Interactions with Automated Vehicles:
The Effect of Drivers' Attentiveness and Presence on Pedestrians' Road Crossing Behavior

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Abstract

The impact of the absence of a human driver in an automated vehicle (AV) on pedestrians' crossing behavior has been the topic of some recent studies, but findings are still scarce and inconclusive. The aim of this study was to determine whether the drivers' presence and apparent attentiveness in a vehicle influences pedestrians' crossing behavior, perceived behavioral control, and perceived risk, in a controlled environment, using a Head-mounted Display in an immersive Virtual Reality study. Twenty participants took part in a road-crossing experiment. The VR environment consisted of a single lane one-way road with car traffic approaching from the right-hand side of the participant. Participants were asked to cross the road if they felt safe to do so. The effect of three vehicle features on pedestrian crossing were studied, which were linked to the presence or attentiveness of the driver: Attentive driver, distracted driver, and no driver present. The effect of two different time gaps between the vehicles (3.5 s and 5.5s), on crossing behavior of pedestrians, were also investigated. The manipulated vehicle yielded to the pedestrians in half of the trials, stopping completely before reaching the pedestrian's position. Results showed that the vehicle's motion cues were the most important factors affecting the time it took pedestrians to initiate a crossing. Contrary to expectations, participants crossed later in the distracted driver condition, compared to the other two conditions. Questionnaire results showed that participants felt they had more control, and felt safer, when the driver was present and attentive. The simulator realism scale showed that the virtual reality experiment was acceptable to participants.

Keywords

Automated Vehicles; Vulnerable Road Users; Virtual Reality; Driver Presence; Driver Attentiveness

1. Introduction

Pedestrians are one of the most vulnerable road users in traffic because of their relative low mass and their lack of a protective shell that can absorb the kinetic energy that is created in a crash with another road user. Accidents between pedestrians and motorized vehicles are the main causes of pedestrians' deaths, globally, with 310500 killed [1]. These accidents happen mainly as a result of a pedestrian attempting to cross the road. Automated vehicles (AVs) are expected to reduce the traffic accidents and thus reduce the amount of pedestrians' fatalities, but empirical evidence is still lacking. AVs will introduce new features that are unknown to pedestrians and could affect the pedestrians' behavior, such as absent human drivers. How the pedestrians could adapt their behavior and its impact on traffic safety is unknown.

Studies on pedestrians' road crossing behavior have shown that the speed of the vehicle, its distance to the pedestrian, road infrastructure, and pedestrians' characteristics are determinant factors of pedestrians' road crossing behavior [2]. The gap between a pedestrian and a vehicle has been a main focus point in a number of studies. The mean accepted time gap by pedestrians, in interactions with traditional vehicles, has been found to be between 3 to 7 seconds. If the time gap is lower than 3 seconds, it is unlikely for a pedestrian to cross, while the likelihood of crossing increases if the gap is higher than 7 seconds [3]. Pedestrians can make a rough estimate of when a vehicle will arrive at their position, but base their crossing decision mainly on the perceived distance [4]. The assessment of the distance and speed of the vehicle deteriorates with increasing vehicle speeds [5]. It can be argued that a pedestrian's perceived safe crossing distance and time gap, when interacting with an AV, might be different compared to when interacting with a traditional vehicle because AVs might use new communication strategies to communicate its intent with pedestrians.

Studying the communication between a driver and a pedestrians has been of interest in recent years [e.g. 4], since the absence of a human driver in these vehicles, or at least one which is responsible for communication of intent, means that future AVs must be equipped with some form of communication strategy, in order to interact safely with other road users in a shared space setting [7]. Currently, different forms of nonverbal communication, such as hand and head movements, are considered an important cue used by pedestrians and drivers but will be absent in the future if AVs are able to operate driverless. However, the importance of this type of communication is currently unclear, since on road interactions without visibility of such gestures occur regularly, for example at night or when glare reduces the visibility of the driver.

A number of different methods have been used to study pedestrians' crossing behavior, in both real-world and laboratory settings. One example includes controlled field experiments, conducted in the real world, their main benefit being that they are very realistic. However, studying pedestrians' crossing behavior in such settings can lead to dangerous situations, which can be challenging in terms of participant recruitment and approval by ethics committees. In addition, field experiments tend to be expensive, time consuming, and difficult to replicate. Therefore, other types of experiments which are more efficient and provide safe, repeatable and controllable environments are needed. Recent advances in immersive technologies has allowed the development of relatively affordable, virtual reality (VR) studies which are flexible, cost-effective, repeatable and safe to conduct in laboratory settings. Of course, there are also limitations associated with VR, including their lesser degree of realism, a more structured and directed behavior of pedestrians, and some VR studies are also associated with simulation sickness.

