times the pedestrian changes it decision to cross the road.

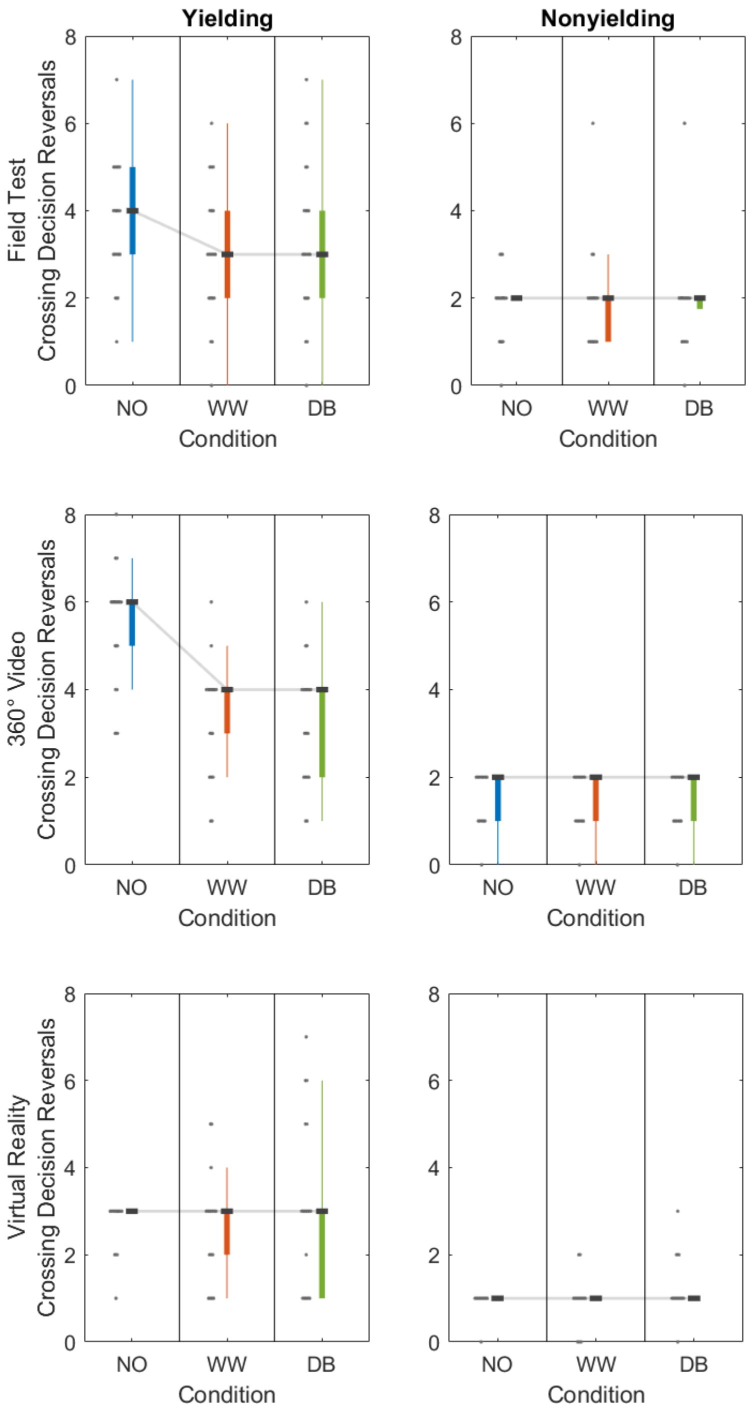
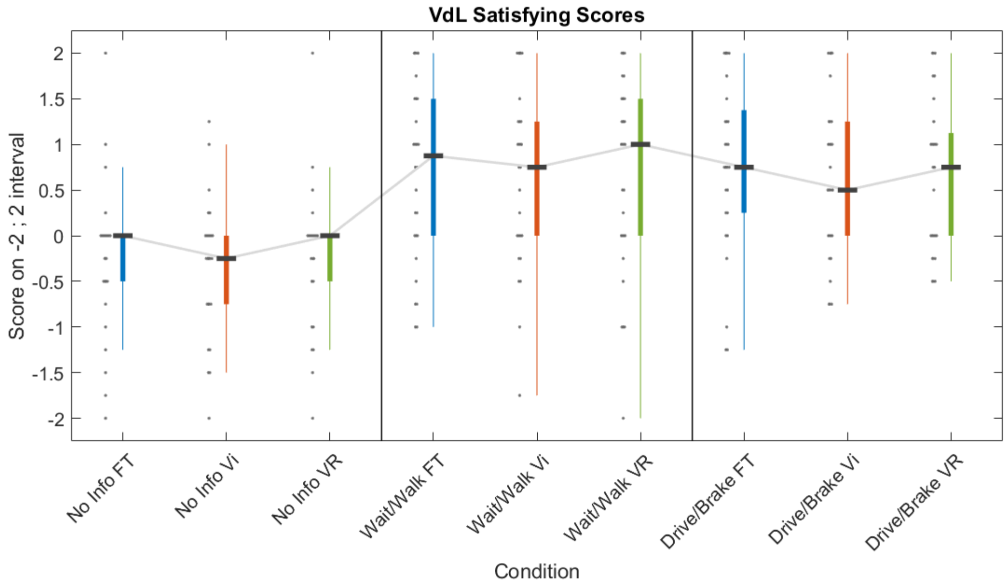


Figure C.9: Time to Collision for each environment. The conditions are: No information (NO), Wait/Walk (WW) and Drive/Brake (DB).

C.12. Subjective Acceptance

Certainty of the decision can be measured by counting the amount of reversals to the original decision.



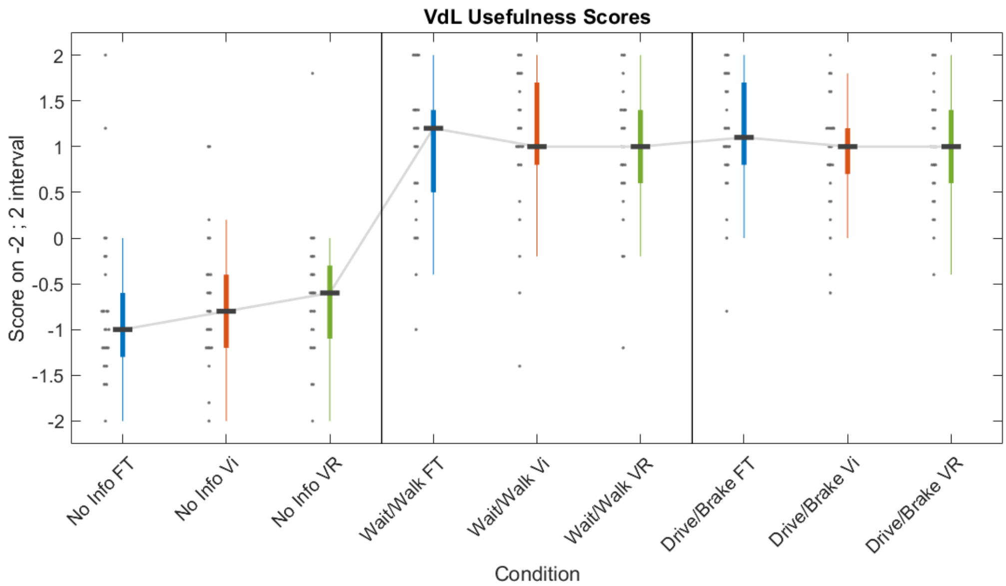


Figure C.10: Van der Laan scores for Satisfying and Usefulness, respectively.

C.13. Overview Table

An overview of all means and standard deviations in each environment is provided in Table C.5. The p-values represent the significance of the effect of the eHMI only, no effects of environment type or environment*eHMI interaction are shown. If Mauchly's test resulted in $p > 0.05$, the assumption of sphericity was confirmed. Values were corrected using Greenhouse-Geisser estimates when the assumption was violated. The subjective metrics were evaluated for each eHMI and do not have separate entries for the Yielding (Y) and Nonyielding (NY) states. Note that the perception ratings were converted into numerical values for statistical analyses.

Table C.5: Means and standard deviations for all dependent measures, including statistical tests for the Field Test (FT), Video (Vi) and Virtual Reality (VR) environments.

