Increasing Pedestrian Safety Using External Communication of Autonomous Vehicles for Signalling Hazards

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Pedestrians are very vulnerable road users. Autonomous vehicles driving on the street are expected to reduce the risks for pedestrians. However, traffic will include manually driven vehicles for the next decades; therefore, the risk remains and can even increase due to pedestrians' overreliance on technology. Thus, we propose to use autonomous vehicles parked at the side of the road to continually survey its surroundings and to issue warnings to pedestrians in potentially risky situations. Findings of a Virtual Reality (*N*=20) study show that participants preferred the communication on the vehicle compared to a communication on the sidewalk, that the visualization grabbed participants' attention, and that overall crossing time was not significantly affected. This concept highlights the potential autonomous vehicles could have in making traffic safer, even while being parked.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**.

Additional Key Words and Phrases: Autonomous vehicles; self-driving vehicles; external communication.

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1 INTRODUCTION

Pedestrian safety is still an ongoing challenge. For instance, in 2018, 6.283 pedestrians died in traffic crashes in the USA [25], and 458 died in Germany [14]. Facilities in the USA were predominantly in urban areas [25]. There are several contributing factors, for example, alcohol involvement of the driver and/or the pedestrian was reported in 48% of pedestrian fatalities in the USA in 2016 [24]. Some of these accidents occur because of reduced or blocked visibility of the vehicle or the pedestrian.

Autonomous vehicles (AVs) are expected to change the interaction between pedestrians and vehicles [19]. With their advanced technology, these vehicles can detect pedestrians and other vehicles. Waymo, for example, claims to recognize (unmapped) signposts up to 500m in advance [40]. Tesla is already able to detect cars multiple vehicles ahead [44].

While substantial efforts are made to increase pedestrian safety, the numbers do not change all too much [26]. Some researchers suggest smart roads to actively warn drivers from potential hazards [63]. Colley et al. already proposed to employ AVs parked at the side of the road for the projection of advertisement or navigational cues [5]. They also proposed to use displays or projections of standing AVs to communicate warnings [5].

We propose a concept directed towards aiding vulnerable road users (VRUs) such as pedestrians by warning them of oncoming traffic. We discuss this concept in light of various use cases and direct towards future research questions.

Contribution Statement: This work provides a novel concept to improve pedestrian safety by signaling potential hazards via AVs or the infrastructure. Results of a VR study (*N*=20) show that participants preferred the visualization on the vehicle but displayed overtrust. Nevertheless, participants highlighted the usefulness to gain attention of distracted pedestrians and the added safety by knowing that a vehicle is approaching.

2 BACKGROUND

This work builds on research in the fields *Traffic Accidents* and *External Communication of AVs*.

2.1 External Communication of AVs

Work on external Human-Machine Interfaces (eHMIs) focuses primarily on crossing scenarios [7] with a single vehicle [11]. Pedestrians stand at the curb of the street and are asked to cross (or to indicate their willingness-to-cross [16]) in front of an approaching AV. In the evaluated scenarios, sight towards the AV is very good (e.g., [7, 9, 16, 34, 48, 51, 57]). Other scenarios, while scarce, were also evaluated: communication with bicyclists in a merging scenario [35], with other car drivers [59], and walking past a highly automated truck blocking a sidewalk [7], for example.

To solidify research gap on potential applications of eHMIs when standing at the sidewalk, we queried the proceedings of the five most cited Human-Computer Interaction venues, according to Google scholar [29]. Due to their focus on (future) mobility, we also retrieved publications from the *Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutoUI)* [3] and the *International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI)* [54]. We included publications from the last decade (01/2010 - 10/2020). The first author carried out the literature search and categorization. We found and screened 45 publications. 30 were excluded. The remaining 15 papers were analyzed regarding the evaluated measurements on the communication and the AV.

Our exclusion criteria were: (1) eHMIs must be the main focus of the work, and (2) the publication must contain some form of user study regarding eHMIs.

The search query for each conference or venue in the respective digital library was: `"query": AllField:("external communication" OR "eHMI" OR "eHMIs") "filter": Conference Collections: [Conference / Venue]`). Our literature search led to the following results:

Vehicle state	Publications + [References]
Moving (on the street)	**15**: [1, 7, 10, 15, 17, 18, 31, 34, 42, 45, 46, 49, 55, 56, 68]
Parked	**0**

Table 1. Publications analyzed by vehicle state (moving or parked) in the reported study.