Using a virtual reality (VR) study, Chia-ming, et al. found that pedestrians make safer decisions and decide faster when the vehicle was equipped with fake eyes mounted on the headlights to establish eye contact [8]. Another VR study [5] has shown that participants feel safe to cross for longer when an external human-machine interface (eHMI) is used to show that a pedestrian may cross. Finally, a VR study found that displaying a green sign, containing a walking pedestrian, and a red sign, containing a standing pedestrian, influenced the pedestrians' crossing behavior in the expected direction [9]. However, these results were in contrast to field study that examined pedestrians' crossing behavior in response to three different signs: a walking pedestrian, a walking pedestrian overlaid with a cross, and a sign displaying the vehicles' speed. The authors found no difference in crossing behavior of the pedestrians in response to the three signs [10]. They concluded that the way the vehicle behaves (i.e. its speed profile and braking behavior, etc.) is more important in influencing a pedestrian's crossing behavior, compared to displayed signs. However, in a different field study pedestrians are reported to prefer receiving explicit information about the vehicle's intention, through eHMIs that communicate awareness and intent, compared to deducing the information from the vehicle's "motion cues" [11].

So far, mixed results have been found regarding the value of external messaging for communicating intent and their effect on pedestrians' crossing behavior. Studies that have used the "Wizard of Oz" technique (which, for example, involves control by a human hidden behind an especially designed seat) found no difference in crossing behavior of pedestrians, compare to when the vehicle was driven by a visible human driver [12], [13]. However, when asked how the individuals felt while interacting with a driverless vehicle, most reported themselves to have acted differently than normal [13], or were simply less willing to cross [14]. Again, the effect of traditional motion cues seem to explain and predict the crossing behavior of pedestrians.

The aim of the current study is to investigate the effect of a driver's presence and a driver's attentiveness on pedestrians' crossing behavior. Here, we employed an immersive virtual reality environment that allowed experimental control over these variables and observe participants'/pedestrians' actual crossing behavior, to collect crossing behavior data from pedestrians, using a series of scenarios, without putting our participants at risk. Since previous studies have shown mixed results regarding whether presence of, or communication by, drivers affected pedestrians' crossing behavior, the aim of this study was to investigate if pedestrians' crossing behavior in VR was affected by the presence of a driver in an approaching vehicle, and whether this behavior was different in the presence of a distracted driver. The results of this study can serve as input for AVs' and urban areas' design.

2. Research Methodology

A repeated measures design was used to study crossing behavior in an immersive virtual reality (VR) environment. The design of this experiment is adopted from Lee, et al. [15]. Participants were asked to cross the road after the first vehicle had passed, if they felt safe to do so. The effect of driver presence and attentiveness, the time gap between the pedestrian and the manipulated vehicle, and vehicle's yielding behavior, on the crossing behavior of pedestrians was examined. The combination of these factors resulted in 12 scenarios, as shown in Table 1.

The posture of the driver of the approaching vehicle was adapted to create an "attentive", forward looking driver, and a "distracted" driver, a rightwards looking, driver (figure 2). The driver was sitting on the right seat of the vehicle behind the wheel as is custom in the UK. The "no driver" condition consisted of a vehicle without anyone inside the vehicle. The vehicle's speed was 30 km/h.

In 50% of the scenarios, the vehicle continued driving with a constant speed of 30 km/h and without yielding to the pedestrian. In the other 50%, the vehicle decelerated and came to a full stop before reaching the pedestrian's position, i.e. yielding to the pedestrian.

Two time gaps were employed: 3.5 seconds and 5.5 seconds. Time gap is an important factor that influences crossing behavior [2, 13, 14] The chosen time gaps resembled a critical and a safer (less critical) situation. We expected that by employing these two time gaps, enough variation in the crossing behavior would be visible.

These 12 scenarios were repeated 3 times per block, and the study consisted of a total of 3 blocks. Thus, each participant faced 108 crossing trials (12 scenarios x 3 repetition per block x 3 blocks). The scenarios were randomized per block per participant to reduce the order effect.

