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WEpod WElly in Delft: pedestrians' crossing behavior when interacting with automated vehicles using Virtual Reality

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1 Introduction

Automated vehicles could have many impacts on society [1]. Taking the control of vehicles from human drivers, who by their nature make mistakes, and giving it to automated vehicles (AVs), which are believed to be accurate and reliable, could, in theory, increase safety. However, how non-automated road users will react and interact with driverless AVs is unknown. In particular, cyclists and pedestrians, the vulnerable road users (VRUs), will not be able to rely on eye contact. In addition, they are vulnerable because of a lack of a metal shield to protect them, their low mass, and their many degrees of freedom in movement makes them hard to predict. At this moment, it is unclear how the interactions between AVs and VRUs will be.

The objective of this study is to investigate the interactions between pedestrians and AVs. We define an interaction as a traffic event involving two or more road users (in this case an AV and a pedestrian), which can affect their behavior and as a result their safety and the traffic efficiency. Examples of such interactions are crossing an intersection, switching lanes, and overtaking. We assume that present-day interactions are influenced by visual and auditory communication between road users. Eye contact, for example, is a form of communication that people use today, and which affects these interactions [2]. This, however, may not be present when AVs become driverless. In addition, AVs could have many appearances, including displays made for communication purposes. These new appearances could impact road users' behavior by changing their expectations [3]. For example, we expect that when road users interact with AVs for the first time they will not have clear expectations about the AV's behavior and thus be more cautious. According to the theoretical framework on the interactions between AVs and road users [4], which takes into account that behavior is influenced by expectations, trust level, behavioral adaptation, and perceived behavioral control, road users' behavior will change over time as they learn and create more accurate and concrete expectations of the AV's behavior and as they adapt their trust levels. In addition, assisting road users in creating the right expectations could guide them to safer and more efficient behavior, for example by displaying a green light indicating that the pedestrian can cross when decelerating compared to displaying nothing. So, AVs' characteristics could guide road users' behavior, but research is needed to understand how interaction behavior will be affected.

In the literature, few real life experiments have been performed to examine the interactions between automated vehicles and pedestrians by having participants experience a crossing situation [5]–[7]. Rothenbücher and colleagues (2016), for example, made use of a vehicle that appeared to be driverless ("ghost driver") but this did not significantly change the way people interacted with it, except when the vehicle malfunctioned. In such cases, people hesitated to cross or waited for the vehicle to make the first move. In two other studies, participants were confronted with an inattentive driver. In one of the studies the participants reported being less willing to cross [8], while in the other their willingness did not seem to change although they noticed that the driver was distracted [9]. When confronted with a communication display on the car, studies found contrasting results. In [6] pedestrians seem to ignore it, while in [10] they appear to take its message into account. However, these types of studies are, for example, costly, time consuming, dependent of weather and traffic, and are strictly ethically examined, which limits their adoption and replication. Studies that do not suffer from these factors are those performed in a VR environment. However, VR has also drawbacks: the setting can be unrealistic, also the behavior of vehicles can be arbitrary, and affect the risk perception due to the feeling that it is unreal. Therefore, careful design of these types of experiments is required. These types of studies are also scarce in the literature in this specific field. Among the few studies that were found, one study attempted simulating eye contact by placing eyes on the vehicles' headlamp. This was found to make the pedestrians decide faster and more accurately whether to cross, and made them feel safer [11]. There are more studies performed on the pedestrians' crossing behavior, especially children's, which have shown that this method "faking eye contact" can show differences in crossing behavior [12]–[14]. In addition, studies have proven that it can be highly immersive [15] and that behavior in a VR simulation can match real world norms [16].

We studied the interactions between pedestrians and vehicles depending on vehicle type, speed, gap size, presence of crossing facilities, and presence of communications displays by making a VR simulation of a crossing situation involving an AV by using 360° videos. This study aimed to investigate how a combination of expected AVs' characteristics could affect pedestrians' crossing intention, and test the usefulness of Virtual reality based on 360° videos for pedestrian crossing behavior research purposes. To the best of our knowledge this type of experiment has not been performed yet. The advantages of 360° videos are the use of realistic looks from the real world in a controlled setting at a low cost and its reproducibility. The drawback is that the user is not able to wander around like in other VR simulations.

2 Research Method

This study is a repeated measures design. The experiment consisted of scenarios, which were filmed with a Nikon Keymission 360° camera that is able to capture all its surroundings, and each scenario consisted of a different combination of variables. These videos consisted out of 3 different scenes (figure 1) which were presented to the participants using consumer-grade Virtual Reality glasses and a Samsung Galaxy S6 screen. We examined the following variables: vehicle type, speed, time gap, presence of a crossing facility, and presence of a traffic sign on the vehicle (Table 1), which resulted in $2^5 = 32$ scenarios.

