Including People with Impairments from the Start: External Communication of Autonomous Vehicles

MARK COLLEY, MARCEL WALCH, JAN GUGENHEIMER, and ENRICO RUKZIO, Institute of Media Informatics, Ulm University, Germany

People with impairments are among the most vulnerable road users in traffic with significantly higher risk of accidents. Upcoming autonomous vehicles are expected to reduce this but demand some form of external communication to be able to signal their intent or other information to pedestrians. Recent research around the design of vehicle-pedestrian communication focuses strongly on concepts for a non-disabled adult population (e.g. visual cues). This work conducted a current literature review of existing concepts (2014-2019) for vehicle-pedestrian communication (29 publications) and evaluated each according to guidelines of universal design and people with disabilities in mind. Our results uncover shortcomings of the proposed concepts (e.g. over 65% rely solely on visual feedback) and combine these insights with a first impressions of those affected (interview with two visually impaired users).

CCS Concepts: • **Human-centered computing** → **Accessibility**.

Additional Key Words and Phrases: Self-driving vehicles; Autonomous vehicles; impaired pedestrians; external communication; intention communication; interface design; inclusive design research; accessibility.

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1 INTRODUCTION

Autonomous vehicles (AVs) are expected to change traffic systems radically. AVs are believed to increase safety and facilitate mobility [18]. However, many more aspects will change with the introduction of AVs. Interpersonal communication for situations, in which people today rely on eye-contact or gestures will vanish, as the vehicle can operate autonomously without a human driver. Recent research projects aim to overcome these upcoming challenges through external communication modalities such as displays, LED strips, movement patterns, auditory or tactile cues [6, 13, 16, 20, 26, 27, 29].

Children are recently started to be included in the evaluation and the design [8, 12]. However, most of the research projects focus mainly on middle aged non-disabled people and thereby exclude a majority of the population with disabilities (e.g. currently exist around 217 million people with moderate to severe vision impairment, 36 million people are blind [5] and 466 million people have disabling hearing loss[1]). One possible approach already suggested by some researchers [2, 13, 20, 29], is applying design principles from universal design [10] to create concepts for external communication that target a larger set of the pedestrian population including people with disabilities.

[1] https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment, Accessed: 07-06-2019

Principle 4a		4a	7a	4d	4c
used modalities	# publications	# essential info in all modalities	# applicable for seated users	# including techniques or devices used	# literacy + language independent
visual only	19 [2, 3, 6–9, 11, 12, 15, 21, 25–27, 32, 37, 38, 41–43]	19 (100%)	7 (41%)	0 (0%)	8 (42%)
visual + auditory	7 [4, 13, 14, 20, 22, 30, 31]	3 (43%)	7 (100%)	0 (0%)	4 (57%)
visual + tactile	1 [23]	0 (0%)	1 (100%)	1 (100%)	1 (100%)
visual + auditory + tactile	2 [28, 29]	0 (0%)	2 (100%)	2 (100%)	2 (100%)
combined	**29**	22 (76%)	17 (58%)	3 (10%)	15 (52%)

Table 1. Categorization of publications on external communication of AVs regarding their used modality

To get a better understanding of the requirements and design challenges, we analyze existing work on external communication with special regard to the universal design principles and point to open research gaps.

2 RELATED WORK

Vehicle sounds. With the emergence of hybrid and electric vehicles, vehicles become much more quiet. Robart and Rosenblum [35] showed that this leads to a much later localization of the vehicle both for sighted as well as for blind participants. The European Union has therefore declared an Acoustic Vehicle Alerting System (AVAS) [1] mandatory for electric and hybrid vehicles from 2021. Research was undergone to find possible solutions. Wolgater et al. [40] found that simulating the noise of an actual engine was preferred. Fleury et al. report that these sounds improve detectability and pitch variation and frequency modulation make them more effective [19].

Coping strategies. Besides using "traditional" aids such as hearing aids, canes or guide dogs, people with impairments have developed specialized coping strategies for navigation. Wiener and Lawson found that visually impaired persons use traffic sounds to make crossing decisions [39]. People with impairments also use technological aids such as GPS based navigation systems to reach their destination faster [34] and with less errors or halts [24]. Commercial navigation aids specifically tailored for their needs have emerged, e.g. BlindSquare [2].

3 ANALYSIS OF EXTERNAL COMMUNICATION DESIGNS

Data collection. Relevant publications in the field of external communication are spread over various journals and conferences. Therefore, the publication databases ScienceDirect (SD) and Google Scholar (GS) were screened. A time frame of five years (2014-2019) was defined as the field of external communication grew significantly in the last years [2].
Search procedure. In both databases, the terms *external communication/features* and *autonomous vehicle* were combined. Additionally, the term *pedestrian* was used (search query: `(External Communication OR Features) AND (autonomous vehicle) AND pedestrian`). In total 433 publications were found (ScD=384, GS=49).