2.1 Participants

Twenty participants took part in the experiment. The participants were required to be in the age range of 18 – 35 years old, be British or resident in the UK for at least 5 years, not suffering from extreme motion sickness, or have a history of epilepsy. Eleven of our sample were female, and all were British. Their age varied from 18 to 33 years old, (M = 22.8; SD = 3.8). The participants were recruited at the University of Leeds and 15 of them were students and the other 5 were employers of the University. Eighteen of the participants reported in a survey that they knew to some extent what an automated vehicle is, and everyone noticed the differences between the driver conditions and could tell which conditions were presented. Twelve participants, 7 males and 5 females, felt that they were interacting with AVs and the other 8 did not. The participants were informed about the virtual reality crossing behavior study, and its duration during recruitment. The experiment was approved by the University of Leeds Research Ethics Committee - Ref: LTTRAN-097. All participants received £10 as compensation for completing the study.

2.2 Apparatus

1.2.1 Virtual Reality simulation

The immersive virtual environment is adapted from Lee, et al. [15] and was built using Unity, and was presented to the participants with a HTC Vive head-mounted display. The HTC Vive was tracked by two lighthouse sensors that translated the wearer's position in the real world. The virtual environment resembled a one-way street with a side walk on both sides of the road in an urban neighborhood as shown in Figure 1. The street featured houses on both sides of the road, and trees and street lights on opposite sides of the road. The participants started on the tree side and were only able to start a new trial from the same side to eliminate the road side as a variable. That meant that they had to cross back if they decided to cross. Two boulders were placed on both sides of the road to indicate the starting position and its opposite if the road was crossed in a straight line. Two different vehicles were present during each scenario and the only difference between the vehicles was the color, the manipulated vehicle was blue and the other white. The vehicles were two saloon vehicles. The windows of the vehicles were removed to prevent reflections from blocking the driver. The drivers were all male. The driver of the white vehicle was different from the other two in terms of hair and clothing.

The recorded measurements inside the virtual reality simulation included the following: the decision to cross per scenario as well as the initiation time which is the time it took for the participant to start crossing [15]. The reference point for the initiation time was set to be the point in time were the first vehicle passed the pedestrian and thus the road was clear for the pedestrian to cross before the arrival of the second vehicle. To measure the initiation time, we used the head movement of the participants to determine the exact moment they initiated their crossing. A down- and forward tilt of the head indicates that the participant is going to start crossing the road [15]. The initiation time is tightly linked with the gap between the pedestrian and the vehicle. The gap becomes smaller when the initiation time is higher.

The crossing time was measured too. The crossing time is the time it took the pedestrian to reach the other side of the road starting at the moment they left the starting position [15]. The crossing time gives an indication of the walking speed of the pedestrian. We hypothesized that the pedestrians would cross the road faster when they felt unsafe as compared to when they felt safe.

Table 1: Factors included in this experiment.

Variable name	Levels	Annotation	Explanation
Driver	3	AD	Attentive Driver
		DD	Distracted Driver
		ND	No Driver
Yield	2	Y	The vehicle yielded for the pedestrian
		NY	The vehicle did not yield for the pedestrian
Gap size	2	SG	Gap between vehicle and pedestrian was 3.5 seconds
		LG	Gap between vehicle and pedestrian was 5.5 seconds

Figure 1. The environment of the crossing experiment including the two vehicles.

Figure 2. The three driver conditions (from left to right): Attentive driver (driver looking straight ahead), distracted driver (driver looking to the right at his phone), and no-driver.

1.2.2 Surveys

Following the VR study, participants were required to complete three short surveys. We used an adapted version of the *trust in automation* survey developed by Payre, Cestac and Delhomme [18] to capture the trust the participants had in automated vehicles. The participants must score their agreement with 6 statements on a 7-points Likert scale. Statements included are for example: *Globally, I trust the automated vehicle*, and *I trust the automated vehicle to avoid obstacles*. Furthermore, we measured the perceived behavioral control the participants felt per driver condition after the VR sessions. Two items adopted from Zhou, Horrey, and Yu [19] were used for this: '*For me, crossing the road in this way would be...',* and '*I believe that I have the ability to cross the road in this way...'*. The items were scored on a 7-point bipolar scale explaining how easy and how much the participants agree with the statements, respectively. Also, the perceived risk per driver condition was measured on a 7-point scale.