After being informed about the experimental procedure the participants were asked to sign an informed consent. Due to the nature of the experiment extra attention was put into informing the participants about possible symptoms to help them to be aware what they could experience. After this, the participants were asked to wear the head-mounted display (HMD) and they experienced shortly the virtual environment in the form of a 360° video. During each trial (of a total 32) a pre-recorded 360° video was shown through the HMD containing a part where the participant approached the intersection, and one of the 32 scenarios. After that, the video stopped, and a question appeared in the HMD; Would you cross? (see figure 1). The participants had to react quickly and verbally once they saw this question. Then, the next trial started. At the end of the experiment a 19-item version of the Presence Questionnaire was used to test the immersiveness of the virtual environment [17], [18]. Afterwards, previous experience with a virtual environment was prompted and a couple of questions were shown to check whether they experienced symptoms of simulation sickness. Finally, we adapted and employed a trust in AVs questionnaire [19].

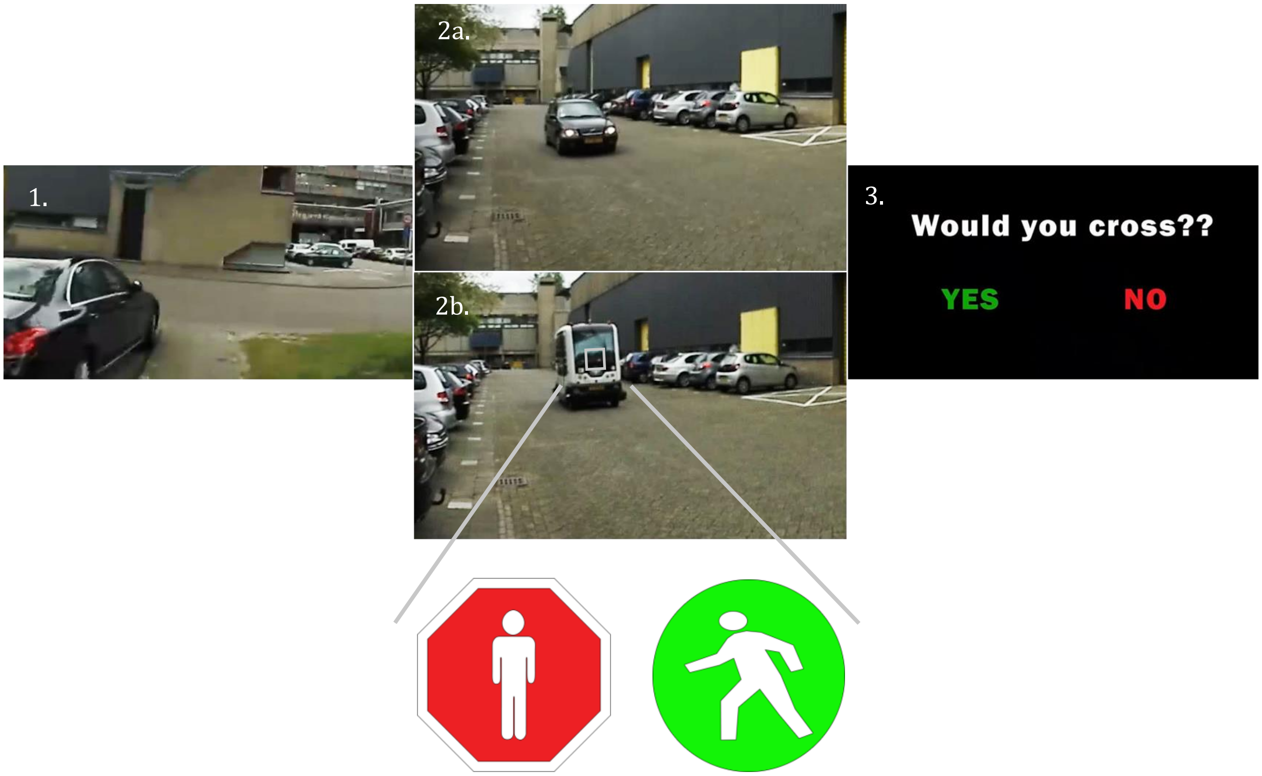

Figure 1. An example of how a trial could look like. It started with scene 1 (from left to right) in which the participant appeared to walk towards the intersection. Scene 2 contains two of the 32 scenarios. In this case scene 2a shows the CV and 2b the AV. Scene 3 prompted the pedestrians whether they would cross. On the bottom, the displays that were photoshopped on the AV are shown.

