For a Better (Simulated) World: Considerations for VR in External Communication Research

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Abstract
In the emerging research field of external communication of autonomous vehicles with vulnerable road users (e.g. pedestrians), there is no agreed upon set of methods to design and evaluate concepts. The approaches vary from pure paper-based design studies over Virtual or Augmented Reality simulation to real-world testing of early prototypes. While there are benefits to each of these approaches, the most promising concept is considered to be the virtual reality (VR) approach since it allows for a quick, realistic and safe evaluation of new designs and concepts. A literature review of existing concepts for vehicle-pedestrian communication revealed that only 7 publications and preprints between 2014 and 2019 used VR in their research. We evaluated each based on criteria relevant for pedestrian crossing decisions and factors important for conducting experiments. Our results show relevant considerations when implementing a VR simulator for external communication research and conducting studies in this field.

Author Keywords
Self-driving vehicles; Autonomous vehicles; pedestrians; external communication; interface design; VR.

CCS Concepts
•Human-centered computing $\rightarrow$ Systems and tools for interaction design;

Factors influencing crossing decision

According to Rasouli and Tsotsos [42] the following **environmental factors** are important:
Physical context: Time of day, Lighting, Street width, Zebra crossing, Weather, Road structure, Road conditions, Location, Right of way, Signal
Dynamic Factors: Gap acceptance, Vehicle speed, Vehicle distance, Communication, Traffic flow, Pedestrian waiting time
Traffic Characteristics: Traffic volume, Vehicle Size, Law enforcement, Vehicle type, Vehicle color

Pedestrian factors are:
Social factors: Pedestrian flow, Group size, Imitation, Social status, Social norms
Demographics: Gender, Age
State: Attention, Trajectory, Speed, Walking pattern
Abilities: Speed & Distance estimation
Characteristics: Law compliance, Faith, Culture, Past experience

In total: **38** factors.

Introduction

Autonomous vehicles (AVs) are expected to alter traffic fundamentally [19]. As AVs will be able to drive without a human operator, driving-task-related interpersonal communication such as eye-contact will decrease or even vanish. This could lead to ambiguous situations when formal rules or established behavior do not suffice and also cause the vulnerable road users (VRUs) to experience higher perceived risk. Academia and industry try to fill this gap through external communication modalities such as displays, projections, LED strips, movement patterns, auditory or tactile cues [5, 16, 17, 21, 34, 36, 38, 49].

There are several challenges to this research: real-world prototypes are expensive and potentially dangerous for participants of the experiments as the maturity level of today's AVs cannot cover all capabilities of automation. Paper prototypes, on the other hand, are quick to develop but tend to lack needed realism [47]. There are various other methods such as using pictures [22], videos [6] or conducting Wizard-of-Oz studies [8, 33]. However, using virtual reality (VR) seems a valid approach with various advantages as this technique allows for quick and low-priced prototyping and evaluation [12, 37]. While there are many simulators for research that focuses on the driver/user of AVs, e.g . CARLA [18] or the software SILAB [32], simulators that focus on the role of the pedestrian in AV research are scarce and relevant factors are not documented.

We collected and compared currently used methods of 7 papers and preprints for evaluating outside communication of AVs with pedestrians in crossing scenarios in VR with the goal of finding current practices. In particular, we focused on factors influencing crossing decisions of pedestrians and metrics as well as questionnaires to assess these decisions. Currently, few VR simulators were proposed but all differ around which relevant factors they model and which metrics they obtain. Our goal is to derive a set of common methodologies and evaluation metrics to create an easily configurable and reusable VR simulator for pedestrian interaction with the goal of being as widely available as the LCT [39] is for driver distraction.

Related Work

Factors that influence pedestrian behavior: Rasouli and Tsotsos surveyed existing literature about AVs that interact with pedestrians [42]. They started the survey with existing work on pedestrian behavior. They found a variety of environmental as well as pedestrian factors that influence crossing decision of pedestrians (see sidebar on page 2). These factors have also been found by other authors [23, 24, 28, 40, 41].