To capture the performance of the VR environment, the Presence Questionnaire and the Miscery Scale (MISC) were employed. The Presence Questionnaire contains 16 items over 4 factors (i.e. involvement, sensory fidelity, adaptation/ immersion, & interface quality). Questions about haptic or sound fidelity were excluded because they were irrelevant. The MISC was used to assess the simulation sickness symptoms of the participants. The participants were able to score how many symptoms they experienced and how heavily on a score from 0 to 10. The MISC was filled in 4 times per participant.

2.3 Procedure

The participants had to fill in an informed consent in which the experiment procedure was printed. They were informed about the possible symptoms related to simulation sickness to help them be aware of what might happen. After that, the participants were informed in detail about the virtual environment. The MISC was filled in before the start of the experiment to have a baseline. They put the equipment on and while they were in the virtual simulation the experiment leader informed them again about where they had to stand, cross, and which button needed to be pressed. The button press was added so the participants could start the trial when they were ready. First, a couple of practice trials were completed until the participant expressed they were ready to start the experiment. Once the experiment started, they experienced 12 different scenarios (3 effects of driver, 2 time gaps, and 2 deceleration profiles) which were repeated 3 times in random order. This was called a block and each block lasted approximately 15 minutes. After the first block, the participant had a break, depending on the participant's need, and the MISC was filled in for the second time. Then, another block was completed, followed by another break and a completion of the MISC survey for the third time. This process was repeated once more. Thus, every participant completed 3 blocks. After the third block, the participants were asked to press a button as soon as they could distinguish the driver seated in the second vehicle, if he was present. This final task consisted of 6 trials because the trials in which the vehicle yielded were removed. Then the participants were asked to fill in an online survey which contained the questionnaires mentioned in sub-section 2.2.2. Once they finished, they received their compensation. In total, the experiment had a duration of 1 hour.

3. Results

3.1 Pedestrians' crossing behavior

In 85% of the trials (N = 1776), the pedestrians decided to cross the road. There was no significant difference per driver condition (Attentive driver 85%, distracted driver 86%, and no driver 85%). A similar result was found when only the non-yielding scenarios were considered (Attentive driver 70%, distracted driver 71%, and no driver 70%). The mean initiation time across all conditions was 0.85 seconds (SD = 2.32). The mean initiation time per driver conditions were the following: attentive driver 0.88 seconds (SD = 2.40), distracted driver 0.87 seconds (SD = 2.31), and no driver 0.82 seconds (SD = 2.25). The mean time it took a participant to cross the road was 4.07 seconds (SD = 2.36). The driver's presence did not have a significant effect on the frequency of crossing, $F(2,1768) = 0.12$, $p = .891$, on the time it took the participants to initiate the crossing, $F(2,1771) = 0.55$, $p = .575$, nor on the time it took the participants to cross the road, $F(2,1771) = 0.55$, $p = .575$. The mean trust in AVs score was 4.1 (SD = 1.0) on a 7-point Liker scale, the more trust the higher the score. Males on average trusted the AV more than females (mean score 4.3 (SD = 1.1) versus 3.9 (SD = 1.0)). Furthermore, participants who thought the vehicles were AVs had a mean score trust of 4.0 for trust (SD = 1.1) while those who did not think the vehicles were AVs had a mean score on trust of 4.3 (SD = 1.0).

To investigate the effects of the considered factors on the initiation time we estimated a linear regression with mixed effects which accounts for the driver condition, time gap, yielding behavior, gender, whether the participant thought the vehicles were automated or not, trust in AVs, the perceived behavioral control per driver, and the perceived risk per driver. To capture the correlations between the observations of the same participant a random intercept was added.

Furthermore, due to absence of assumptions in the error structure an unstructured covariance matrix was considered (Singer, 1998).

Table 2: Estimation results of the initiation time model.