With our criteria, we found no work that focused on the possibilities eHMIs provide for parked AVs (see Table 1). However, through manual search, we found one work by Colley et al. [5], who explored how external displays on vehicles as navigation cues, advertisement, warnings, or aesthetics. Safety-related visualizations were found most useful while there were some privacy issues related to, for example, presenting navigation cues for pedestrians. The authors did not, however, conduct a user study on such safety-related visualizations. Nevertheless, the potential of eHMIs goes beyond signaling that it yields or that the pedestrian can cross.

2.2 Traffic Accidents and Improving Pedestrian Safety

2.2. % of all deaths globally are attributed to road crashes and are predicted to be the fifth leading cause of death by 2030 [21]. Vulnerable road users such as pedestrians, cyclists and motorcyclists [32] accounted for 46% of the victims in the European Union in 2017 and were particularly exposed in urban areas [13]. In the urban area in general, 37% of the fatalities occurred [13]. Pedestrians are most likely to be killed in December, during which 13% of the fatalities occur [13]. This has been attributed to the poor lighting conditions [13]. In the US in 2018, most pedestrian fatalities were not located at an intersection (72%; [60]).

Sieß et al. [63] propose to use smart roads to display games as well as potential dangers related to children running on or ice covering streets. The authors do not evaluate the concepts but only questioned three experts.

Colley et al. [5] showed participants a real-world application of external displays. This exploration revealed various important themes such as privacy as well as safety concerns. These safety relating concepts were much liked by the participants. The concepts discussed all revolved around one's vehicle displaying information towards other pedestrians.

Mobile applications could also be used to warn both the driver and the pedestrian of potential safety-critical situations. Hussein et al. [36] propose a collision prediction algorithm to increase situational awareness for pedestrian smartphone users by issuing a warning in case a possible collision was detected. Hwang and Jeong [37] presented *SANA* an application issuing such a warning additionally to the driver. However, such assessments are based on GPS data, which is not sufficiently precise [38]. Other concepts using a smartphone include the camera to detect approaching vehicles [69] when talking on the phone. However, this approach is limited by the field of view of the camera. *Viziblezone* [70] uses proprietary communication between a vehicle and a smartphone to assess the risk of encounter and warns the driver of the vehicle if necessary. Further concepts include making the smartphone display see-through capable by using the camera [47] or pavement lights [4]. Holländer et al. [33] proposed the application *SmomDe* and evaluated with the four guidance methods Bars, Traffic Light, Map, and Notify. Participants preferred the non-intrusive bars indicating from which side a vehicle appears. Their concept, however, assumes that *every vehicle* can communicate with the application. This is unrealistic in mixed traffic.

3 CONCEPT

We propose to use external communication features of future AVs that are idly standing at a curb to aid both oncoming vehicles and other VRUs. Instead of turning off completely, we propose an energy-saving mode that allows the AV to still survey the surroundings for potential hazards. As mixed traffic (including manually driven vehicles) is likely, presenting warnings to pedestrians attempting to cross the street could increase their situation awareness and could, therefore, increase safety.

3.1 Modalities, Assumptions, and Simulated Implementation

The information on upcoming traffic alone could provide sufficient information to the pedestrian to be alert. However, including information about the direction of the upcoming traffic could direct the pedestrian's focus. Therefore, we propose to display only warnings of upcoming traffic.

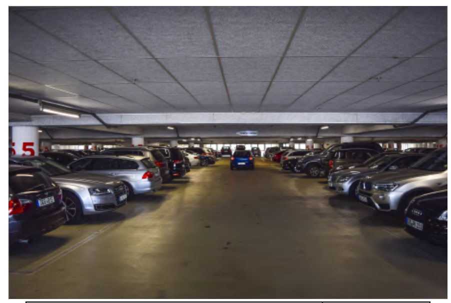
This information could be provided via several means. A smartphone, as indicated by previous research [33], is only useful if it is already in active use. Otherwise, tactile feedback (i.e., vibrating) could be mistaken for a text message, and auditory feedback could be overheard or blocked via the settings. Therefore, according to the design space on eHMIs [8], we used the loci *vehicle* and *infrastructure* for the communication. To this end, laterally mounted displays [6] on the vehicle and a smart sidewalk capable of displaying information were simulated for the experiment. To make the communication noticeable, the visual warnings are displayed in a frequency of 2 Hz. While flashing with 4 - 8 Hz attracts the most attention [12], we reduced this as the proposed visualization should also not be too distracting from actually observing traffic.