(VR) Simulators in other areas: Simulator studies have been widely used in autonomous driving, looking at driver behavior and interactions [43]. These studies have been investigated regarding validity and reliability [3] and have been shown to be a safe method to assess basic task performance [48]. Therefore, they are still used both in academia as well as in industry [1]. Hock et al. investigated how to design valid simulator studies [26] and found eight stages: *Sample, Briefing, Simulator Sickness, Takeover, Secondary Task, Simulator Training, User Interface,* and *Validity*. VR simulators have also been used in pedestrian research. Deb et al. [13] found that the VR simulator is a valid method to capture pedestrian behavior. They base this on the comparable walking speed in reality and the virtual environment (VE). Work by Bhagavathula et al. [2] also showed that there are no statistical significant differences between real and virtual environments in perceived risk, safety of crossing, perceived distance of the vehicle and perceived speed. No differences were found in the presence score.

Methods of external communication research: Clamann et al. investigated communication displays for the vehicle-to-pedestrian interaction with displays on a van [9]. A driver operated the van but participants were told that this person was there for data collection. Lagstrom and Lundgren [33] used a Wizard-of-Of approach. The vehicle was equipped with

Analysis Criteria

According to the advantages stated by [11], we have investigated the following factors.

- Validity (1)
- Interaction type (2, 3)
- Questionnaire (2, 3)
- Environment, street arrangement & localization (1, 3)
- Measurements (2)
- Customizability (1)

Customizability refers to the setting and variation of factors influencing crossing decisions of pedestrians [42].

# adjustable parameter	# publications
0	1 [7]
1	3 [4, 16, 27]
2 - 10	2 [10, 12]
>10	1 [37]
combined	7

Table 1: Publications on external communication of AVs with VR

two steering wheels where one was hidden from sight allowing them to pretended that the person in the driver's seat was not actually driving. Fridman et al. assessed external displays with online crowdsourcing [22]. Chang et al. [6] used video to compare communication modalities.

Literature Survey on VR Simulators

The publication databases ScienceDirect (SD) and Google Scholar (GS) were screened (search query: `(External Communication OR Features) AND (autonomous vehicle) AND pedestrian)`). In total 433 publications were found (ScD=384, GS=49). These were screened for the use of VR by the first author resulting in 7 publications and preprints. Simulators have several advantages to other methods of testing. De Winter et al. [11] state that the main ones are: (1) Controllability, reproducibility, and standardization, (2) Ease of data collection, (3) Possibility of encountering dangerous driving conditions without being physically at risk, (4) Novel opportunity for feedback and instruction. We analyze existing VR simulators (see Table 1) according to these advantages (see analysis criteria in the sidebar on page 3).

Validity. Some researcher have already implemented VR simulators for their external communication research. Mahadevan et al. [37] re-implemented the proposed communication concepts of an earlier study [38] in VR and found that for both studies there were both qualitative and quantitative support for the use of explicit interfaces. They therefore claim that a VR simulator is a valid method to evaluate these designs.

Interaction type. Publications are split into two groups of interaction: using a controller with which a crossing is indicated [7, 10, 37] and walking in the VE [4, 12, 16, 27].

Questionnaires. Most of the publications report that they used some sort of check for simulator sickness (e.g. 4 times SSQ [31] or the single item misery scale [46]). Additional ratings had to be given for the comfort (2 times), understanding (2 times), preference of external features (2 times), safety (2 times), the presence questionnaire of Witmer et al. [50] (1 time). Additional questionnaires used are the PBQ [14], PRQF [15] and the NASA-TLX [25]. There is no consistent set of questionnaires used in this field of research resulting in low comparability of the results. Two publications implemented parts of their questionnaire in the VE: Mahadevan et al. [37] used comfort sliders, Deb et al. [12] asked for the simplicity to understand the feature and the difficulty to cross.