			No Info (NO)		Wait/Walk (WW)		Drive/Brake (DB)				Pairwise Comparison		
Metric	Yielding ψ	Test	mean	SD	mean	SD	mean	SD	sphericity	p	NO-DB	DB-WW	NO-WW
Spatial Button Press Ratio [%]	**Y**	FT	50.441	22.909	65.251	30.569	63.939	31.510	corrected	0.0005	-	-	-
		Vi	53.147	20.884	67.821	19.710	67.666	25.795			0.034	-	0.000
		VR	49.334	23.152	57.942	31.399	56.581	27.747			-	-	-
	NY	FT	44.960	20.716	34.712	20.545	45.503	16.763	confirmed	0.001	-	-	-
		Vi	47.349	18.857	40.992	18.394	43.480	18.032			-	-	-
		VR	52.632	18.235	45.117	22.734	48.941	17.178			-	-	-
Time-Based Button Press Ratio [%]	**Y**	FT	40.365	22.468	51.560	22.200	45.459	21.827	corrected	0.135	-	-	-
		Vi	80.563	14.909	62.504	13.457	59.595	22.238			0.002	-	0.000
		VR	52.261	18.453	55.992	21.652	53.471	25.083			-	-	-
	NY	FT	44.664	20.501	35.095	20.442	45.817	16.543	confirmed	0.000	-	-	-
		Vi	48.383	18.718	40.351	17.897	43.644	17.609			-	-	0.037
		VR	52.664	18.248	45.207	22.730	48.976	19.217			-	-	-
Gap Acceptance [m]	**Y**	FT	47.253	17.370	39.520	27.977	40.317	26.76	corrected	0.0324	-	-	-
		Vi	47.198	17.654	35.613	18.865	38.706	23.376			-	-	0.005
		VR	39.291	17.553	36.643	24.031	37.268	23.764			-	-	-
	NY	FT	49.257	16.278	55.907	16.877	46.128	12.856	confirmed	0.009	-	-	-
		Vi	42.154	14.404	45.706	13.898	44.824	14.193			-	-	-
		VR	35.500	13.685	41.273	16.924	38.391	14.436			-	-	-
Time To Collision [s]	**Y**	FT	18.473	3.890	16.168	7.688	16.476	7.739	corrected	0.000	-	-	-
		Vi	19.991	3.968	15.915	5.520	16.304	6.786			0.04	-	0.000
		VR	12.707	2.112	11.520	4.384	11.563	4.492			-	-	-
	NY	FT	6.822	2.396	7.586	2.464	6.215	1.735	corrected	0.016	-	-	-
		Vi	5.385	1.860	5.933	1.732	5.782	1.786			-	-	-
		VR	4.268	1.646	4.964	2.034	4.614	1.739			-	-	-
Decision Reversals	**Y**	FT	3.931	1.580	3.071	1.386	3.308	1.619	confirmed	0.000	-	-	-
		Vi	5.556	1.219	3.481	1.156	3.333	1.240			0.000	-	0.000
		VR	2.821	0.476	2.607	1.100	2.2821	1.701			-	-	-
	NY	FT	1.885	0.653	1.828	1.002	1.862	0.953	corrected	0.394	-	-	-
		Vi	1.630	0.565	1.556	0.577	1.593	0.572			-	-	-
		VR	0.964	0.189	0.929	0.466	1.143	0.524			-	-	-
Satisfaction [-2 2]	-	FT	-0.241	0.806	0.670	0.958	0.768	0.945	corrected	0.000	0.001	-	0.003
		Vi	-0.313	0.732	0.616	0.989	0.625	0.875			0.001	-	0.000
		VR	-0.223	0.759	0.616	1.068	0.643	0.831			0.000	-	0.001
Usefulness [-2 2]	-	FT	-0.814	0.850	0.993	0.803	1.129	0.651	corrected	0.000	0.000	-	0.000
		Vi	-0.714	0.700	1.036	0.798	0.929	0.621			0.000	-	0.000
		VR	-0.650	0.701	0.964	0.726	0.971	0.608			0.000	-	0.000
Perceived as [1 4]	-	FT	1.964	1.347	2.786	1.371	2.679	1.416	corrected	0.001	-	-	-
		Vi	3.000	1.277	3.607	0.685	3.429	0.920			-	-	0.03
		VR	2.071	1.331	3.071	1.303	2.857	1.325			0.01	-	0.002

D

Steps for conducting the experiment

First Session

Arrival of participant

- Welcome participants and assign participant number.
- Provide the participant with informed consent form and let them sign it.
- Participants fill in the questionnaire called: Questionnaire before experiment (on paper).
- Brief the participants about the experimental tasks.
- Assign experiment 360° video, V.R or field test).

Steps for virtual reality (V.R) and 360° *Video environment*

- Guide participant 1 to back cabin of the van.
- Open the distance and speed estimation task in either 360° video or virtual environment.
- Let the participant wear the headset and headphones.
- Play the estimation task and record participant estimations on the input table.
- After completion of task, participant were asked to perform same tasks in field tests.

Steps for field test

- Let the participant 2 go to the marked position on sidewalk facing towards the road.
- Inform the technicians about the participant number through wireless radio.
- Record participants distance and speed estimates on the input table.
- After completion of task, participant asked to perform estimation tasks in 360° video or V.R.

Gap acceptance task

- Give instructions to participants for gap acceptance task.
- First participant takes position on the sidewalk.
- Let the technician know the participant number for trial order and run the Matlab script to record button press.
- Let the participant fill in the acceptance and trust scale after every two gap acceptance trials.
- Let the participant fill the Motion sickness and Presence questionnaire after completion of all the tasks.
- During questionnaire: save GPS logs and button press data with participant number.

Second Session

Arrival of participant

- Welcome participants to the lab.
- Let the participants read the informed consent form.
- Brief the participants about the experimental tasks in virtual reality.
- Let the participants perform distance and speed estimation tasks in the remaining virtual environment.
- Let the participant perform the gap acceptance task in the same environment.

Gap acceptance task conducted in the 360° *video environment*

- Give instructions to participant for gap acceptance task.
- Open the gap acceptance video in Gear VR and run the Matlab script to record button press.
- Let the participant wear the Gear VR headset and play the video.
- Let participant do the actual experiment.
- Let the participants fill the Acceptance scale, Motion sickness and Presence Questionnaire after the experiment.
- During questionnaire: save button press data with participant number.

Gap acceptance task conducted in the animated Virtual Reality environment

- Give instructions to participant for gap acceptance task.
- Open the Unity model for gap acceptance task.
- Let the participant wear the Oculus Rift headset.
- Play a test scenario.
- Let participant do the actual experiment.
- Let the participants fill the Acceptance scale, Motion sickness and Presence Questionnaire after the experiment.
- During questionnaire: save button press data with participant number.

After completion of all tasks

- Thank the participant for their participation and offer them a snack or drink.
- Collect feedback from the participants regarding the experiments.

E

Day Planning

- **08:30 h:** Meet at CITG faculty in room 4.30 (TU Delft)
- **08:30 to 09:15 h:** Discussion, move and setup equipment at test location (road is open)
- **09:15 to 09:45 h:** Close road and check all equipment
- **09:45 to 10:00 h:** Participant 1 and 2 arrival and briefing
- **10:00 to 10:45 h:** Participant 1 and 2 perform experimental tasks
- **10:45 to 11:00 h:** Participant 3 and 4 arrival and briefing
- **11:00 to 11:45 h:** Participant 3 and 4 perform experimental tasks
- **11:45 to 12:00 h:** Participant 5 and 6 arrival and briefing
- **12:00 to 12:45 h:** Participant 5 and 6 perform experimental tasks
- **12:45 to 13:15 h:** Lunch
- **13:15 to 13:30 h:** Participant 7 and 8 arrival and briefing
- **13:30 to 14:15 h:** Participant 7 and 8 perform experimental tasks
- **14:15 to 14:30 h:** Participant 9 and 10 arrival and briefing
- **14:30 to 15:15 h:** Participant 9 and 10 perform experimental tasks
- **15:15 to 15:30 h:** Open the road and return all equipment to CITG faculty

Table E.1: Assistant and Tasks: Before the start of experiment

Assistant	**Task**
Edwin and Peter	Setup test vehicle and cameras
Rakshit and Marc	Place traffic cones, setup VR and 360° equipment Start GPS logging, enable eHMI

Table E.2: Assistant and Tasks: During the experiment

Assistant	**Task**
Edwin and Peter	Drive the test vehicle
Rakshit	Conduct DE and SE tasks in VR and 360° environments Stay with participants during GA tasks
Marc	Conduct DE and SE tasks in real environment Control and check eHMI state during GA tasks
Lisa, Kishore, Vishwajeet	Traffic control

F

Participant Booklet

Informed consent form

Research title: *"A study on Pedestrian's gap acceptance, distance and speed perception in virtual reality and on the road with external human-machine interfaces (eHMIs)."*

Researchers

Rakshit Agarwal - master student   email: rakshit.agarwal13@gmail.com
Marc Barendse - master student   email: marcbarendse@live.nl
Dr.ir. Riender Happee - supervisor   email: r.happee@tudelft.nl
Dr.ir. J.C.F. de Winter - supervisor   email: j.c.f.dewinter@tudelft.nl

Location of the experiment

For the Virtual Reality (VR) tests: Cognitive Robotics Laboratory (34 F-0-220)
Faculty of Mechanical, Maritime and Materials Engineering
Delft University of Technology
Mekelweg 2, Delft

For the field test: Heertjeslaan, Delft

Introduction

Please read this consent form thoroughly before participating in the experiment. This form describes the purpose, general procedure, and possible risks of participating in the study. Your signature is required prior to participation.

Purpose of study

This study has two aims: Firstly, assessing simulator fidelity through a comparison of human distance and speed perception in real and virtual environments. Secondly, the evaluation of different types of information displayed for vehicle-to-pedestrian communication.

Duration

The experiment is divided into two tests: The first is a field test, which takes place on the road. The second test uses a virtual reality environment and takes place in the 3mE faculty building. Your participation in this study will last approximately 2 hours in total: 1 hour for the field test and 1 hour for the VR test.

Procedure and Instructions

Before the experiment starts
Firstly, you will be asked to fill in a short questionnaire about your gender, age and personality.
Secondly, you will be asked to stand at the marked position on the curb.
If you are participating in the VR test, you will be asked to wear the VR equipment and get used to the virtual environment by looking around.

During the experiment
Both tests consist of 6 distance estimations, 2 speed estimations and 6 gap acceptance tasks. For the estimations, you will be asked to state your estimate to the experimenter verbally at a certain moment. For the gap acceptance task, you will be provided a remote with a button. You will be asked to press the button continuously while you feel safe to cross. However, you are strictly advised to **NOT CROSS THE ROAD** in any condition. In between the gap acceptance tasks, you will be asked to answer a questionnaire to assess your subjective experience and acceptance of the vehicle-to-pedestrian communication.

After the experiment
You will be asked to fill in three short questionnaires about motion sickness, feeling of presence and realism of the environment, and trust in automation.

Risks and discomforts
There is a risk of experiencing slight discomfort when you are wearing the head mounted display. If you experience eyestrain, nausea, disorientation or any other kind of discomfort kindly inform the experimenter so that you take a break. You can also cease to participate in the experiment further if you do not feel comfortable.

Confidentiality
The data collected in this study will be kept anonymous. Your personal details will not be published in this research article or any future documents.

Right to refuse or withdraw
The participation in this study is completely voluntary. You can refuse to participate or withdraw at any time during the experiment, without any penalty.

Questions
For any questions you can contact any one of the researchers mentioned above.

I have read and understood the information provided above. I give permission to store and use of collected data for the purposes of this study described above. The results of the study will not be made available in a way that could reveal the identity of individuals. I voluntarily agree to participate in this study.

______________________	______________________	________
Name of participant	Signature	Date

Questions before the experiment (Participant information)

Please fill in this questionnaire as honestly as possible. Your data will be kept anonymous.