The detection of upcoming traffic was simulated to function reliably 5s before arrival. For the velocity of 50 km/h, this equals a distance of 70m. We assume this to be a reasonable estimate as Waymo claims to detect (unmapped) signposts even 500m in advance [40].

3.2 Potential Use Cases

Attribute	Value
Right of way	Vehicle
HRU Character	Pedestrian
Attention HRU	Yes
Impairment of HRU's perception	View
Impairment of Driver's perception	View
Speed Vehicle	30; 50 km/h
Speed HRU	4.4 km/h
Distance between Vehicle and HRU	3-10 m

a & Table 2 Cars parking at the curb [39].



Attribute	Value
Right of way	HRU
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Impairment of HRU's perception	View
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Distance between Vehicle and HRU	3-10 m

b & Table 3 Parking lot [67].

Fig. 1. Two exemplary use cases with their corresponding situational characteristics as proposed by Füst et al. [27].

We provide two use cases for the proposed concept. This is non-exhaustive. We favored lower speed, unsignalized, and typical city use cases, as they come with a higher complexity where the number of pedestrians is increased. All pictures were collected from pixabay.com and have been published under the Pixabay license [58]. For the description of each of the use cases, we defined the criteria *Right of way*, *Human Road User (HRU) Character*, *Attention HRU*, *Impairment of the HRU's perception*, *Speed of AV*, *Speed of HRU*, and the *Distance between vehicle and HRU*. These are based on Füst et al.'s taxonomy of traffic situations for the interaction between AVs and HRU and use the same value facets [27]. Additionally, we added *Impairment of Driver's perception* with the same facets as *Impairment of HRU's perception*. In Figure 1a, a residential area with numerous parked vehicles on both sides of the road, is shown. Visibility conditions are, even in good weather, poor. This is especially true for small people, including wheelchair users and children. In Figure 1b, a parking lot is shown. In 2007, there were $\approx$ 10.000 injuries for children under the age of 14 in the US in parking lots [22]. 25% of these were attributed to vehicles backing up and bad sight conditions. For 2015, 95.000 people were injured in the USA [23]. Of these, 29.000 were non-occupants. 15.000 vehicles were driving forward, 12.000 backwards [23]. The proposed concept could reduce these numbers in both use cases by providing relevant information about crossing vehicles.

3.3 Benefits & Limitations

The benefits of such a concept are increased safety for all road users. Through such a concept, AVs could be seen as "guardian angels", a concept already proposed for drivers [52], thus leading to increased acceptance.

Higher energy consumption is the first limitation. An AV without sufficient energy will not be able to survey its surroundings. People ignorant of such limitations could believe that it is safe to cross (if the AV is clearly marked as being autonomous; see [1]) as they could *unlearn* to actively monitor their surroundings (see "Crosswalk chicken" [53]). However, with the assumption that electric vehicles will become more prevalent [2], parked AVs will often be connected to a charging station. In this case, energy consumption should not be an issue. Another important aspect in this regard is the distribution of AVs in mixed traffic. If vehicles are not distinguishable regarding their automation capabilities, which is currently debated [1], VRUs and drivers could be irritated what to expect of such standing vehicles. Also, human drivers familiar with AVs' warnings could drive more reckless as they trust the AVs to warn the pedestrians.

4 EXPERIMENT

To evaluate the effects of such communication, we designed and conducted a within-subject study with N=20 participants.

Our study was guided by the exploratory research question:

> How are (1) behavior as well as (2) Trust, (3) Situation Awareness, the (4) Crossing Decision, and (5) Preference of pedestrians impacted by cognitive load, visualization of approaching direction, and location of communication?

4.1 Participants

The required sample size was computed applying an a-priori power analysis using G*Power [20]. To achieve a power of .90, with an alpha level of .05, 20 participants should result in an anticipated medium effect size (0.25 [28]) in a within-factors repeated measures ANOVA.

Participants were recruited via mailing lists, social media, and notice boards. The sample consisted of N=20 participants (7 female, 13 male) with an average age of M=27.80 (SD=4.81). Participants showed a *Propensity to Trust* [43] of M=2.87 (SD=.60). On 5-point Likert scales (*1=strongly disagree*, *5=strongly agree*), participants reported a high interest in AVs (M=3.90, SD=1.12) and believed such a system to ease their lives (M=4.10, SD=1.12). Participant were unsure whether AVs become reality until 2030 (M=3.50 , SD=1.05).