Environment, Street Arrangement & Localization. One work was able to change environment types [37] (rural vs urban) and had pedestrians walking of the sidewalks. In all publications, a clearly western urban setting was used. It is not clear how eventual signposts were modelled in all publications, but in the cases that some were visible, they were also clearly western.

Measurements. Through the controlled conditions of a VE, several data can be measured. Position of the participant in the VR world [12, 16], head rotation [2, 12, 16], waiting time [7, 12, 16] and crossing time [12, 16] were logged.

Customizability. As shown by Rasouli & Tsotsos [42], several factors influence pedestrian behavior (see sidebar on page 2). Only one publication mentioned these factors [37]. However, 3 of the 7 reported some customizability besides changing the model under evaluation (see Table 1). Deb et al. [12] are able to vary the design under evaluation as well as the vehicle size. The VR simulator of de Clerq et al. [10] allowed for the variation of four characteristics: (1) type of vehicle, (2) yielding behavior, (3) presence and type of external human machine interface (eHMI), and (4) timing of the eHMI.

Mahadevan et al. [37] are able to configure 19 factors which are summarized under four categories (see Table 2).
While this customizability is already far more extensive than in any of the other VR simulators, there are still some drawbacks

CONSIDERATIONS

1. Regularly check for simulation sickness (e.g. SSQ [31], discomfort score [20]) and don't exceed an hour for the evaluation.
2. Keep factors for pedestrian behavior (see e.g. [42]) in mind and, if needed, make them configurable.
3. Embodied interaction seems more suitable to create high immersion and presence [44].
4. Questionnaires can be implemented in VR to avoid the need to take off the VR headset.
5. Consider including objectives or penalty/reward systems to increase validity [26].

Category	Factors
Vehicle factor	vehicle autonomy, vehicle color, vehicle size, vehicle speed, vehicle slowdown characteristic at a crosswalk and stopping distance
Street characteristic	number of vehicles on the street, traffic direction (one-way vs two-way), number of lanes, lane order of vehicles with different autonomy levels (fixed to specific lanes vs free flow), type of crosswalk intersection, type of street scene (rural vs urban environment), lighting conditions (day vs night), weather (clear vs foggy)
Pedestrians	group size, demographics, age, ability, social norms
Interface prototype	variations

Table 2: Configurable Factors of Mahadevan et al. [37]

of this implementation: Truly mixed traffic is not simulated in this simulator as there is only one kind of vehicles per lane (automated, partly automated or manually driven). Another drawback is how the automated vehicles are modelled, there is no way of recognizing whether the vehicle is in autonomous mode or not other than the presence of a vehicle. There is a variety of modifiable parameters, but some of the ones mentioned in [42] are missing. While some of the pedestrian factors are non-changeable (e.g. faith, past experience), *attention* could be altered through engagement in other tasks. On the side of environmental factors, *street width*, *road conditions*, *location of the pedestrian under evaluation (near the curb or far away)* and *pedestrian waiting time* could be altered.

Discussion

Interaction type. Rogers et al. [44] found that high fidelity interaction resulted in higher immersion (IEQ [29]) and higher presence (E2I [35]). Therefore, we argue that actually walking (or in general higher embodiment) could result in higher immersion and higher presence and should therefore be used as an interaction modality.

Questionnaires. Conducted directly in the VE, they are feasible and could help to keep participants immersed and could therefore lead to more reliable results [45]. However, as simulation sickness is a drawback of VR, sessions should not be overlong (max. 1 h [30]).

Environment, Street Arrangement & Localization. A clearly urban western environment was mostly used. This is understandable as the research was conducted in western countries, but it shows a typical problem: as culture is an important factor in crossing decisions [42], other settings with subjects of different cultures have to be explored.

Customizability. Only one publication [37] referred to factors influencing pedestrians decision to cross and allows to vary them. While it is not necessary that every simulation is able to vary them, the rationale behind this decision should be given.