Table 1

Variables included in this experiment

Variable type	Levels	Variables	Meaning
Vehicle	2	AV	Automated Vehicle (without a sign)
		CV	Conventional Vehicle
Crossing facility	2	ZC	Zebra Crossing present
Speed		NZC	No Zebra Crossing present
	2	V1	Vehicle driving speed 10 km/h
		V2	Vehicle driving speed 20 km/h
Gap	2	Gap2s	Gap between vehicle and pedestrian was 2 seconds
		Gap4s	Gap between vehicle and pedestrian was 4 seconds
Communication display* (figure 1)	2	Green sign	The AV was equipped with a green sign on the front window
		Red sign	The AV was equipped with a red sign on the front window

Note: * Communication display was only shown on the AV.

3 Results

This study is on-going thus, at this stage only the preliminary findings in the trials data and in the presence questionnaire are presented. Data analysis and statistical testing is ongoing and will include a statistical model explaining the crossing behavior of pedestrians based on the variables introduced in this experiment. The pilot study included 7 participants, 2 males and 5 females, who were semi-randomly divided in two groups which determined the order of the scenarios, and resulted in 207 trials (7 participants x 32 trials – 22). One participant dropped out after 10 trials due to simulation sickness.

First, we examined the differences using in the decisions to cross over all totals of variables (see figure 2). Analyses of the crossing responses were undertaken by using binary logistic regression modelling of the data to examine the impact on the crossing decision of the variables vehicle type, vehicles' speed, presence of crossing facility, and gap size were in the model (table 2) which was not significant $\chi^2(1) = 3.183$, $p = .922$. The vehicles' speed was the only predictor in the model that was not significant. Vehicle type has an odds ratio (OR) of 2.2, presence of a zebra crossing has an OR of 0.5, and gap size has an OR of 2.2. These ORs are in line with our expectations. In a later stage we will also analyze interaction effects and, for example, the effect of the communications signs on crossing behavior (figure 3).

The Presence questionnaire data of 19 items on a 7-point scale was analyzed. It contained 4 factors: involvement, sensory fidelity, adaptation/ immersion, and interface quality. The scores on these 4 factors and the total score on the Presence questionnaire are shown in Table 3. The final score of 4.6 indicates that participants experience a moderate amount of presence using the HMD.

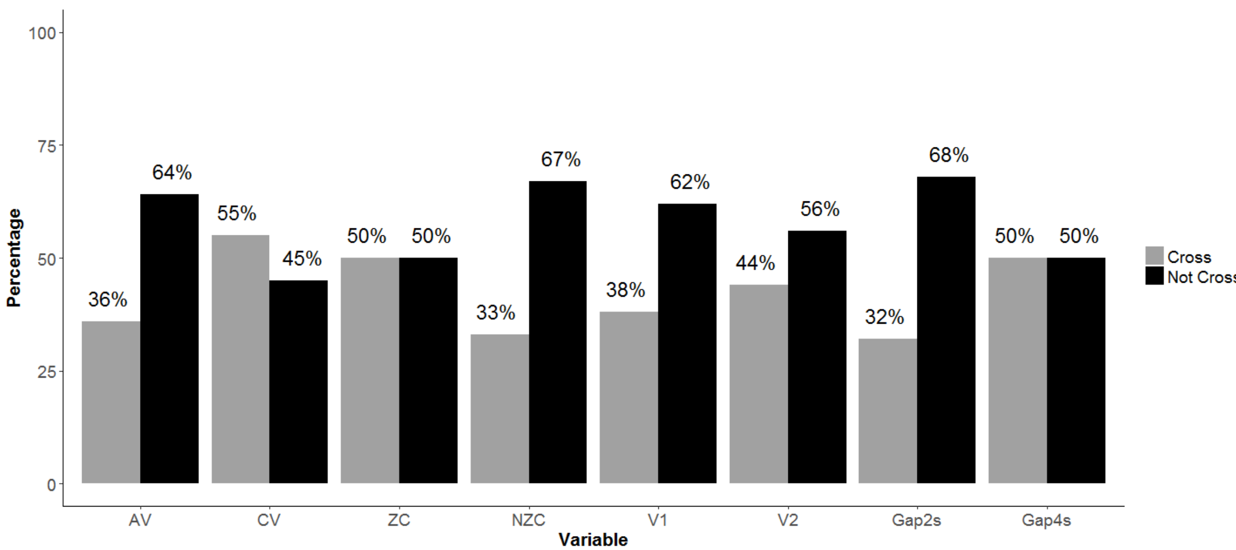

Figure 2. The proportions of decisions-to-cross are plotted per variable. On the x-axis the corresponding variable is shown.