4.2 Materials

To evaluate the proposed concept of external communication of potential hazards, we implemented an immersive room-scale VR study in Unity [66]. In the simulation, at the start, vehicles drive past the participant from both sides (see Figure 2). In the following, vehicles approach only from the left side. The gap between the vehicles increases by 1s per vehicle passing (see Figure 2). The simulation provided typical city background noise. An HTC Vive Pro was used. On the opposite side, a large canvas is attached to the building. Depending on the condition, the n-back task is displayed there. An Unsigned Crossing was chosen as previous work showed that communication was perceived better in such situations, potentially due to the increased vulnerability compared to scenarios with Traffic Lights [62]. Because of space constraints, we added a gain factor of 1.9 in the straight forward and sideways axis. We chose the one-sided traffic as we wanted to minimize any traffic-related effects. For example, as the warning vehicle was standing slightly to

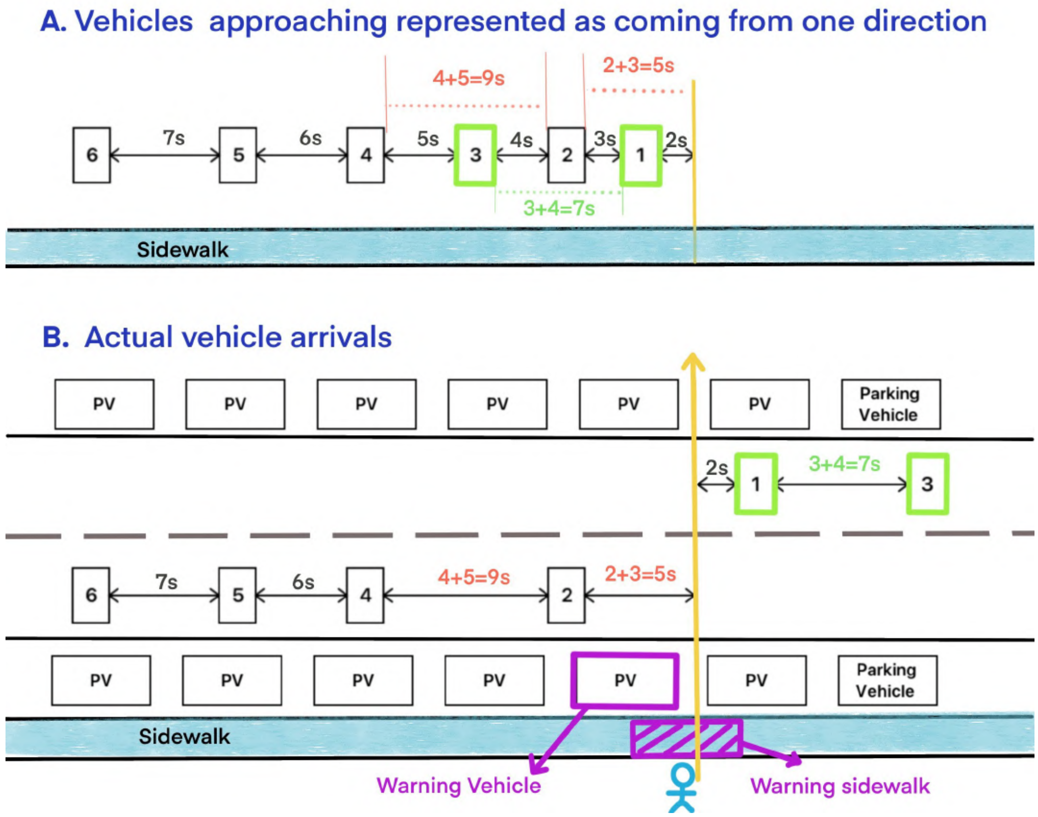

Fig. 2. Schematic presentation of the simulation. The gap between the (numbered) vehicles is shown alongside the ego-position. In the first 3s, no vehicle approached. Then, after another 2s, the first vehicle approached from the right. After an additional 3s (i.e., 5s after the start), the second vehicle arrived. After four more seconds (or 7s after the first vehicle), the third vehicle drove past. 5s afterwards, or 9s after the second vehicle, the fourth vehicle drove past. Afterwards, only vehicles from the left approached with each increasing the gap by one second. (A) shows a hypothetical approaching from one side, (B) the actually used arrivals. Not to scale.

the left (see Figure 2), the direction from which vehicles approach could have an effect due to the increased need to adjust the field of view.