*Required

1. **What is your participant number? (If not known ask the experimenter for your participant number)** *

____

2. **Nationality** *

____

3. **Age (in years)** *

____

4. **Gender** *
Mark only one oval.
   - Female
   - Male
   - Prefer not to say
   - Other: ______________________________

5. **Are you in possession of a driver's license?** *
Mark only one oval.
   - Yes
   - No

6. **How often did you drive a vehicle in the last 12 months on average?** *
Mark only one oval.
   - Everyday
   - 4 to 6 days a week
   - 1 to 3 days a week
   - Once a month to once a week
   - Less than once a month
   - Never
   - I prefer not to respond

7. **How many kilometres did you drive by car in the last 12 months?** *
Mark only one oval.

- 0 to 100 km
- 100 to 1000 km
- 1000 to 5000 km
- 5000 to 10000 km
- More than 10000 km

8. **On average, how often did you travel by foot in the last 12 months?** *
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 month
- Never

9. **Do you wear glasses at the moment?** *
Mark only one oval.

- Yes
- No
- I wear contact lenses

10. **Are you colour blind?** *
Mark only one oval.

- Yes
- No

11. **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.

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

- Yes, multiple times
- Yes, once
- No

Brief Sensation Seeking Scale

Please fill in this questionnaire as honestly as possible. Your data will be kept anonymous.

13. **I would like to explore strange places.** *

Mark only one oval.

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

14. **I get restless when I spend too much time at home.** *

Mark only one oval.

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

15. **I like wild parties.** *

Mark only one oval.

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

16. **I like to do frightening things** *

Mark only one oval.

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

17. **I would like to take off on a trip with no pre-planned routes or timetables.** *

Mark only one oval.

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

18. **I prefer friends who are excitingly unpredictable.** *

Mark only one oval.

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

19. **I would like to try bungee jumping.** *

Mark only one oval.

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

20. **I would love to have new and exciting experiences, even if they are illegal.** *
Mark only one oval.

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

Participant No.	**Test type:**
Distance estimation	**Start time:**
Distance 1	
Distance 2	
Distance 3	
Distance 4	
Distance 5	
Distance 6	
	End time:
Speed estimation	**Start time:**
Speed 1	
Speed 2	
Speed 3	
Speed 4	
	End time:

Participant No.	**Test type:**
Distance estimation	**Start time:**
Distance 1	
Distance 2	
Distance 3	
Distance 4	
Distance 5	
Distance 6	
	End time:
Speed estimation	**Start time:**
Speed 1	
Speed 2	
Speed 3	
Speed 4	
	End time:

Participant No.	**Test type:**
Distance estimation	**Start time:**
Distance 1	
Distance 2	
Distance 3	
Distance 4	
Distance 5	
Distance 6	
	End time:
Speed estimation	**Start time:**
Speed 1	
Speed 2	
Speed 3	
Speed 4	
	End time:

Van Der Laan (Acceptance Scale)

*Vereist

1. **Participant no.**

2. **Trial Number** *

3. **I find the display in front of the vehicle: (please tick one box on every line)**
Markeer slechts één ovaal.

	1	2	3	4	5	
USEFUL						USELESS

4. *Markeer slechts één ovaal.*

	1	2	3	4	5	
PLEASANT						UNPLEASANT

5. *Markeer slechts één ovaal.*

	1	2	3	4	5	
BAD						GOOD

6. *Markeer slechts één ovaal.*

	1	2	3	4	5	
NICE						ANNOYING

7. *Markeer slechts één ovaal.*

	1	2	3	4	5	
EFFECTIVE						SUPERFLUOUS

8. *Markeer slechts één ovaal.*

	1	2	3	4	5	
IRRITATING						LIKEABLE

9. *Markeer slechts één ovaal.*

	1	2	3	4	5	
ASSISTING	⬭	⬭	⬭	⬭	⬭	WORTHLESS

10. *Markeer slechts één ovaal.*

	1	2	3	4	5	
UNDESIRABLE	⬭	⬭	⬭	⬭	⬭	DESIRABLE

11. *Markeer slechts één ovaal.*

	1	2	3	4	5	
RAISING ALERTNESS	⬭	⬭	⬭	⬭	⬭	SLEEP-INDUCING

12. **Do you have any comments about the interface?**

13. **How do you think the vehicle was driving (e.g. autonomously, steering wheel, remote controlled)?**

Van Der Laan (Acceptance Scale)

*Vereist

1. **Participant no.**

2. **Trial Number** *

3. **I find the display in front of the vehicle: (please tick one box on every line)**
Markeer slechts één ovaal.

	1	2	3	4	5	
USEFUL						USELESS

4. *Markeer slechts één ovaal.*

	1	2	3	4	5	
PLEASANT						UNPLEASANT

5. *Markeer slechts één ovaal.*

	1	2	3	4	5	
BAD						GOOD

6. *Markeer slechts één ovaal.*

	1	2	3	4	5	
NICE						ANNOYING

7. *Markeer slechts één ovaal.*

	1	2	3	4	5	
EFFECTIVE						SUPERFLUOUS

8. *Markeer slechts één ovaal.*

	1	2	3	4	5	
IRRITATING						LIKEABLE

9. *Markeer slechts één ovaal.*

	1	2	3	4	5	
ASSISTING	⬭	⬭	⬭	⬭	⬭	WORTHLESS

10. *Markeer slechts één ovaal.*

	1	2	3	4	5	
UNDESIRABLE	⬭	⬭	⬭	⬭	⬭	DESIRABLE

11. *Markeer slechts één ovaal.*

	1	2	3	4	5	
RAISING ALERTNESS	⬭	⬭	⬭	⬭	⬭	SLEEP-INDUCING

12. **Do you have any comments about the interface?**

13. **How do you think the vehicle was driving (e.g. autonomously, steering wheel, remote controlled)?**

Mogelijk gemaakt door Google Forms

Van Der Laan (Acceptance Scale)

*Vereist

1. **Participant no.**

2. **Trial Number** *

3. **I find the display in front of the vehicle: (please tick one box on every line)**
Markeer slechts één ovaal.

	1	2	3	4	5	
USEFUL						USELESS

4. *Markeer slechts één ovaal.*

	1	2	3	4	5	
PLEASANT						UNPLEASANT

5. *Markeer slechts één ovaal.*

	1	2	3	4	5	
BAD						GOOD

6. *Markeer slechts één ovaal.*

	1	2	3	4	5	
NICE						ANNOYING

7. *Markeer slechts één ovaal.*

	1	2	3	4	5	
EFFECTIVE						SUPERFLUOUS

8. *Markeer slechts één ovaal.*

	1	2	3	4	5	
IRRITATING						LIKEABLE

9. *Markeer slechts één ovaal.*

	1	2	3	4	5	
ASSISTING						WORTHLESS

10. *Markeer slechts één ovaal.*

	1	2	3	4	5	
UNDESIRABLE						DESIRABLE

11. *Markeer slechts één ovaal.*

	1	2	3	4	5	
RAISING ALERTNESS						SLEEP-INDUCING

12. **Do you have any comments about the interface?**

13. **How do you think the vehicle was driving (e.g. autonomously, steering wheel, remote controlled)?**

Trust scale for automation

Please fill in this form with reference to the display in front of the vehicle.

*Vereist

1. **Participant Number** *

2. **The vehicle is deceptive** *
   Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Extremely

3. **The vehicle behaves in a deceitful manner** *
   Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Extremely

4. **I am suspicious of the vehicle's intent, action, or outputs** *
   Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Extremely

5. **I am wary (cautious) of the vehicle (voorzichtig)** *
   Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Extremely

6. **The vehicle's action will have a harmful or injurious outcome** *
   Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	Extremely

7. **I am confident in the vehicle** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Extremely

8. **The vehicle provides security** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Extremely

9. **The vehicle has integrity** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Extremely

10. **The vehicle is dependable** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Extremely

11. **The vehicle is reliable** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Extremely

12. **I can trust the vehicle** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Extremely

13. **I am familiar with the working of the vehicle** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Extremely

14. **Do you have any comments on having a display or interface in general?** *

Mogelijk gemaakt door Google Forms

Motion Sickness Questionnaire (WOZ)

Please fill in this questionnaire post experiment. This questionnaire consists of 16 questions. Kindly, mark your selection in the form.
Instructions : Choose how much each symptom below is affecting you right now.

*Required

1. **General discomfort** *

Mark only one oval.

- None
- Slight
- Moderate
- Severe

2. **Fatigue** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

3. **Headache** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

4. **Eye Strain** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

5. **Difficulty Focusing** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

6. **Sweating** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

7. **Nausea** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

8. **Blurred Vision** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

9. **Dizziness with eyes open** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

10. **Dizziness with eyes closed** *

Tick all that apply.

- [ ] None
- [ ] Slight
- [ ] Moderate
- [ ] Severe

11. **Vertigo (sensation of feeling off balance)** *

Mark only one oval.

- ( ) None
- ( ) Slight
- ( ) Moderate
- ( ) Severe

SUS Presence Questionnaire for Field Test

*Vereist

1. **Please rate your sense of being at a road in the test environment (as in how much realistic does this setup feel?), on a scale of 1 to 7, where 7 represents your normal experience of being in a place.** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Much

2. **To what extent were there times during the experience when the test environment was the reality for you? (There were times during the experiment when the test location was like a real road crossing for me...)** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
At no time	⬭	⬭	⬭	⬭	⬭	⬭	⬭	At all times

3. **When you think back to the experience, do you think of the test environment more as images that you saw or more as somewhere that you visited? (The test location seems to me more like....)** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Images that I saw	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Somewhere I visited

4. **During the time of the experience, which was the strongest on the whole, your sense of being at the public road or of being elsewhere? I had a stronger sense of...** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Being elsewhere	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Being at the public road

5. **Consider your memory of being at the public road crossing. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the road crossings, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements. (I think of the test location as a place in a way similar to other places that I've been today).** *
   Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not at all								Very Much

6. **During the time of your experience, did you often think to yourself that you were actually at a road crossing? (During the experience I often thought that I was really standing at a road crossing).** *
   Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Not very often								Very much so

G

Ethics Committee Approval

Date 18-01-2019
Contact person Ir. J.B.J. Groot Kormelink, secretary HREC
Telephone +31 152783260
E-mail j.b.j.grootkormelink@tudelft.nl

Human Research Ethics Committee
TU Delft
(http://hrec.tudelft.nl/)

Visiting address
Jaffalaan 5 (building 31)
2628 BX Delft

Postal address
P.O. Box 5015 2600 GA Delft
The Netherlands

Ethics Approval Application: Virtual reality and on-road study to analyse interactions between pedestrians and automated vehicles
Applicant: Winter, Joost de

Dear Joost de Winter,

It is a pleasure to inform you that your application mentioned above has been approved.