Fixed Coefficients		Estimates	Std. Error	t	p
β_0	Intercept (mean)	-0.24	1.26	-0.19	.85
β_{Driver}	Driver (ND, AD[1])	-0.04	0.03	-1.45	.15
β_{Driver}	Driver (DD, AD[1])	0.07	0.04	1.99	.05
$\beta_{gapsize}$	Time gap (3.5s, 5.5s[1])	3.08	0.13	23.53	<.001
β_{yield}	Yielding behavior (NY, Y[1])	-0.03	0.02	-1.18	.24
β_{Gender}	Gender (M, F[1])	-0.12	0.02	-7.76	<.001
β_{AVs}	AVs? (Yes, No[1])	0.24	0.01	16.23	<.001
β_{Trust}	Trust in AVs	-0.01	0.01	-1.80	.07
β_{PBC}	Perceived Behavioral Control	0.04	0.05	4.61	<.001
β_{PR}	Perceived Risk	-0.02	0.01	-2.42	.02
$\beta_{Int:Yield\&Driver}$	Yielding behavior*Driver (DD*NY)	-0.10	0.04	-2.71	.01
$\beta_{Int:Yield\&TimeGap}$	Yielding behavior*Time gap (3.5s*NY)	-3.17	0.13	-24.08	<.001
Random Effects		**Estimate**	**Std. Error**	Z	p
μ_0	ParticipantID: intercept (var)[2]	1.595			
Model Performance					
-2LL	3405.4				
AIC	3637.9				
BIC	4220.2				

[1]Reference category. [2]Variable was redundant.

Of the different driver conditions, only the distracted driver differed significantly from the attentive driver condition, as shown in Table 2. So, the initiation time of the participants was longer in the distracted driver condition. In addition, when the vehicle did not yield and there was a distracted driver, the initiation time was significantly lower as compared to the other scenarios. Time gap was a very strong factor that influenced the initiation time. The initiation time was significantly longer when the time gap was 3.5 seconds compared to 5.5 seconds. This is explained by the interaction between the yielding behavior and time gap. When the time gap was 3.5 seconds and the vehicle did not yield, the initiation time was significantly shorter as compared to the other combinations of time gap and yielding behavior. Yielding behavior of the vehicle did not have a significant effect on the initiation time.

Furthermore, the gender of the participants had a significant effect on the initiation time. Male pedestrians have shorter initiation time compared to female pedestrians. The effect of expecting to be interacting with automated vehicles had a significant positive effect on the initiation time which means that participants that thought they were interacting with AVs started crossing the road later and thus accepted a smaller gap. In contrast, trust in automated vehicles did not affect the initiation time significantly. The perceived behavioral control per driver condition had a small significant positive effect on the initiation time. Perceived risk had a small significant negative effect.

3.2 Perceived Behavioral Control (PBC) & Perceived Risk

After the VR study, participants were asked to complete the perceived behavioral control (PBC) and the perceived risk questionnaires, for each of the three driver conditions. Significant differences were found between the various driver manipulations and the behavioral control the participants perceived, $F(2,519) = 9.89$, $p < .001$. The participants' perceived behavioral control was significantly higher with the attentive driver (M = 5.61, SD =1.29) as compared to the inattentive (M = 4.55, SD = 1.40) and no-driver conditions (M = 5.03, SD = 1.44), as revealed by posthoc tests with Bonferroni correction, $p < .001$. The perceived risk is significantly different between driver manipulations, $F(2,519) = 144.92$, $p < .001$. A Bonferroni test showed again that score on perceived risk score was significantly higher with the attentive driver (M = 5.69, SD =1.24) as compared to the inattentive (M = 3.02, SD = 1.60) and no-driver conditions (M = 3.98, SD = 1.57), $p < .001$ meaning that they felt safer during the attentive driver condition as compared to the other two conditions.

3.3 Visibility driver

To assess when and if the driver was visible for the participants, a task was completed. The participants pressed a button if and when they saw that there was a driver inside. The moment the button was pressed and the distance from the pedestrian to the vehicle were recorded. The amount of errors (e.g. pressing when there is no driver or vice versa) were logged. Fifteen participants did not make any error. Four participants had 1 error out of six and one had 2 errors. The mean distance a participant was able to distinguish a driver sitting inside the vehicle was 34.2 meters (SD = 14.5). The distance varied from 10.3 to 75.3 meters. The time it took the vehicle to close the mean distance was 4.1 seconds.

3.4 Miscery Scale (MISC)

The results of the MISC can be found in figure 3. The participants did not experience simulation sickness during our experiment. The mean score was at all times below 1. The highest MISC score was "2" which indicates that the participants experienced vague dizziness, warmth, headache, stomach awareness, and/ or sweating. None of the participants dropped out because of simulation sickness.