4.3 Measurements

The system logged the accuracy of the participants in the n-back task and the duration of the entire crossing as well as the duration each participant stayed in the various areas (see Figure 5).

Before and after the study, participants answered the *Propensity to Trust* subscale of Körber [43]. After each condition, participants filled out a questionnaire asking them to rate the subjective mental load using the mental load subscale of the raw NASA-TLX [30] on a 20-point scale, subjective situation awareness using the 10-dimensional Situation Awareness Rating Technique (SART) [65], and trust using the Trust in Automation scale [41]. Participants were also asked on a 7-point Likert scale on what they based their decision on (*1 = Other Factors* to *7 = Communication*). Also, participants were asked to name these other factors.

Finally, participants were asked about the reasonability and necessity of such communication, were asked to rank the systems (including *no communication*) and were asked for open feedback.

4.4 Study Design

Fig. 3. Virtual Reality simulation. (1) shows the warning on the vehicle, (2) additionally with direction information, (3) and (4) show the concept for the infrastructure.

The study was designed as a $2 \times 2 \times 2$ within-subjects experiment. The independent factors were *cognitive load* (yes (via n-back task)/no), *visualization of approaching direction* (yes/no), and *location of communication* (vehicle/infrastructure, i.e., the sidewalk; see [8]). Additionally, two baselines, one with and one without the induced cognitive load were conducted, resulting in 10 conditions.

Cognitive Load: There are numerous ways pedestrians could be distracted from potential hazards. A non-exhaustive list includes talking animatedly with other pedestrians, daydreaming, listening to music, seeing advertisements on a billboard, or using a smartphone. Additionally, the pedestrians' view could be blocked (e.g., by tall vehicles). While the case of using a smartphone was already investigated in prior research (see Section 2.2), we investigated a crossing scenario without a smartphone but, depending on the condition, with induced cognitive load. To induce a low cognitive load, we employed the 1-back task. Participants saw one letter and had to input whether this letter matches the previously displayed one. Every 2s, a new letter was displayed for 1.5s. The display of a green checkmark accompanied a correct input. A red cross appeared in case of a wrong or a late (after 1.5s) input.

4.5 Procedure

After providing informed consent and receiving an overview of the study, participants filled out a demographic questionnaire. Afterwards, participants were able to adjust the VR headset and see the VR scene without traffic to get accustomed to the scenery. Then, participants were randomly assigned to the conditions using a Latin Square. Subsequently, participants were informed about the study objectives and were compensated with € 10. Each session lasted approximately 60 min. The study was conducted in English. The hygiene concept for studies regarding COVID-19 (ventilation, disinfection, wearing masks) involving human subjects of our university was applied.

5 RESULTS

We used Friedman's ANOVAs (non-parametric data) or repeated measure ANOVAs to compare the ten conditions. To investigate main and interaction effects of *cognitive load* × *visualization of approaching direction* × *location of communication*, for the non-parametric data [64], we used the factorial non-parametric analysis of variance provided by Lüpsen [50]. We included a random intercept for participants for every dependent variable due to hierarchical data (measurements nested within participants). For post-hoc tests, Bonferroni correction was used. Described effects are shown in bold lines. Effect sizes were calculated using Rosenthals's formula [61].

5.1 Cognitive Load, Trust, Situation Awareness, and Decision Factors

The non-parametric analysis of variance (NPVA) showed a significant effect (F=79.94, df=1, p<.001, r=-0.44, Z = -5.50) of *cognitive load* on the mental workload subscale of the NASA-TLX [30]. Cognitive load was significantly higher with the 1-back task (M=9.77, SD=5.15) than without (M=6.17, SD=3.84).

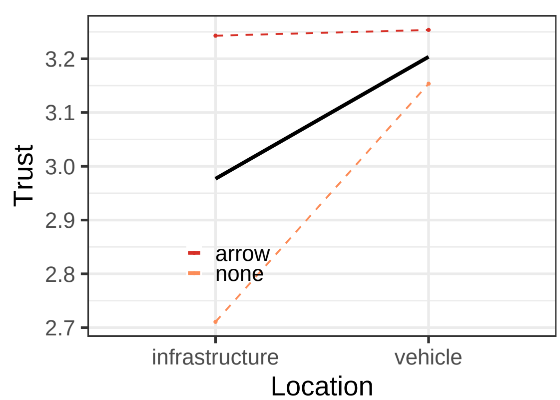

Fig. 4. Main effect of *location* on trust.