Good luck with your research!

Sincerely,

Prof. Dr. Sabine Roeser
Chair Human Research Ethics Committee TU Delft

Prof.dr. Sabine Roeser
TU Delft
Head of the Ethics and Philosophy of Technology Section
Department of Values, Technology, and Innovation
Faculty of Technology, Policy and Management
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H

RDW Exemption Form

REQUIRED INFORMATION FOR THE ASSESSMENT OF TESTING WITH SELF-DRIVING VEHICLES

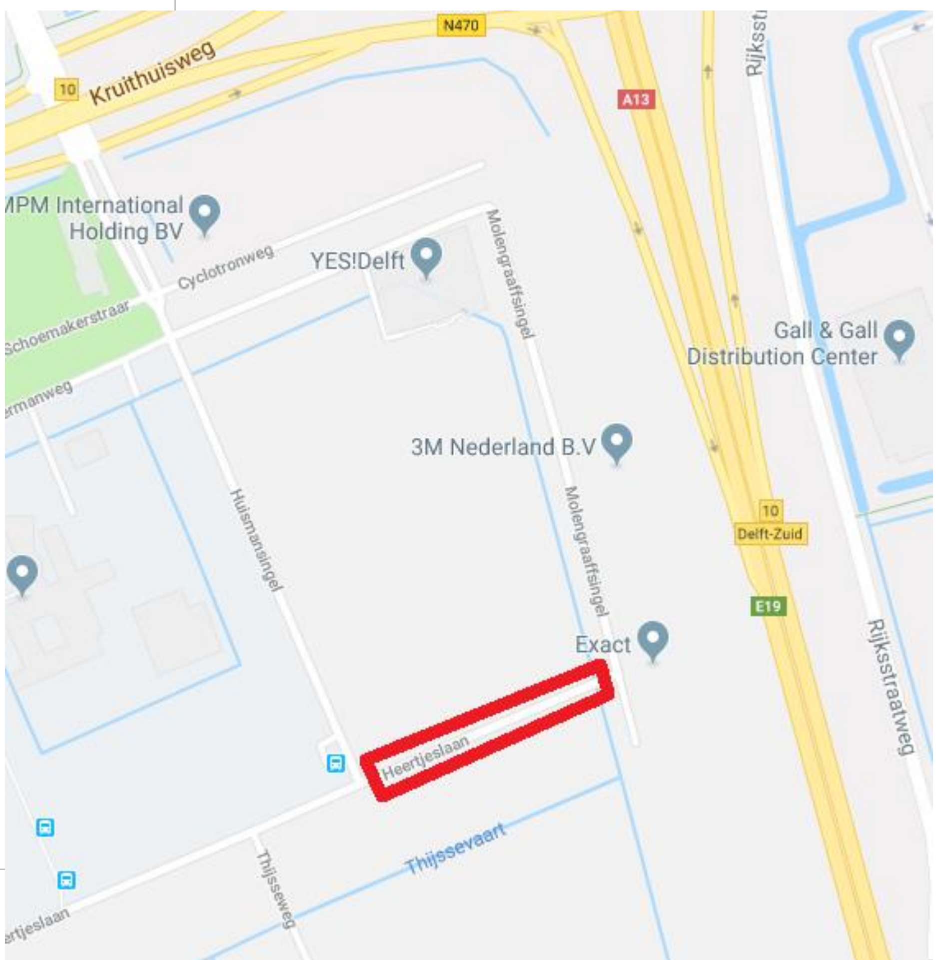
Formulier

PROJECT INFORMATION	
Project Name	Field study to analyse interactions between pedestrians and automated vehicles

CONTACT PERSON / PROJECT MANAGER

Last Name	1. Barendse 2. Agarwal	First Name	1. Marc 2. Rakshit	Insertion	
Phone number	1. +31-(0)615517554 2. +31-(0)649513585	Email	1. M.J.Barendse@student.tudelft.nl 2. rakshit.agarwal13@gmail.com		

TEST		
Explain in one paragraph the purpose of the test – Is it a demonstration or an experiment? – Which scenario is tested?		The aim of the study is twofold: (1) validation of pedestrian simulators for interaction with autonomous vehicles and (2) investigating the usage of an external interface on an automated vehicle to replace driver-to-pedestrian communication.
Where does the trial take place?	Which city, village, province?	Delft, Zuid-Holland
	Which type of roads are used (motorway, provincial road, etc.) incl. speed limits	Local road, 50 km/h speed limit
	What is the exact route (street names or possibly route map)	Heertjeslaan between Molengraaffsingel and Huismansingel.



<table>
<tr><td></td><td>Which other traffic uses these roads (cyclists, pedestrians, cars, freight traffic)?</td><td colspan="4">Cars, cyclists, pedestrians.
For safety and to avoid interference, the experiment will be performed when no traffic is present. Traffic regulators will be present at both sides of the road, to enable trespassing of other traffic if required while temporarily halting the experiment.</td></tr>
<tr><td colspan="2">On what day or in which period does the trial take place?</td><td>From</td><td>19 February 2019</td><td>To</td><td>21 February 2019</td></tr>
<tr><td colspan="2"></td><td>+ pilot</td><td colspan="3">10 January 2019
(backup 17 January 2019 in case of adverse weather)</td></tr>
</table>

<table>
<tr><th colspan="3">VEHICLE / DRIVER</th></tr>
<tr><td rowspan="5">General description of the vehicle: is it (similar to) a:</td><td>☐ Bus</td><td></td></tr>
<tr><td>☐ Truck</td><td></td></tr>
<tr><td>■ Passenger car</td><td>Toyota Prius</td></tr>
<tr><td>□ ‘People mover’</td><td></td></tr>
<tr><td>☐ Others, namely</td><td></td></tr>
<tr><td colspan="2">At what speed does the vehicle travel?</td><td>30 km/h for most of the experiment
One speed estimation test, performed at a speed that is common for human drivers on this road (50-60 km/h)</td></tr>
<tr><td colspan="2">Which aspects of the driving task are automated (for example: Steering / Acceleration and braking / Monitoring the driving environment / Monitoring the vehicle)?</td><td>None, vehicle will be driven manually</td></tr>
<tr><td colspan="2">Does the vehicle look different from current vehicles in the road image? If so, how does it differ?</td><td>One screen will be mounted before the bonnet of the vehicle, above the license plate. The rest of the vehicle looks like an unmodified Toyota Prius.

</td></tr>
<tr><td rowspan="2">Does the vehicle behave as an average driver would behave?</td><td>Does the vehicle, for example, follow the traffic rules and signs? If not, how does it differ?</td><td>Vehicle is driven by human driver and follows all traffic rules.</td></tr>
<tr><td>Does the vehicle comply with informal traffic rules? If not, how does it differ?</td><td>Vehicle confirms with informal traffic rules as it is driven by a human driver. However, as the vehicle should appear to be driving autonomously, communication with the driver will not be possible for participants.</td></tr>
<tr><td colspan="2">What information will the vehicle use from the roads, such as stripes, signs, lights, etc.?</td><td>No information from the roads will be used or recorded.
For analysis of the experiment, GPS and dashcam videos will be recorded.</td></tr>
<tr><td colspan="2">Is there always a driver / operator in the vehicle?</td><td>Yes, two skilled operators are on the driver’s and passenger seat on the front row of the vehicle, and one experimenter is on a back seat in the vehicle at all times. The participant remains at the sidewalk at all times.</td></tr>
<tr><td colspan="2">What tasks does the driver / operator have? (for example programming, data collection, etc.)</td><td>One of the two operators drives the vehicle manually, with the steering wheel inputs. The other operator monitors the safety during the experiment.</td></tr>
</table>

		The experimenter informs the operators about the experimental conditions, and communicates with traffic regulators.
Intervention / Taking over tasks	How is the driver / operator informed that the system is no longer working and he / she must intervene / take over tasks?	Not applicable. System is driven by a human at all times.
	In what way can the driver / operator intervene?	The drivers can intervene in all ways possible as in a regular vehicle: Steering, braking, turning off the engine, etc.
	How much time is there to intervene / take over tasks?	All circumstances, including the time, would be the same as in a non-automated vehicle. The length of the road stretch is 245 m. The participant is located halfway, at 122,5 m. At the maximum speed of 50 km/h (13.89 m/s), there would still be 122,5/13.89 = 8.82 s available for deceleration before the end of the road stretch has been reached. We would like to note that participants are asked to stay at the sidewalk at all times and never cross the road and that there is no other traffic present.
How much experience does the driver / operator have?	What training did the driver / operator have, to deal with the system? Or how is the driver informed to deal with the system?	System specific training.
	Experience with the system:	2 year expert on the system.
	Experience on the (Dutch) road:	31 years
What information is offered to a driver / operator while driving (for example, about the operation of the system, route information, communication with other drivers or a 'control room')?		All information as present in a regular vehicle. Intent of the vehicle is shown to participants using the display in front of the vehicle.

PASSENGERS / OTHER ROAD USERS	
Will there be passengers? If so: Who are these (for example, dignitaries, press, students, project staff, etc.?)	The two operators and the experimenter are the three people inside the vehicle (project staff). Outside of the vehicle, one extra experimenter (project staff) and one participant (student) are located at the sidewalk, while observing the vehicle. Two traffic regulators, one on each side of the road, will make sure no other road users are present on the road during an experiment.
Are other road users and / or local residents informed about the practical test? If yes, how?	Traffic density on this road is low, with employees of adjacent companies (Exact and 3M) being the most likely users. TU Delft Park Management will inform these companies before the experiments are conducted. During the experiments, two traffic regulators, one on each side of the road, will regulate oncoming traffic and inform road users about the experiment so that no traffic is present during testing. When passing the road is required, the experiment will be halted temporarily.
Has consideration been given to the possibility that other road users are testing the vehicle? (for example: other road users test whether the vehicle indeed brakes automatically) -> if so, how is this dealt with?	Not applicable, no other road users present.