Conclusion & Future Work

VR seems to be a valid approach to model external communication from AVs to VRUs. However, most VR simulators today focus on a single aspect the authors want to evaluate. Creators of these simulators should focus more on known factors influencing VRUs in their crossing decisions. There is also no common understanding which and how questionnaires should be used in the simulator, although there is evidence that questionnaires in the VE provide higher immersion. We will focus on implementing a VR simulator according to the derived considerations (see sidebar on page 4) next.

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REFERENCES

1. Gerd Baumann. 2019. Stuttgarter Fahrsimulator. `http://www.fkfs.de/pruefeinrichtungen/fahrsimulatoren/stuttgarter-fahrsimulator`. (2019). [Online; accessed 11-06-2019].
2. Rajaram Bhagavathula, Brian Williams, Justin Owens, and Ronald Gibbons. 2018. The Reality of Virtual Reality: A Comparison of Pedestrian Behavior in Real and Virtual Environments. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 62. SAGE Publications Sage CA: Los Angeles, CA, 2056–2060.
3. Evi Blana. 1996. Driving Simulator Validation Studies: A Literature Review. (1996).
4. Marc-Philipp Böckle, Anna Pernestål Brenden, Maria Klingegård, Azra Habibovic, and Martijn Bout. 2017. SAV2P: Exploring the Impact of an Interface for Shared Automated Vehicles on Pedestrians' Experience. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. ACM, 136–140.
5. Chia-Ming Chang, Koki Toda, Takeo Igarashi, Masahiro Miyata, and Yasuhiro Kobayashi. 2018a. A Video-based Study Comparing Communication Modalities between an Autonomous Car and a Pedestrian. In *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 104–109.
6. Chia-Ming Chang, Koki Toda, Takeo Igarashi, Masahiro Miyata, and Yasuhiro Kobayashi. 2018b. A Video-based Study Comparing Communication Modalities between an Autonomous Car and a Pedestrian. In *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 104–109.
7. Chia-Ming Chang, Koki Toda, Daisuke Sakamoto, and Takeo Igarashi. 2017. Eyes on a Car: an Interface Design for Communication between an Autonomous Car and a Pedestrian. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 65–73.
8. Michael Clamann, Miles Aubert, and Mary L. Cummings. 2017a. Evaluation of Vehicle-to-Pedestrian Communication Displays for Autonomous Vehicles. *Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles* (2017).
9. Michael Clamann, Miles Aubert, and Mary L Cummings. 2017b. *Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles*. Technical Report.
10. Koen de Clercq, Andre Dietrich, Juan Pablo Nï£¡ï£¡ez Velasco, Joost de Winter, and Riender Happee. 2019. External Human-Machine Interfaces on Automated Vehicles: Effects on Pedestrian Crossing Decisions. *Human factors* (2019), 0018720819836343.
11. J De Winter, PM Van Leeuwen, and Riender Happee. 2012. Advantages and disadvantages of driving simulators: A discussion. In *Proceedings of measuring behavior*, Vol. 2012. Citeseer, 8th.
12. Carruth D. Fuad M. Stanley L. Deb, S. Comparison of child and adult pedestrian perspectives of external features on autonomous vehicles using virtual reality experiment. accepted.
13. Shuchisnigdha Deb, Daniel W Carruth, Richard Sween, Lesley Strawderman, and Teena M Garrison. 2017. Efficacy of virtual reality in pedestrian safety research. *Applied ergonomics* 65 (2017), 449–460.

14. Shuchisnigdha Deb, Lesley Strawderman, Daniel W. Carruth, Janice DuBien, Brian Smith, and Teena M. Garrison. 2017a. Development and validation of a questionnaire to assess pedestrian receptivity toward fully autonomous vehicles. *Transportation research part C: emerging technologies* 84 (2017), 178–195.

15. Shuchisnigdha Deb, Lesley Strawderman, Janice DuBien, Brian Smith, Daniel W. Carruth, and Teena M. Garrison. 2017b. Evaluating pedestrian behavior at crosswalks: validation of a pedestrian behavior questionnaire for the US population. *Accident Analysis Prevention* 106 (2017), 191–201.