The NPVA also revealed a significant main effect of *location* (F=7.53, df=1, p=.013, r=-0.20, Z = -2.49; see Figure 4) on trust. Trust was significantly higher for the vehicle (M=3.20, SD=.80) than for the infrastructure (M=2.98, SD=1.00). It also showed a significant effect of *visualization of approaching direction* (F=4.39, df=1, p=.0497, r=-0.16, Z = -1.96). Trust was significantly higher for visualizing the direction via an arrow (M=3.25, SD=.88) than for not visualizing it (M=2.93, SD=.91).

The NPVA showed an almost significant main effect of *location* on situation awareness (F=4.18, df=1, p=.055, r=-0.15, Z = -1.91). Values indicated higher situation awareness for the vehicle (M=18.49, SD=5.23) than for the infrastructure (M=17.09, SD=5.56). The NPVA also found almost significant effects for *cognitive load* (F=4.16, df=1, p=.056, r=-0.15, Z = -1.91) and *location* × *visualization of approaching direction* (F=3.47, df=1, p=.06) for the decision factor. Without induced cognitive load, values for taking the external communication into account regarding the crossing decision, were higher (*M*=3.17, *SD*=2.21) but still low. Asked about what participants based their decision on, most reported using the implicit communication of the approaching vehicles, namely speed and distance, as decision factors.

5.2 N-back Task Performance, Crossing, and Retention Times

The NPVA found no significant differences for the performance in the 1-back task neither for correctness (total *M*=1.97, *SD*=1.47) nor for number of inputs (total *M*=3.84, *SD*=2.23). These numbers show a correctness rate of *M*=.55 (*SD*=.33).

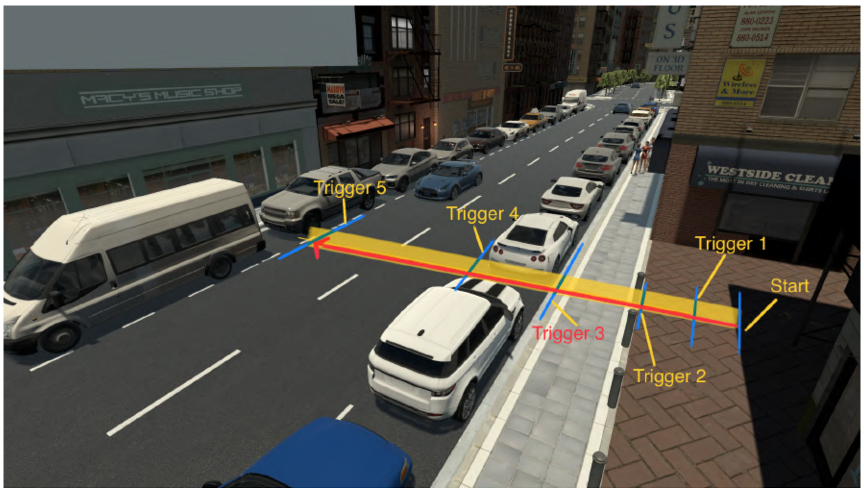

Fig. 5. Triggers used for the logging of the crossing durations. The distance between trigger one and two was 1.18m, between two and three 2.16m, between trigger three and four 2.3m and between trigger four and five 6.68m. The distance from the start to trigger one was 0.5m. In total, this added up to 12.58m.

The NPVA found a significant difference for the overall crossing time for the levels of *cognitive load* (F=17.05, df=1, p<.001, r=-0.27, Z = -3.44). Participants needed longer to cross with distraction (*M*=26.55s, *SD*=10.40) than without distraction (*M*=22.96s, *SD*=8.87). Therefore, for the entire crossing time, we looked at subsets of the data for the two levels of the induced cognitive load. Friedman's ANOVAs found no significant difference within the conditions per induced cognitive load (p=.39 without and p=.27 with induced cognitive load). We also looked into the durations from one area to the next (see Figure 5 and Figure 6). The NPVA found an almost significant effect of *cognitive load* (F=3.67, df=1, p=.071, r=-0.14, Z = -1.81) and *visualization of approaching direction* (F=3.49, df=1, p=.077, r=-0.14, Z = -1.77) on the time in the zone 4 (between the vehicles). As shown in Table 4, participants waited longer if no direction was given.