ORGANIZATION	
Is there a protocol about what happens in unexpected events (traffic jam on the route, flat tire, unexpected traffic)?	Due to unexpected traffic, technical difficulties or adverse weather conditions, the experiment can be halted at all times.
Who takes the decision to continue or shut down the experiment in case of unforeseen events?	If the deem it necessary, this is indicated by the traffic regulators or operators.

		There is always one experimenter inside the vehicle who is finally responsible and makes this decision. For contact details see contact person.
Test results	Has the system been tested before (on a test track or public road)?	The vehicle has been deployed several times in a myriad of researches, including on the same road. It has not been tested with a computer screen mounted attached to the front yet.
	Are the results available? If so, please attach. If not, please provide a concise summary of the results.	Yes, a similar experiment was performed on the Heertjeslaan. - News article https://www.delta.tudelft.nl/article/how-autonomous-cars-influence-pedestrians-behaviour - Research paper including results and data https://www.sciencedirect.com/science/article/pii/S1369847817305715
	Has an FMEA been performed? If so, we would like to receive the results here.	n.n.b.

Incident and Calamity Plan

Introduction
The technology for automated vehicles is in the early stages of development and their use in public areas is increasingly becoming more relevant. The Researchlab Automated Driving Delft (RADD) sets objectives in the front line of these developments for studying the interaction of automated vehicles with other road users in complex operating situations on the TUD campus designated for operation. The application of automated vehicles is safeguarded by security measures, but a rest risk for incidents is ever present.

Traffic operations take place in public areas and so, automated transport lies strongly in public interest. For this reason, it can be expected that any incident rapidly attracts attention of the public and the(social) media. An alert response from the communication department and press officer of the TUD is extra important. This equally applies if the automated vehicle in question is not the cause of the incident.

Risk
Within the crisis management of the government, incidents and calamities are distinguished based on the impact area. If the impact of the accident only concerns the people directly concerned, it is said to be a normal incident. On the other hand, if the impact area stretches to the direct surroundings (impact area), then it is a calamity and is therefore scaled up to GRIP 1 level including the fixed procedures, roles and responsibilities of the municipality concerned depending on where the calamity takes place. From that moment, the communication surrounding the event lies with the Veiligheidsregio which uses OVD depending on the nature of the event. It is important that the TU Delfts crisis agents remain connected to these bodies.

A traffic accident with an automatic vehicle is more likely to fall within the category of 'incidents’. That is to say, a collision that has occurred in which, in addition to material damage, there are also injured persons. The driving speeds on the campus are low (<30 kmph), but the falling of a victim cannot be ruled out. This also applies to fire hazards. A precondition is that the experiment always acts within the limits of Dutch law.

Area Management
Activities within the framework of the RADD are mainly carried out on the TUD campus and thereby fall under the area management of the TUD. The Green Village also falls in this context under the care of the TUD.
A smaller part of designated RADD routes lie outside the campus and fall under the area management of the municipality of Delft. The 'Procedure outside the Campus' described below applies here. This includes:

- the route concerning the bicycle path to station Delft Zuid
- the use of the designated part of the Prinses Beatrixlaan, with other traffic being either permitted or not.
- the Thijsseweg.

Note: Not all these routes have been incorporated is use from the start, however are mentioned here in advance.

Most important emergency numbers:

	Phone number (s)	
Meldkamer (Control Room) TUD	**+31 (0) 15 2782777**	**+31 (0) 15 2781226**
Meldnummers Municipality of Delft	**112 (Emergency number)**	**09008844 (Police force)**

Basic principles at incidents and calamities

1. With every event, the foremost care and attention is towards human suffering. That applies to the first action at the place of the event, for the communication, and to later action.
2. After taking action of 1, the RADD employee (steward / driver / operator) who is involved in the event will immediately call the Control Room concerned, who will immediately take over further actions.
3. After point 2, the existing procedures of TUD and/or the Municipality of Delft for accidents and emergencies will take effect, depending on the location of the event.

Tasks for the Steward/driver

1. Examines whether there are any wounded or casualties and does what he can to organize first emergency aid. For this he can also use other attendees, because he has to call the emergency room as soon as possible. He ensures that the situation on site is 'frozen' and secured, until the emergency services arrive.
2. Directly after point 1, the Steward calls the Meldkamer (Control Room) of the TU Delfts/municipality and follows further instructions. This for example, may concern:
    a. Measures regarding the care for the wounded/victims
    b. Measures regarding the traffic situation
    c. Measures regarding the public

   He remains near the vehicle unless the MeldKamer (Control Room) instructs differently.
3. He calls the Operator, who is already aware of the incident / calamity via the Supervisor system that he has at his disposal for this purpose.
4. He only addresses emergency services and not the press or third parties. For that, he refers to the communication department of the TUD.
5. He completes the Claim Form in the settlement of the incident. He finds that in the log book in the vehicle.
6. He participates afterwards in the analysis of the event.

Tasks for the operator in the Control Room

- Ensures that the telephone number of the MeldKamer (Control Room) of TU Delft and the Municipality of Delft is directly available in the vehicles involved in the test (in the logbook).
- Informs every user of the RADD of the safety procedures prior to the test.

1. If there is no steward or driver in the vehicle, the Operator is the first in line and acts as described above in Steward / driver. He then communicates directly with the occupants (and bystanders) via the intercom(s).
2. If there is a Steward/driver, he maintains contact, takes responsibility and provides the Steward/driver support where necessary. For example, with:
    a. Measures regarding the care for the wounded/victims

    b. Measures regarding the traffic situation
    c. Measures regarding the public.
3. The Operator immediately stops any other ongoing tests in the RADD and goes as quickly as possible to the location of the event to take over the role of the steward / driver.
4. The Operator refers all questions from the press or third parties to the TUD communication department. He does not speak to the press himself.
5. He informs the manager of RADD.
6. He ensures that all documentation about the event has been collected and kept. This concerns in particular the logs of the vehicle systems.
7. He participates afterwards in the analysis of the event and in the decision-making about possible adjustments in the program of the RADD.

Tasks for the MeldKamer (Control Room)

Note: Tasks mentioned below apply both to the MeldKamer (Control Room) of the TUD and of the Municipality of Delft.

1. Enables the necessary emergency services after a call from the steward / driver if there are any injuries or casualties.

Note: Alarm services have an alarm booklet per vehicle type with relevant information such as placement and type of battery, location of main switch, etc.

2. Regulates direct support for the Steward on the spot and gives him instructions on what to do until the support is on-site.
3. Acts further according to the procedures known to him for incidents and calamities and thereby ensures:
    a. Organizing an incident team for management after the event.
    b. Enabling the communication department of the TUD (also if the event took place outside the TUD).
    c. Informing the board of TUD and the municipality of Delft. Note: regardless of the location of the event, it is recommended that both management organizations are informed.
4. The MeldKamer (Control Room) that receives the first notification also informs the other MeldKamer (Control Room), i.e. the TUD Emergency Centre also informs the Municipality of Delft and the Municipal Information Centre / Emergency Centre informs the TUD Emergency Centre.

Tasks for the manager RADD

The Manager of the RADD is the manager of the Operator. He is informed by the Operator and then takes the following actions:

1. Stopping the test
2. Informing own management line.
3. Inform of the RDW concerning the granted exemption.
4. Completing the TUD reporting form (1G4S or Topdesk or obtaining a hard copy at the control room)
5. Organization of the analysis of the event, decision making about measures to be taken and follow-up of their implementation.
6. Decision-making about resumption of the test and possible other consequences for the program of the RADD.

Contacts

MeldKamer (Control Room) TUD	Fixed number	**+31 (0) 15 2782777**
	Mobile number	**+31 (0) 15 2781226**
Emergency numbers Delft municipality	Emergency number	**112 (also works on the campus)**
	Police force	**09008844**
Operator RADD/Control Room		
Manager RADD		
Communication Department TUD	Karen Collet	+31 (0) 15 2785408
	Michel van Baal	+31 (0) 15 2785454

Definitions

- Normal Incident: event has only impact on the direct people concerned
- Accident - incident resulting in material damage and / or injuries;
- Event: incident, calamity or unforseen event;
- Calamity: event having impact on more than only the direct people concerned, stretching to the direct surroundings (impact area), GRIP1
- Steward: person who is present in the automatic vehicle and has the responsibility of 'driver'. He can intervene by braking the vehicle. If necessary, he can also drive the vehicle manually.
- Driver: person who controls - if necessary, remotely – and can take over from an automatic vehicle; this person is not necessarily present in the vehicle.
- Operator: person in the Control Room who monitors vehicles; can be 'remote driver' for automatic vehicles
- Supervisor system: monitors position, speed and other characteristics of the automatic vehicle and the immediate environment at the service of the operator and offers the operator to operate a number of vehicle systems and the vehicle intercom (s).
- User of the RADD: employee (s) of an organization (internal TUD or external) who performs tests in RADD.
- Manager RADD: the manager responsible for the RADD and directs the Operator(s).

Signatures of researchers

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J Literature Summary

Pedestrians make up 22% of road fatalities worldwide, with most accidents happening in urban environments. As there is a trend of an increasing level of automation in vehicles, safe and efficient interaction between pedestrians and automated vehicles will be of great importance in the future. Traffic is a chaotic, self-organizing system that can be ambiguous, and therefore, situations may arise for which clear rules cannot be determined. Introduction of fully autonomous vehicles (AVs) on public roads will lead to less useful social interaction between road users. In an AV, either no driver is present and no communication will be possible, or an inattentive driver (or passenger) is present, who could communicate certain cues that do not reflect the actual states or intents of the vehicle. This means no meaningful explicit nonverbal communication will be possible. This is a potential shortcoming of an AV, as social cues like eye contact and gestures are shown to increase subjective comfort and safety ratings in earlier research.

The literature review evaluates the current role of communication in a road crossing scenario and describes how the introduction of autonomous vehicles might affect this communication. Before crossing a road, a pedestrian makes the decision to do so, based on an awareness of the situation. In situation awareness, three phases can be distinguished: perception of the situation, comprehension of the other road users, and a prediction of future events. The decision can be influenced by several environmental (weather, type of road) and individual (age, prior knowledge and experiences) factors, but also perceived communication signals have an influence. In conventional vehicles, this communication, mainly informal and nonverbal, seems to provide a compensation for errors, have a signalling function (drivers are more likely to yield after mutual eye contact), and increase comprehension of others (virtually reducing a pedestrian to a moving black box results in more driver errors).