16. Shuchisnigdha Deb, Lesley J. Strawderman, and Daniel W. Carruth. 2018. Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. *Transportation research part F: traffic psychology and behaviour* 59 (2018), 135–149.

17. Debargha Dey and Jacques Terken. 2017. Pedestrian interaction with vehicles: roles of explicit and implicit communication. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 109–113.

18. Alexey Dosovitskiy, German Ros, Felipe Codevilla, Antonio Lopez, and Vladlen Koltun. 2017. CARLA: An open urban driving simulator. *arXiv preprint arXiv:1711.03938* (2017).

19. Daniel J Fagnant and Kara Kockelman. 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice* 77 (2015), 167–181.

20. Ajoy S Fernandes and Steven K Feiner. 2016. Combating VR sickness through subtle dynamic field-of-view modification. In *2016 IEEE Symposium on 3D User Interfaces (3DUI)*. IEEE, 201–210.

21. Evelyn Florentine, Mark Adam Ang, Scott Drew Pendleton, Hans Andersen, and Marcelo H. Ang Jr. 2016. Pedestrian notification methods in autonomous vehicles for multi-class mobility-on-demand service. In *Proceedings of the Fourth International Conference on Human Agent Interaction*. ACM, 387–392.

22. Lex Fridman, Bruce Mehler, Lei Xia, Yangyang Yang, Laura Yvonne Facusse, and Bryan Reimer. 2017. To walk or not to walk: Crowdsourced assessment of external vehicle-to-pedestrian displays. *arXiv preprint arXiv:1707.02698* (2017).

23. Azra Habibovic. 2018. Communicating intent of automated vehicles to pedestrians. *Frontiers in psychology* 9 (2018), 1336.

24. W Andrew Harrell. 1991. Factors influencing pedestrian cautiousness in crossing streets. *The Journal of Social Psychology* 131, 3 (1991), 367–372.

25. Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

26. Philipp Hock, Johannes Kraus, Franziska Babel, Marcel Walch, Enrico Rukzio, and Martin Baumann. 2018. How to Design Valid Simulator Studies for Investigating User Experience in Automated Driving: Review and Hands-On Considerations. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 105–117.

27. Christopher R. Hudson, Shuchisnigdha Deb, Daniel W. Carruth, John McGinley, and Darren Frey. 2018. Pedestrian Perception of Autonomous Vehicles with External Interacting Features. In *International Conference on Applied Human Factors and Ergonomics*. Springer, 33–39.

28. Joseph E Hummer, H Douglas Robertson, and DC Nelson. 1994. Manual of Transportation Engineering Studies. *Institute of Transportation Engineering, by Prentice-Hall, inc, Englewood Cliffs, New Jersey* (1994).

29. Charlene Jennett, Anna L Cox, Paul Cairns, Samira Dhoparee, Andrew Epps, Tim Tijs, and Alison Walton. 2008. Measuring and defining the experience of immersion in games. *International journal of human-computer studies* 66, 9 (2008), 641–661.

30. Jen Karner. 2016. How long in VR is too long? `https://www.vrheads.com/how-long-vr-too-long`. (2016). [Online; accessed 12-06-2019].

31. Robert S Kennedy, Norman E Lane, Kevin S Berbaum, and Michael G Lilienthal. 1993. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology* 3, 3 (1993), 203–220.

32. Hans-Peter Krüger, Martin Grein, Armin Kaussner, Christian Mark, and others. 2005. SILAB-A task-oriented driving simulation. In *Driving Simulation Conference*.

33. Tobias Lagstrom and Victor Malmsten Lundgren. 2015. AVIP-Autonomous vehicles interaction with pedestrians. *Master of Science Thesis, Chalmers University of Technology* (2015).