	No direction		With direction		Baseline	
	M	SD	M	SD	M	SD
Zone 1 (start to trigger one)	4.19	3.70	4.08	4.19	3.00	2.63
Zone 2 (trigger one to two)	3.27	3.82	3.48	4.63	3.43	5.27
Zone 3 (trigger two to three)	5.05	5.30	5.17	6.14	2.25	1.17
Zone 4 (trigger three to four)	**5.56**	5.36	**4.18**	3.05	5.38	5.76
Zone 5 (trigger four to five)	7.63	3.99	7.39	3.45	8.70	4.91
Total	25.86	10.06	23.65	9.47	22.76	10.24

Table 4. Time in different zones and finishing time with & without directional information

A Friedman's ANOVA found a significant difference for the standing between trigger 2 and 3 (see Figure 5) in the conditions without induced cognitive load (p<.001). Post-hoc tests revealed a significant difference between the baseline (M=1.60, SD=.69) and the *vehicle with arrows* (M=5.05, SD=5.44) and the *infrastructure without arrows* (M=6.64, SD=7.59).

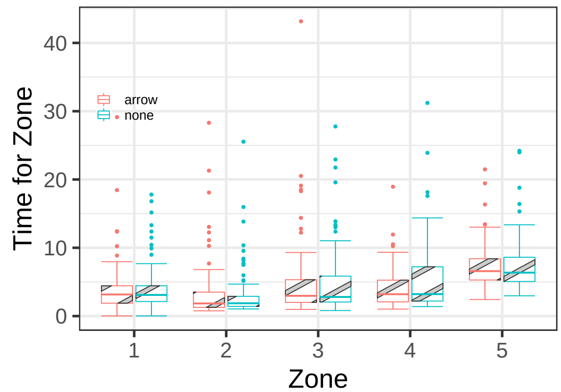

Fig. 6. Time (in seconds) per zone and per level of *visualization of approaching direction*.

Six participants were hit by an approaching vehicle. Three of these occurred in the baselines. The baselines only account for 20% of all the trials, still, half of the hits occurred in these. Therefore, we conclude that the indication of a warning helped in increasing pedestrian safety.

5.3 Preference and Open Feedback

The *vehicle with arrow* received rankings indicating the highest preference, i.e., the lowest mean (M=2.40, SD=1.47). The *infrastructure without arrow* received rankings indicating the lowest preference (M=3.65, SD=1.18). Mean rankings were close. A Friedman's ANOVA showed no significant difference in the mean rankings χ^2 (4)=7.28, p=.12. Nevertheless, both systems including an arrow were rated best followed by no communication. Both systems without *visualization of approaching direction* received the worst rankings. These values, however, do not reflect the diverse opinions. For example, 9 participants rated *vehicle with arrow*, 6 *no communication* as their most preferred. However, 7 participants also named *no communication* as their number 5 (least preferred). These diverse opinions were also reflected in the open feedback. While some participants highlighted the distraction when having to look at the road (see also [7]), others claimed "Especially good is the communication on the road" [P5].

Most participants agreed that the visualization grabbed their attention. However, there were diverse opinions on the usefulness. In the open feedback, participants stated their expectation that they could fully rely on the communication. When asked about the usefulness to only warn pedestrians and, therefore, to increase safety via increased caution, 19/20 agreed to the usefulness of the proposed systems. In the discussion after the crossing experiment, 19 participants expressed their willingness to accept such a communication system in real life, believing that it would help improve the safety of crossing the street. One participant considered the communication system as too complex and unnecessary. Regarding improvements proposals, 7 participants stated that they would prefer the information presented on the other side of the road. This would solve the "main problem [...] that the indicator is shown way before you actually get to the dangerous part of the road" [P1]. Participants found the VR environment immersive. This is also supported by their reliance on implicit factors for their crossing decision (see Section 5.1), which participants also reported in the open feedback. Asked about whether participants noticed that traffic was always the same, only 4/20 (20%) reported that they somewhat believed to notice it.

6 DISCUSSION

We found that a visualization on the vehicle leads to higher trust in the communication compared to displaying the same information on the sidewalk. This is in line with previous work that indicated that projection-based communication leads to distraction [7]. This is also supported by the almost significant difference in situation awareness between the communication on the vehicle and the infrastructure. We found that most people still rely on the implicit communication [56] of the approaching vehicles (see Section 5.1). We argue that with our concept, this behavior is supported. When only displaying a warning without directional information, pedestrians have to check the environment themselves and can not rely on the communication. Nevertheless, they will be warned and alerted to possible dangers. In the following, we discuss the results and our interpretation regarding practical implications and the impact on traffic safety.