Table 2

Logistic regression model

	Vehicle type (CV= 0)	Speed of the vehicles (V2 = 0)	Presence of crossing facility (NZC = 0)	Gap size (4 seconds = 0)	Constant
B-coefficient	,768	,242	-,680	,797	-,332
S.E.	,334	,296	,299	,297	,375
p-value	,021	,413	,023	,007	,376
Odds Ratio (Exp(B))	2,156	1,274	,507	2,219	,718

Note: Crossing was encoded as 0 and not crossing as 1. $R^2 = 0.113$

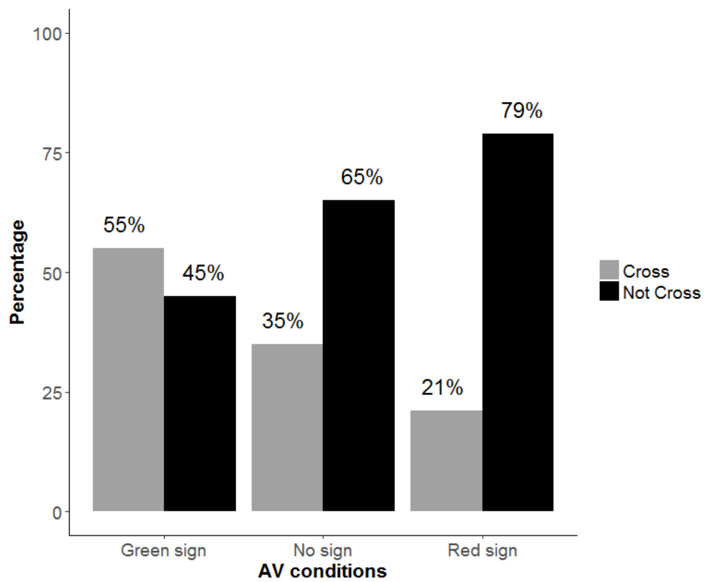

Figure 3. Here, the proportions of decisions-to-cross per sign displayed by the AV are presented.

Table 3

Descriptive Statistics of the Presence Scales

	Involvement	Sensory fidelity	Adaptation/ Immersion	Interface quality	Mean score
Mean	4,40	5,61	5,77	2,50	4,57
Std. Deviation	0,73	0,68	0,56	1,24	0,39

4 Discussion

This ongoing study aims to create a better understanding of the effect AVs' characteristics will have on interactions with VRUs. At the same time, the applicability of 360° video for research purposes of this type of research questions is tested. Our logistic regression model was not significant, however, vehicle type, presence of crossing facility, and gap size were significant predictors of crossing intention. Meaning that crossing intention is affected by these three variables. Participants confronted with an AV were 2.2 times more likely to not cross compared to when confronted with a CV, this is also true when comparing a gap size of 2 seconds with the 4 seconds gap size. When confronted with no zebra crossing, the participants were .5 times more likely to cross compared to when a zebra crossing was present. The reason why participants reported to have less crossing intentions when the AV was present, could be that this vehicle was not known to them and thus, they had no expectations on how it could behave and thus neither about how they should behave. This result is in agreement with our previously presented framework [4] and our expectations. We are aware that the looks of the vehicle could have been the cause of this behavior and thus not necessarily the fact that it is an AV. However, we expect that some AVs will introduce these distinctive looks. In contrast, we do not expect road users to immediately know that these vehicles are automated. That is why in this paper we study the effect of the physical appearance.

The presence questionnaire data showed that the use of 360° videos as VR has an acceptable score (average 4,57 out of 7) of presence, despite the low score for interface quality, and is comparable to a study which uses a computer simulated environment [15]. However, one should take into account that by using 360° videos interacting with the environment is not possible. This was not interesting for our purposes, though. 360° videos could provide a simple and cheap solution for researchers looking to deploy their experiments at different locations as only a HMD is needed for the experiment once the videos are recorded. These videos can easily be shared with other researchers all over the world to study cultural differences, for example.

In conclusion, this pilot has shown promising preliminary findings which show that pedestrians may change their behavior when interacting with an AV depending on its appearance. The final study is expected to give a better understanding of the other variables on crossing behavior.

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