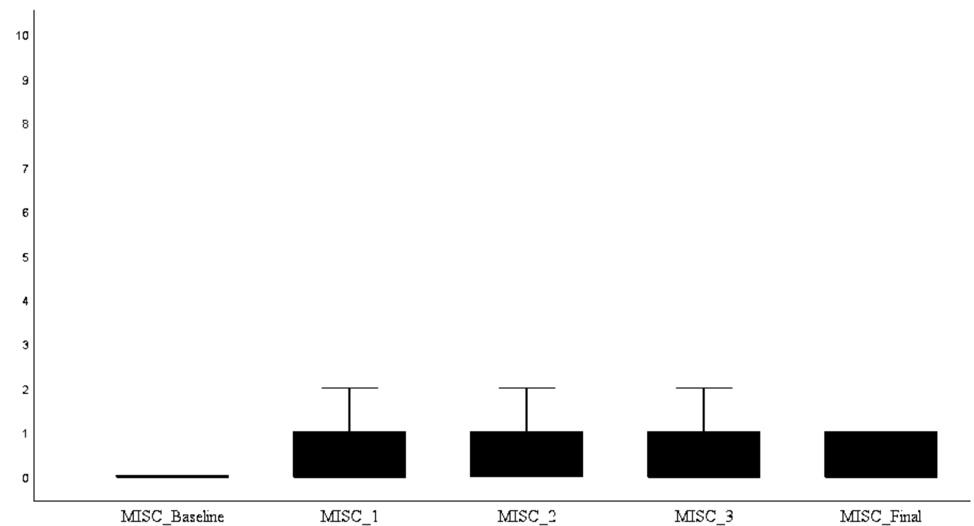

Figure 3. The results of the Misery Scale (MISC) per session (baseline, session 1-3, and afterwards/final).

3.5 Presence Questionnaire

The Presence questionnaire was used with 16 items on a 7-point scale (1 = low presence, 7 = high presence). The descriptive statistics can be found in Table 3 for 3 factors: involvement, adaptation/immersion, and interface quality. The factor sensory fidelity was removed from the scale, because it was irrelevant for this study. The factors "Involvement" and "Adaptation/Immersion" scored high relative to the "Interface quality" factor.

Table 3: Descriptive Statistics of the Presence Scales (Range: 1 (low) to 7 (high)).

	Involvement	Adaptation/ Immersion	Interface quality	Total mean
Mean	5.28	5.87	2.58	4.96
Std. Deviation	0.69	0.51	1.06	0.44

4. Discussion

The aim of this study was to investigate the effect of driver presence and attentiveness on the crossing behavior of pedestrians. In addition, users' perceived behavioral control and perceived risk were measured per driver condition. Finally, the realism of the virtual reality environment was tested.

Our main findings were as follows. Driver condition (attentive, distracted or no driver) was shown to have an effect on the time it took participants to start their crossing. This effect was only significant in the distracted driver condition and was small and positive. Therefore, pedestrians accepted a smaller gap when they were confronted with a distracted driver, as compared to when there was an attentive or absent driver. This result was unexpected, since we assumed that a distracted or absent driver would be perceived as riskier than the attentive driver condition comparable to what was found in the previous literature [6]. If that was the case, we would have found lower initiation times in the riskier scenarios meaning that the participants accepted a bigger, safer gap in comparison to the attentive driver condition. It could be that the participants that thought that the vehicles were automated assumed that the vehicle was in automated mode when the driver was distracted. Participants who did not think the vehicles were automated could have assumed that there was no need to worry because the driver did not feel that way either. This was not supported by the findings on the perceived behavioral control and perceived risk. It could have been that it took the participants more time to decide whether to cross or not if the driver was distracted. This seems to be the most likely explanation. The time gap had a large effect on the initiation time. When the time gap was 3.5 seconds, participants crossed later than when it was 5.5 seconds. This is counterintuitive but it can be explained by the interaction time gap has with yielding behavior. The interaction shows that when the time gap is 3.5 seconds and the vehicle did not yield, the initiation time of the participants to cross was significantly shorter as compared to the other scenarios. This was as expected. Pedestrians will decide sooner whether to cross or not if the time they have to decide is limited. The more time it takes the pedestrians to decide, the closer the vehicle gets to them. We did not find an effect of yielding behavior of the vehicle on the initiation time. So, whether the vehicle yields or not did not affect whether the pedestrians decided to cross sooner or later except when the vehicle did not yield and there was a distracted driver or when the gap was 3.5 seconds. So, the motion cues had the biggest impact on the time it took the pedestrians to initiate a crossing. This is in congruence with previous studies [8, 10, 11]. Additional findings were the following: We found a significant effect of gender on initiation time. Male participants started crossing the road earlier than females. Further, one's expectation to be interacting with AVs had a significant effect on initiation time, too. When one expected that the vehicles were automated, he or she decided to cross later.