6.1 Crossing Time

Congruent with our expectations, participants needed longer to cross with induced mental workload. We found that the participants needed longer between trigger 2 and 3 without induced cognitive load for the areas. Therefore, we state that participants were aware of this communication as confirmed by them. We also found a significantly shorter duration between trigger 4 and 5 for the system infrastructure with arrows compared to a baseline. We hypothesize that this is caused by the additional information presented by the arrows. While the arrow was also displayed on both sides of the vehicle, this information was easily accessible by looking back in the infrastructure condition. We observed this behavior in approximately five cases. However, the most important finding regarding crossing time is that participants waited (almost significantly) longer in-between the parked vehicles (between trigger 3 and 4; see Figure 5) without directional information presented (see Table 4). However, in most cases, participants were neither significantly quicker nor slower with the warning displays. Therefore, we conclude that showing such warnings warns pedestrians of potential dangers and is, therefore, beneficial to traffic safety.

6.2 Purpose of the Communication

Overtrust in communication was already shown to be a potential problem of external communication of AVs [7, 34]. Some participants misinterpreted the information as instructions (and even demanded "clearer instructions" [P17]). Therefore, while most participants preferred system **with** direction information of the approaching vehicles, we believe that this information should not be displayed. Pedestrians would still be warned, but they would still have to look for approaching vehicles themselves. The attention gaining mechanism (blinking warning) was assessed as effective as indicated by all participants. A system communicating whether it is safe to cross will also probably result in legal issues in the case of an accident [7]. We also showed that without showing the direction of approaching vehicles, participants waited longer between the vehicles (zone 4; see Table 4, Figure 5, and Figure 6). While time to cross is negatively impacted, safety is most likely to be heightened by this.

6.3 Usefulness with Varying Number of Autonomous Vehicles

Some participants stated that the communication should have occurred, for example, on the vehicle on the opposite road. Others highlighted, more generally, that information should be available at the "the dangerous part of the road" [P1].

Regarding a concept using smart infrastructure, such improvement proposals are easily addressable. However, in the envisioned scenario and in accordance with the presented results, AVs could and should be used for the information visualization. The process of finding a parking spot will most likely not be deterministic and, therefore, having the information on the opposite side will not be always possible. This was accounted for in the presented study as we visualized the information on the close side of the street. Nevertheless, the concept was found useful by most participants regarding attention-grabbing. Regarding the information presentation, Colley et al. [6] presented possible display locations. This, additionally, to the proposed concept, includes surfaces such as the bumper, grille, the hood, windows, or even on-road projections. Especially the hood, the windshield, or on-road projections seem a feasible attempt to address the information presentation issue. Projections were already investigated in the context of street crossing in front of AVs [57, 62]. However, the goal of the concept is mostly to warn (distracted) pedestrians of oncoming traffic, not to act as a signaling light (cf. [7]). We believe that, even with a small number of AVs presenting these cues, such a warning mechanism could increase safety. When AVs do not visualize this information, no deficit occurs. Therefore, we argue that this concept should be considered for future AVs.

6.4 Limitations of the Study Design

Our proposed concept is intended to help pedestrians assess traffic before crossing in unclear scenarios. This is especially important for distracted pedestrians. Distraction can occur and take numerous forms: headache, conversation, (smart-)phone usage, watching billboards, etc. However, in our experiment, we simulated cognitive load with a standardized method (1-back task) to obtain comparable results. Additionally, participants were clearly aware of the study setting as a VR simulation was used. Participants were, therefore, not totally distracted and, thus, external validity is difficult to assess. Nevertheless, such artificial settings were used in other works to measure pedestrian behavior and attitudes [33]. Nonetheless, participants stated that the attention-gaining component of the communication was useful. Studying the usefulness of the proposed concept in the real world is difficult as a high risk of crashes may be prevalent, especially if distraction is taken into the study design. Future work could address this issue by simulating approaching vehicles in the real world via Augmented Reality technology.

7 CONCLUSION AND FUTURE WORK

Overall, we present a concept that makes use of the advanced technical capabilities of (future) AVs when parked at the side of a street. This concept could increase pedestrian safety by displaying warnings if approaching manually driven and automated vehicles are detected. In a VR study (N=20), we showed that, while issues such as overtrust could occur, participants trusted such a visualization on a vehicle significantly more and that communication on this location lead to almost significantly higher situation awareness. However, we argue that information on approaching vehicles should not include directional information but should only be used as an attention-gaining and warning mechanism. Our work highlights the potential of AVs in making traffic safer not only with regard to safer driving.

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