A myriad of external Human-Machine Interfaces (eHMIs) has been proposed by the industry and in academia to fill the communication void. The interfaces differ in modality, amount of modes possible and perspective of the information. Four possible types of information can be provided by an eHMI, outlined by a combination of two axes: perspective (allocentric – egocentric) and content (current state – future intent). A review of proposed eHMI concepts and research findings suggests that an egocentric (pedestrian-based) perspective is regarded as more clear, while some scholars point out that an allocentric (vehicle-based) perspective is safer, as it does not require directing the information towards a specific road user. Text seems to be preferred above symbols, and for visual interfaces, the colours green and red seem to have the strongest association with cross and do not cross, respectively. Positive effects on experienced comfort and perceived safety are found, but the effect on behaviour is ambiguous. This could be attributed to a variation in pedestrian characteristics, to differences in the type of information that was provided, or to a measurement method that is too coarse. Most previous knowledge on eHMIs is based on questionnaire studies of static images, observations and recordings. Some studies use virtual reality-based simulations, but only a limited number of on-road tests is available. Most studies focus on subjective measurements and use the outcome of a crossing decision at one location as objective variable.

Further research using objective measures with finer measurement methods to determine the effects of complementing an AV with different types of information is proposed. By using a continuous measurement method, the cross/do not cross decision and the vehicle behaviour could be related more clearly. This could help to reveal which types of eHMIs have positive effects on safety and traffic flow, and which have the highest usefulness in practical situations.

K

Pilot Study

VR AND FIELD STUDY TO ANALYSE INTERACTIONS BETWEEN PEDESTRIANS AND AUTOMATED VEHICLES

PILOT STUDY
BRIEFING

Pilot Study Date: January 10, 2019
Document Date: January 10, 2019

Rakshit Agarwal (4606337)
Marc Barendse (4144899)
Delft University of Technology

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0.1 INTRODUCTION

This Pilot study is being conducted for the Master's thesis project required for the completion of vehicle engineering degree. The thesis topics are as follows:

- **"Investigating the usage of an eHMI as replacement for driver-pedestrian communication in autonomous vehicles"** by Marc Barendse(4144899)
  Research question: Does the presence of an eHMI improve safety and traffic flow compared to the presence of an active driver in terms of gap acceptance?
  Supervised by: Dr.ir. Riender Happee and Dr.ir. J.C.F. de Winter
- **"Validation of Pedestrian simulators for interaction of pedestrians with autonomous vehicles"** by Rakshit Agarwal(4606337)
  Research question: How does pedestrian performance differ in terms of perception and behaviour in VR compared to real life in terms of speed and distance estimation and presence?
  Supervised by: Dr.ir. Riender Happee and Dr.ir. J.C.F. de Winter

The theses will involve repetition of the same experiment using three methods of exposure: Wizard-of-Oz (WoZ), animated Virtual Reality (VR) and a 360 degree video in a Head-Mounted Display (HMD).
The main purpose to conduct this WoZ pilot study is to test the feasibility of the experimental design in the WoZ part. The pilot study will also indicate the expected effect size for the final experiments. First, the setup will be tested in all scenarios to test the electronics. Then, a 360 degree video will be recorded for the head-mounted display experiment. Finally, a small scale study of the final experiments is being conducted in order to test the approach and the procedure.

0.2 LOCATION

The field test will be conducted at the Heertjeslaan, 2629 JD Delft. This is a 200m long two way road. The test location can be seen in the figure 1 and 2. The Google maps link for the location is `https://www.google.com/maps/place/Heertjeslaan,+2629+JD+Delft/@51.9883336,4.3799372,17z/data=!4m5!3m4!1s0x47c5b58737fe3c07:0xf392c82fd1900c62!8m2!3d51.988324!4d4.3820779`. The road will be closed down for other traffic during the experiments.

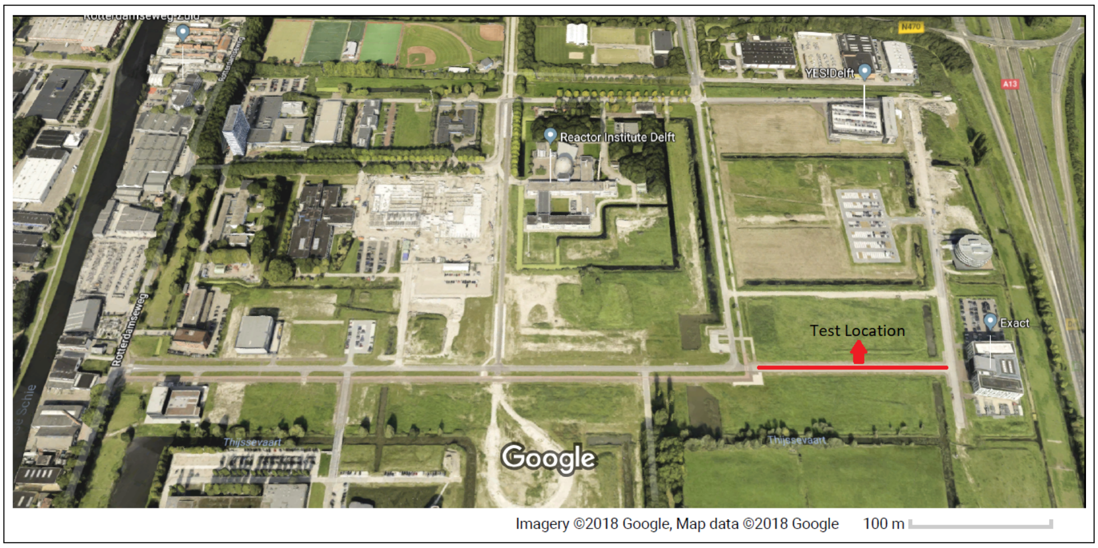

Figure 1: Test Location

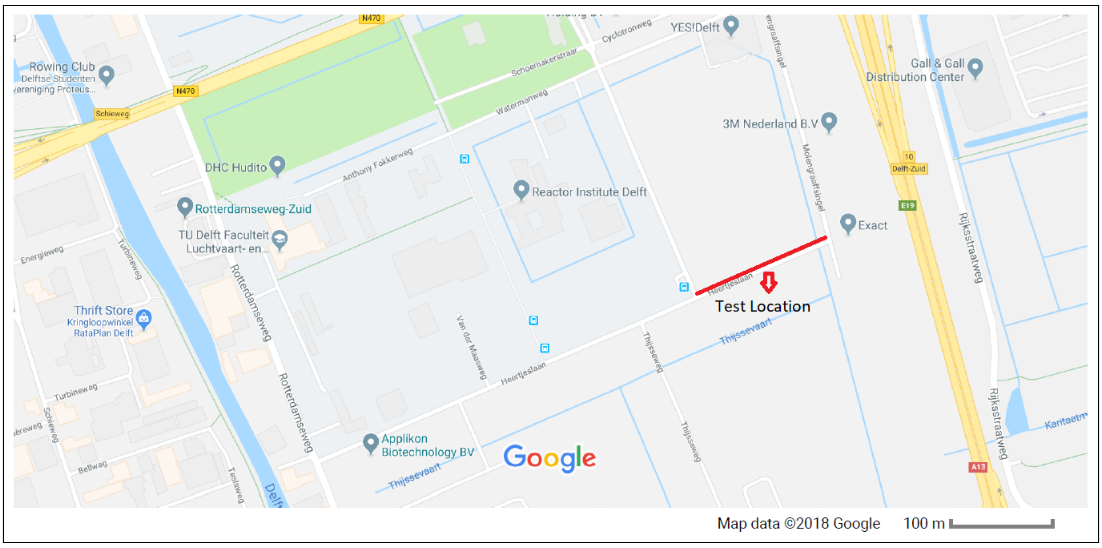

Figure 2: Test Location

0.3 EQUIPMENT

The vehicle used for the experiment is the Toyota Prius as owned by the RADD. It is controlled by joystick inputs from the technician in the passenger seat. The driver is inattentive to make the vehicle appear autonomous (Wizard of Oz). The front of the vehicle is fitted with an eHMI interface (TFT monitor with 17 inch screen diagonal), as can be seen in Fig 3.

Figure 3: Test Vehicle

Equipment inside the vehicle:
- Laptop inside vehicle to control eHMI, charger
- Dash cam with GPS recording inside vehicle

Equipment outside the vehicle:
- Measuring tape
- Traffic barriers , walkie talkies, safety vests
- Cones for distance reference, coloured tape
- Cameras for recording 3x, recording system, stands
- 360 Degree camera with batteries
- Power generator, table, coffee machine
- Button for gap acceptance, laptop for button and questionnaires, charger

The layout of the equipment on the site is shown in Fig. 4.