34. Yeti Li, Murat Dikmen, Thana G. Hussein, Yahui Wang, and Catherine Burns. 2018. To cross or not to cross: Urgency-based external warning displays on autonomous vehicles to improve pedestrian crossing safety. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 188–197.

35. JJ-W Lin, Henry Been-Lirn Duh, Donald E Parker, Habib Abi-Rached, and Thomas A Furness. 2002. Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. In *Proceedings ieee virtual reality 2002*. IEEE, 164–171.

36. Victor Malmsten Lundgren, Azra Habibovic, Jonas Andersson, Tobias Lagström, Maria Nilsson, Anna Sirkka, Johan Fagerlönn, Rikard Fredriksson, Claes Edgren, and Stas Krupenia. 2017. *Will there be new communication needs when introducing automated vehicles to the urban context?* Springer, 485–497.

37. Karthik Mahadevan, Elaheh Sanoubari, Sowmya Somanath, James E Young, and Ehud Sharlin. 2019. AV-Pedestrian Interaction Design Using a Pedestrian Mixed Traffic Simulator. In *Proceedings of the 2019 on Designing Interactive Systems Conference*. ACM, 475–486.

38. Karthik Mahadevan, Sowmya Somanath, and Ehud Sharlin. 2018. Communicating awareness and intent in autonomous vehicle-pedestrian interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 429.

39. Stefan Mattes. 2003. The lane-change-task as a tool for driver distraction evaluation. *Quality of Work and Products in Enterprises of the Future* 57 (2003), 60.

40. Eryn O'Dowd and Thomas V Pollet. 2018. Gender Differences in Use of a Pedestrian Crossing: An Observational Study in Newcastle upon Tyne. *Letters on Evolutionary Behavioral Science* 9, 1 (2018), 1–4.

41. Marie Pele, Jean-Louis Deneubourg, and Cedric Sueur. 2018. Decision-making processes underlying pedestrian behaviours at signalised crossings: Part 2. Do pedestrians show cultural herding behaviour? *arXiv preprint arXiv:1805.11834* (2018).
42. Amir Rasouli and John K Tsotsos. 2019. Autonomous vehicles that interact with pedestrians: A survey of theory and practice. *IEEE Transactions on Intelligent Transportation Systems* (2019).
43. King M Roberts. 1980. FHWA highway driving simulator. *Public Roads* 44, HS-031 069 (1980).
44. Katja Rogers, Jana Funke, Julian Frommel, Sven Stamm, and Michael Weber. 2019. Exploring Interaction Fidelity in Virtual Reality: Object Manipulation and Whole-Body Movements. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. ACM, 414.
45. Valentin Schwind, Pascal Knierim, Nico Haas, and Niels Henze. 2019. Using Presence Questionnaires in Virtual Reality. (2019).
46. Martijn L van Emmerik, Sjoerd C de Vries, and Jelte E Bos. 2011. Internal and external fields of view affect cybersickness. *Displays* 32, 4 (2011), 169–174.
47. Miriam Walker, Leila Takayama, and James A Landay. 2002. High-fidelity or low-fidelity, paper or computer? Choosing attributes when testing web prototypes. In *Proceedings of the human factors and ergonomics society annual meeting*, Vol. 46. SAGE Publications Sage CA: Los Angeles, CA, 661–665.
48. Ying Wang, Bruce Mehler, Bryan Reimer, Vincent Lammers, Lisa A D'Ambrosio, and Joseph F Coughlin. 2010. The validity of driving simulation for assessing differences between in-vehicle informational interfaces: A comparison with field testing. *Ergonomics* 53, 3 (2010), 404–420.
49. Sylvain Wehnert. 2016. Mercedes-Benz F015–autonome Mobilität der Zukunft. In *Karosseriebautage Hamburg 2016*. Springer, 159–159.
50. Bob G Witmer, Christian J Jerome, and Michael J Singer. 2005. The factor structure of the presence questionnaire. *Presence: Teleoperators & Virtual Environments* 14, 3 (2005), 298–312.