Overall, the participants needed between 75.3 and 10.3 meters of distance from them to the vehicle to be able to distinguish the driver. On average, 34.2 meters was enough to tell whether there was a driver present. This meant that the participants saw the driver 4.1 seconds before the vehicle arrived next to the participant because the vehicle was travelling at 30 km/h. So, the driver was most probably visible to the participant before they could cross when the time gap was 3.5 seconds. On the other hand, the driver was visible on average 1.4 seconds after the participant was able to cross when the time gap was 5.5 seconds. This means that the driver condition would have a major effect on the shorter time gap because it was better distinguishable but this was not supported by the data. No interaction effect between driver condition and time gap was found. Thus, the effect of being able to spot the driver did not influence the initiation time. Only six errors were made out of 120 trials which indicates that the participants were fairly good at identifying whether there was a driver present at some point. It must be taken into account that the virtual windows of the vehicle were removed, and that the low speed of the vehicle was in place to make sure the driver would be visible. Even with the adaptations we made, the vehicle needed to be relatively close to the pedestrian. Furthermore, the test took place in a virtual world which means that the findings cannot be directly translated to the real world. However, it does raise questions about the utility of eye contact. Although, some papers seem to hint that eye contact is used by pedestrians to decide whether to cross [e.g. 21], it seems that eye contact cannot be used in all situations. Still, interactions occur without the possibility of seeing the other road users' eyes leaving unclear the importance of eye contact. Our findings show that there is a limited range in which the driver can be distinguished and it is to be expected that the vehicle needs to be even closer for a pedestrian to be able to see the drivers' eyes. In addition, the vehicles' behavior was a better predictor of the crossing behavior meaning that the importance of the driver may be overestimated. Further, this leads

to questions about the usability and relevance of electronic Human-Machine interfaces (eHMIs) as the readability of these interfaces will depend on factors such as the speed of the vehicle and distance to the pedestrian, lighting conditions, and objects blocking the view.
As expected, the score on perceived behavioral control when interacting with a present and attentive driver was higher than when compared with the other two conditions. So, the participants felt they were most likely to cross successfully when the driver was attentive. In addition, the scores on perceived risk when the driver was present and attentive were higher than in the other conditions. In other words, the participants perceived more risk when interacting with a distracted or non-present driver as compared to an attentive one. Nevertheless, only the distracted driver condition lead to a small significant effect on crossing behavior. The participants needed more time to decide whether to initiate the cross. The explanation could be that a distracted driver is perceived riskier because it is unclear whether the vehicle is operating in automated mode. In contrast, when no driver is presented, the vehicle operating automatically seems more likely. Nevertheless, the effects on crossing behavior were small compared to other factors such as time gap.
In terms of realism, the scores on the presence scale are good overall, except on the interface quality. This is surprising as the head mounted display used is one of the best consumer grade available in terms of resolution and refresh rate and better than the one used in another study that received a comparable score but used a smartphone based VR [8]. The reason for this could have been the lag experienced by the participants when the head mounted display lost its connection with the computer. The scores on the misery scale were good and showed that the participants experienced vague symptoms of simulation sickness at most. Mostly, no symptoms were experienced. This is to be expected according to previous studies [8, 23]. The use of this type of virtual reality proved to be useful for this kind of studies.

The task designed to test how well the driver was visible was performed at the end of the virtual reality session leaving unclear at what moment the participants started to notice the various driver conditions. This was done on purpose to not influence the crossing decision tactics of the participants.

This VR study illustrated that the most important factor affecting pedestrians' road crossing behavior was the motion cues derived from the vehicle, rather than the presence or state of the driver. Immersive virtual reality is a useful tool to study the mechanisms of pedestrians' crossing behavior.

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