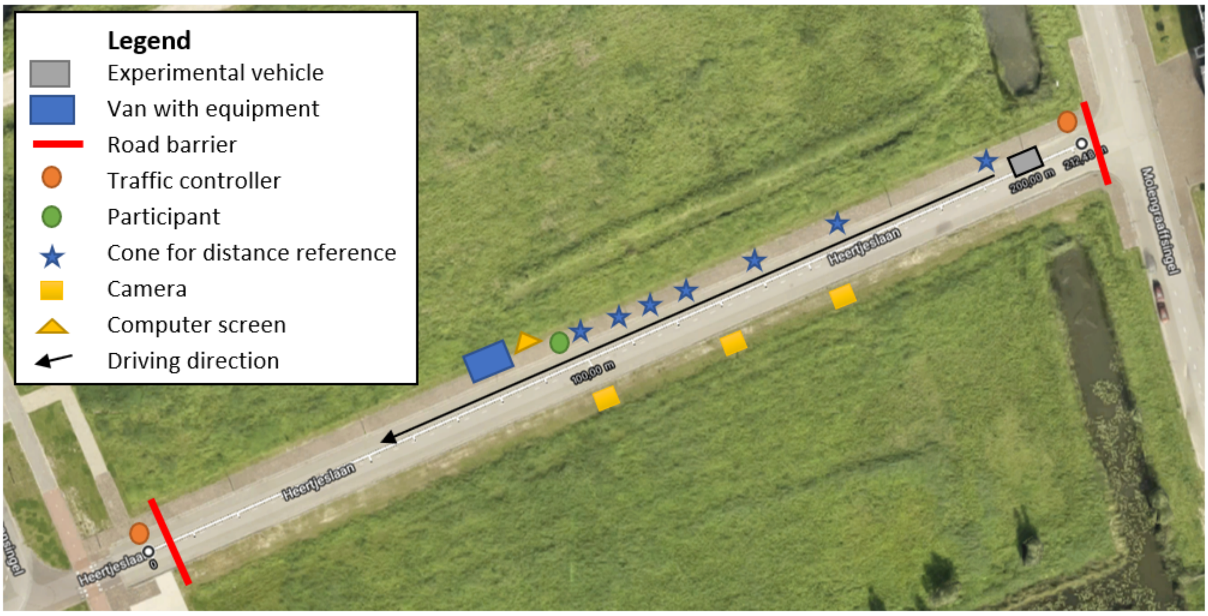

Figure 4: Site Layout

0.4 Day Planning

From	To	Task
8:30	08:30	Meet at CITG
8:30	10:00	Discussion, instruction, setup test equipment at location (road is open).
10:00	10:15	Close road, test vehicle and equipment
10:15	10:45	Practice session for the technicians
10:45	11:30	Record the 360 degree video corresponding to all three tasks
11:30	11:45	Arrival of the first participant
11:45	12:45	Participant 1 performs the experiment
12:45	13:15	Lunch, Arrival of participant 2
13:15	14:15	Participant 2 performs the experiment
14:15	14:30	Arrival of participant 3, Calibration of the equipment
14:30	15:30	Participant 3 performs the experiment
15:30	16:00	Open the road and return equipment to CITG

0.5 TASKS

1. Setup (09:00 - 10:00)
   Edwin, Peter: Car and cameras, Rakshit, Marc: Briefing, Computer, Measurements. Start, synchronise time, check pc/internet/button, check eHMI, test all equipment. Check switching on silver/blue cone and visibility.

2. Filming (10:00 - 11:30)
   Edwin, Peter: Drive, Rakshit: Instruct Drivers, Marc: Traffic, Kishore: Traffic Perform all manouevres, 1/2 takes depending on time

3. Test 1 (11:45 - 12:45)
   Edwin, Peter: Drive, Marc/Rakshit, Michael/Kishore: Experiment/Traffic

4. Test 2 (13:15 - 14:15)
   Edwin, Peter: Drive, Marc/Rakshit, Michael/Kishore/Wouter: Experiment/Traffic

5. Test 3 (14:30 - 15:30) - more or less if possible
   Edwin, Peter: Drive, Rakshit/Marc, Michael/Kishore/Wouter: Experiment/Traffic

6. Open road (15:30 - 16:00)

0.6 Steps for conducting the experiment

The steps for conducting the experiments are as follows:

1. Invite the participant to the test location.
2. Assign participant number.
3. Hand over the consent form to the participants.
4. Participants will fill in the pre-experiment questionnaires.
5. The participants will be requested at the particular location for the trial.
6. An introduction to the location and explanation about the first task
7. Perform first task: Distance Estimation
8. A 2 minute break and explanation about the second task: Speed Estimation
9. Perform speed estimation (two estimates at second and penultimate cone)
10. A 2 minute break and explanation about the third task: Gap Acceptance
11. Fist eHMI condition
12. Ask participant to fill in post-interaction questionnaire on computer
13. Repeat point 11 and 12 for the two other eHMI conditions
14. Participant will be requested to fill in a post-experiment questionnaire after the experiments.
15. Participants will be handed over the debriefing form.
16. Thank the participant for their participation.

0.7 Trial overview

Participant 1 (Distance estimation task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	5	Vehicle parked at 63m
	2nd	6	Vehicle parked at 100m
	3rd	1	Vehicle parked at 10m
	4th	2	Vehicle parked at 16m
	5th	3	Vehicle parked at 25m
	6th	4	Vehicle parked at 40m

Figure 5: Distance estimation task sequence for participant 1

Participant 1 (Speed estimation task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	1	Vehicle speed of 50km/hr
	2nd	2	Vehicle speed of 30km/hr

Figure 6: Speed estimation task sequence for participant 1

Participant 1 (Gap acceptance task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	3	Vehicle yields, showing eHMI1 (Cross) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)
	2nd	4	Vehicle does not stop, showing eHMI1 (Don't Cross) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr)
	3rd	2	Vehicle does not stop, showing eHMI0 (No eHMI) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr)
	4th	1	Vehicle yields showing eHMI0 (No eHMI) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)
	5th	6	Vehicle does not stop, showing eHMI2 (Not Braking) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr
	6th	5	Vehicle yields showing eHMI2 (Braking) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)

Figure 7: Gap acceptance task sequence for participant 1

Participant 2 (Distance estimation task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	6	Vehicle parked at 100m
	2nd	2	Vehicle parked at 16m
	3rd	5	Vehicle parked at 63m
	4th	4	Vehicle parked at 40m
	5th	1	Vehicle parked at 10m
	6th	3	Vehicle parked at 25m

Figure 8: Distance estimation task sequence for participant 2

Participant 2 (Speed estimation task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	2	Vehicle speed of 30km/hr
	2nd	1	Vehicle speed of 50km/hr

Figure 9: Speed estimation task sequence for participant 2

Participant 2 (Gap acceptance task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	5	Vehicle yields showing eHMI2 (Braking) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)
	2nd	6	Vehicle does not stop, showing eHMI2 (Not Braking) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr
	3rd	1	Vehicle yields showing eHMI0 (No eHMI) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)
	4th	2	Vehicle does not stop, showing eHMI0 (No eHMI) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr)
	5th	4	Vehicle does not stop, showing eHMI1 (Don't Cross) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr)
	6th	3	Vehicle yields, showing eHMI1 (Cross) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)

Figure 10: Gap acceptance task sequence for participant 2

Participant 3 (Distance estimation task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	2	Vehicle parked at 16m
	2nd	4	Vehicle parked at 40m
	3rd	6	Vehicle parked at 100m
	4th	3	Vehicle parked at 25m
	5th	5	Vehicle parked at 63m
	6th	1	Vehicle parked at 10m

Figure 11: Distance estimation task sequence for participant 3

Participant 3 (Speed estimation task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	1	Vehicle speed of 50km/hr
	2nd	2	Vehicle speed of 30km/hr

Figure 12: Speed estimation task sequence for participant 3

Participant 3 (Gap acceptance task)			
Start Time	Order	Scenario code (Cone number)	Scenario
	1st	1	Vehicle yields showing eHMI0 (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)
	2nd	2	Vehicle does not stop, showing eHMI0 (No eHMI) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr)
	3rd	4	Vehicle does not stop, showing eHMI1 (Don't Cross) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr)
	4th	3	Vehicle yields, showing eHMI1 (Cross) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)
	5th	5	Vehicle yields showing eHMI2 (Braking) (Vehicle speed = 30km/hr, Starts decelerating near the pedestrian and stops)
	6th	6	Vehicle does not stop, showing eHMI2 (Not Braking) (Vehicle speed = 30km/hr, No deceleration, cross the pedestrian with 30km/hr

Figure 13: Gap acceptance task sequence for participant 3

The pilot study was conducted on the 10th of January 2019 at the test location Heertjeslaan, Delft. The setup was tested, the methodology and planning were verified and 360° recordings were captured for the tasks in the video environment. Two staff members performed all three tasks in the real environment.

Distance Estimation

Fig. K.1 shows the mean estimates of the distance with standard deviations in distance estimates. The mean values are shown in red, the error bars show the value of the standard deviation. As can be observed in Fig. K.2, both the mean error and the standard deviation in the error are higher for distances above 40 m.

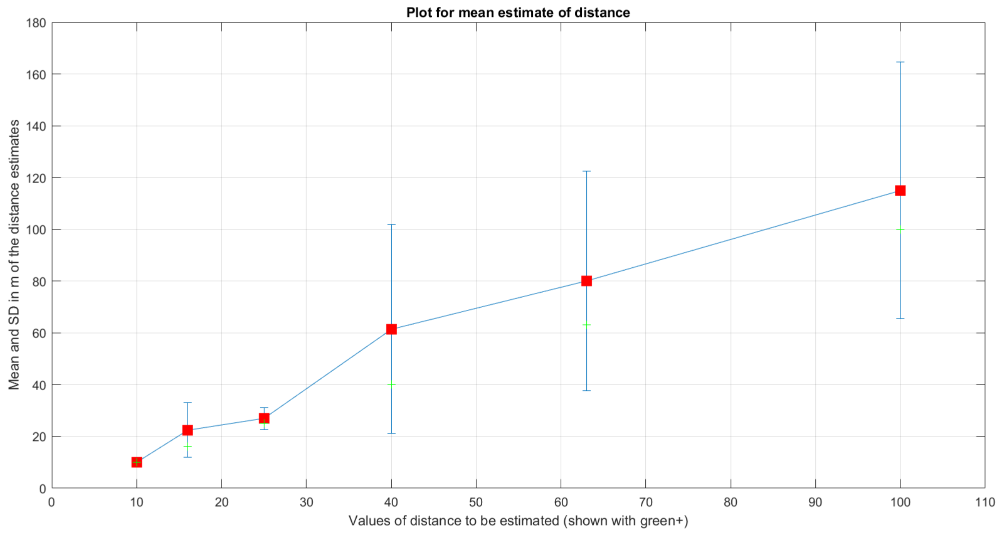

Figure K.1: Distance estimation means and standard deviation [m] for two participants.

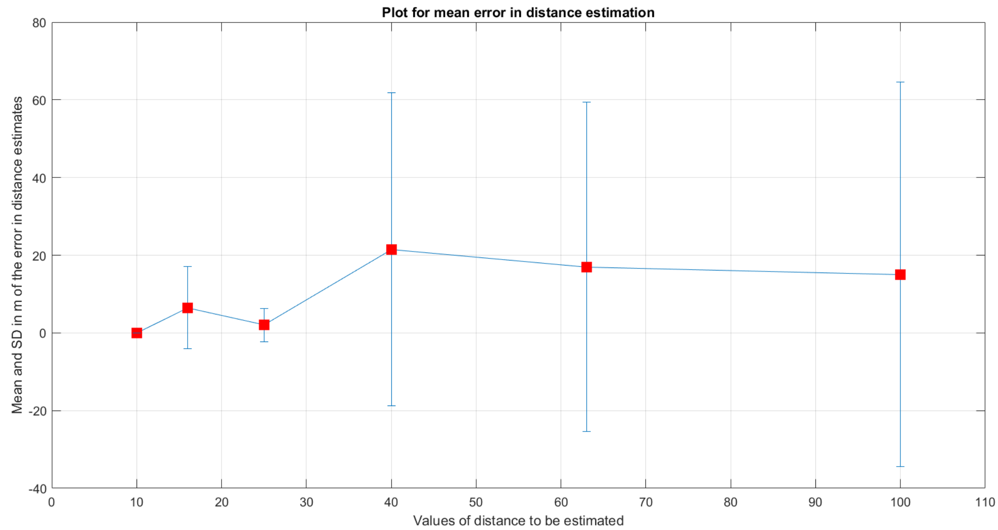

Figure K.2: Estimation error means and standard deviation [m] for two participants.

Speed Estimation

In the pilot study, speed estimation has been performed for two speeds (30 and 50 km/h) at two distances: 63 and 16 meters to reveal any differences in speed estimation at a different distance. The two speed values have been chosen as they correspond to the two limits in Dutch urban environments. The "estimate now" cue was provided at both distances. At 63 m, the error seems to be smaller for a larger speed, while at 16 m a contradictory effect can be observed (see Fig. K.4 and K.3).

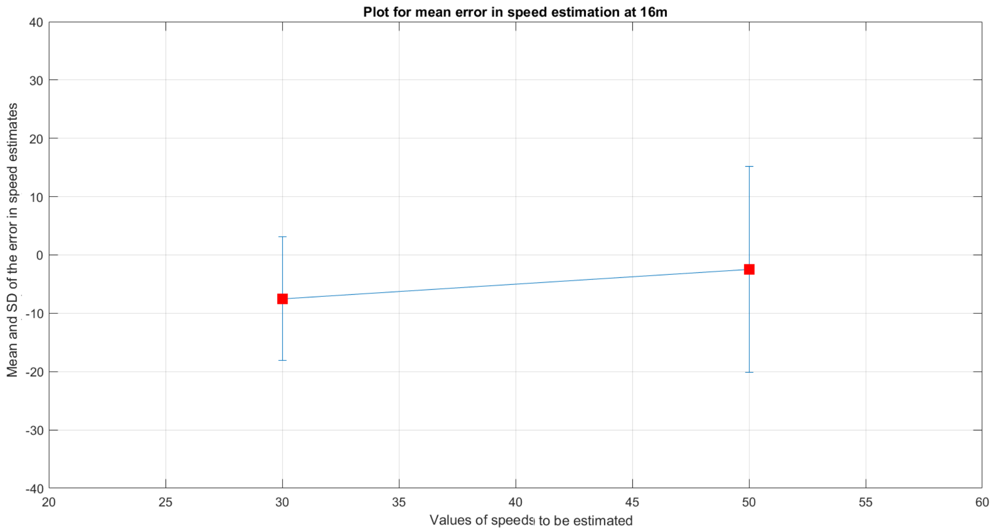

Figure K.3: Speed estimation error means and standard deviation [m] at approximately 16 m for two participants.

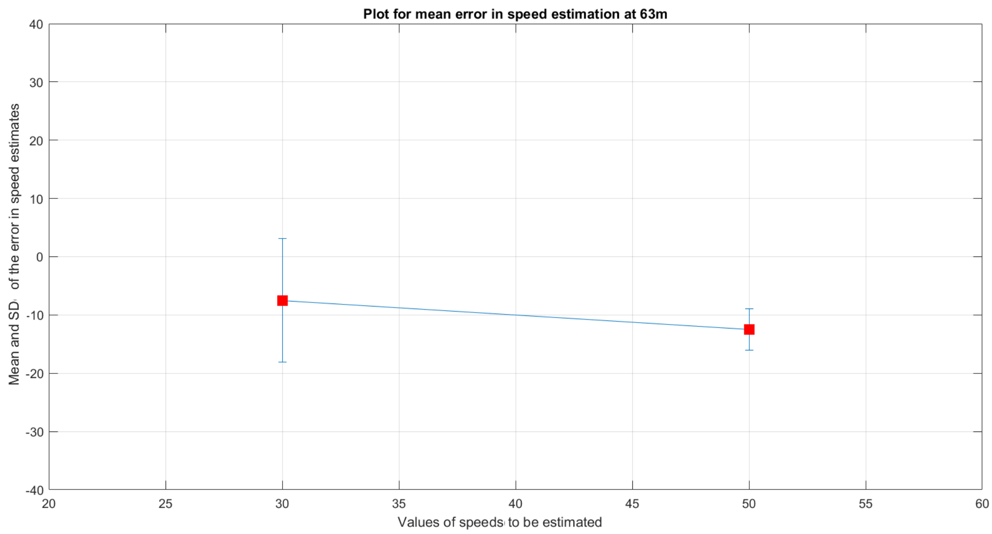

Figure K.4: Speed estimation error means and standard deviation [m] at approximately 63 m for two participants.

Gap Acceptance

The gap acceptance task has been performed using three types of information. The first moment of button release is regarded als the critical gap acceptance. The median values and spread of this gap can be observed in Fig. K.5. Allocentric state based information seems to increase the cricital gap, while egocentric advisory information seems to decrease the critical gap slightly. However, no significant conclusions can be drawn based on such a small sample size. Continious analysis of the button press data allows for a more detailed interpretation then focussing on one point. In Fig. K.6, it can clearly be observed that the a very small gap has been accepted in three trials, which indicates that the message of the eHMI has been trusted in these cases.

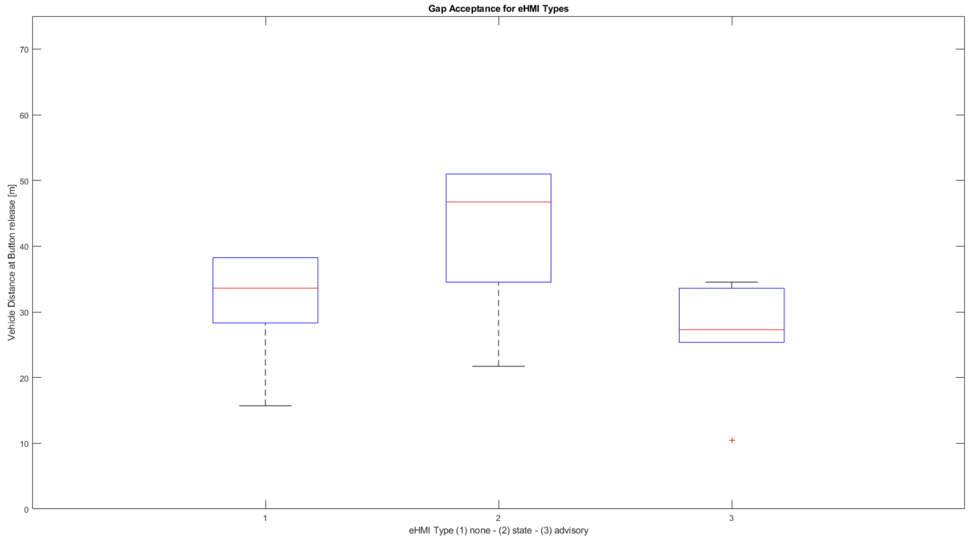

Figure K.5: Cricital gap acceptance for (1) No eHMI, (2) Allocentric state information and (3) Egocentric advisory information for two participants.

It seems that the button has not been pressed in any trial after the vehicle had passed by. This underlines the need for clear instructions during the experiment.

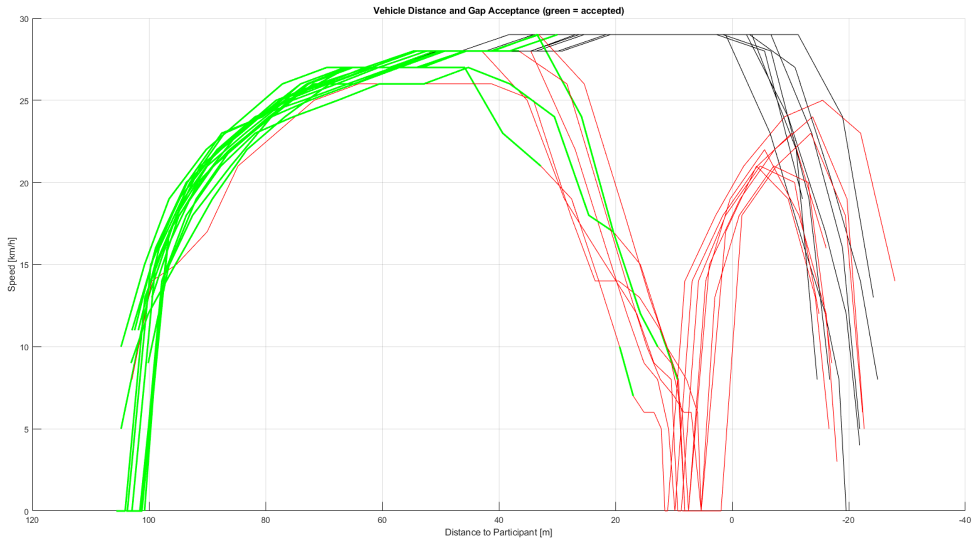

Figure K.6: Vehicle trajectory in terms of speed [km/h] and distance to the pedestrian [m], combined with button input. When the pedestrian felt safe to cross, the button was pressed and the graph is shown in green. When the button was released, the graph is shown in red. Black lines indicate nonyielding trials.

Based on the pilot study, some possible improvements have been found for the experiment:

- The estimates seem to show a large variation. A larger sample size is required.
- The speed estimates show contradicting effects and estimation at two distances proved to be difficult for the participants. One distance will be chosen.
- For a more efficient planning, two participants can perform the tasks together, in such a way that one performs the task while the other is provided with a questionnaire or break and vice versa.
- A custom eHMI has to be designed for higher brightness, as a bright computer monitor will be insufficient in sunny conditions.

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