Screening criteria. Four criteria were defined to narrow the search. The papers had to be about (1) AVs intended for streets (no water or air based vehicles, e.g. [36]). Additionally, (2) external communication to pedestrians had to be investigated, not, e.g. communication to other vehicles. The publications included for analysis had to be (3) original full

[2] `http://www.blindsquare.com/`, Accessed: 07-06-2019

papers or Work in Progress (due to the novelty of the field) and had to be (4) written in English or German. If the paper had references that matched the 4 criteria, that paper was also added. Additionally, `researchgate.net` was screened for all first authors that had were previously found. The screening was performed by the first author. This resulted in a sample of **29** publications.

Evaluation criteria. Some of the universal design principles [10] were used for the evaluation of the design concepts (see sidebar). They were chosen with the automotive context in mind.

Findings from Literature Survey The overview given in Table 1 shows that most of the research aims at using visual cues (19/29) to enable external communication of AVs. While this seems a valid approach for the sighted population, there are obvious drawbacks for the visually impaired as well as for distracted persons. We have also looked at the applicability of the designs for seated users, e.g. people in wheelchairs. The designs were considered to be applicable if the visual cues (displays, LED strips) were located at the top or the center of the vehicle. Projections were also seen as applicable. Visual cues at the bottom of the vehicle were rated as non-applicable because there could be gaze-blocking objects at the curb of the street (high grass, rails). Only 7/19 (41%) were applicable for seated users using these criteria. Several publications claim that *text* is the least ambiguous (visual) modality to convey information [6, 13, 21]. This is, however, contradictory to principle 3c, accommodating for a wide range of literacy and language skills, as it excludes the illiterate as well as foreigners and children.

7 publications investigated visual and auditory (or acoustic) designs. While only 3 (43%) of the publications provided the same essential information in both modalities helping visual impaired, the auditory aspect helps seated users. Language and literacy independence was only given in 4/7 cases as text was used both in the visual as well as in the auditory design.

Only one publication combined visual and tactile (or haptic) cues. These cues were realized in a smartphone app by warning the user of a potential accident [23]. This could work well for seated users with various impairments and is an approach that includes a device often used by people with impairments. It was rated language and literacy independent as the app could be used with one's own preferences (language).

Mahadevan et al. combined three modalities (visual, auditory and tactile) [28, 29]. For this, they used displays, LED strips, a speaker, printed hands as well as smartphones. They did not systematically try every combination of these devices, which is why the essential information was not always conveyed in all modalities used. The proposed designs did include techniques or devices used by people with impairments, were (partly) language and literacy independent (rated as "yes" as most cues were independent). The designs were appropriate for seated users. They [29] mention that it has to be evaluated how many cues are too many to avoid information overload [17].

General Considerations The literature review in condensed form (see Table 1) shows that while many designs for external communication of AVs have been proposed with visual cues, other modalities have been widely avoided. The analysis also shows that many universal design principles have not been followed (**none** of the proposed designs fulfill all criteria). To be able to truly propose a universal design, it seems necessary to include people with impairments in the design process. 9 out of 29 (31%) publications actually do mention *accessibility* or *impairment* but none of the work explicitly addresses this audience.

4 INCLUDING PEOPLE WITH IMPAIRMENTS

We have contacted several supra-regional groups of visually impaired persons. Several groups have agreed to collaborate with us to address the problems and find potential solutions.

A first telephone conference with two representatives was held. After giving their consent, the conference was recorded. The first author created a transcript of the phone call and conducted a first thematic analysis about the topics of interest brought up by the two visually impaired participants.

The participants emphasize the need to be included in the design of such external communication tailored to their special needs. They agreed with the findings of Wolgater et al. [40] that they would prefer actual engine sounds. The participants have therefore agreed to continue to work with us, to aid us in understanding their situation and to evaluate other approaches. Telephone conferences as well as focus groups will be held in June, July and August 2019.

5 DISCUSSION & FUTURE WORK

This work has analyzed 29 publications in the field of external communication of AVs with regard to the universal design principles. The overview has shown that several modalities to convey information are not evaluated sufficiently. It has also shown that the special needs of people with impairments are mostly unmet in the proposed designs. We therefore propose to include people with impairments in the design and evaluation process. In the future we plan to extend this first analysis to a more detailed evaluation of currently existing concepts including different populations with disabilities in the design process.

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6 ADDITIONAL: IN SIDEBAR IN ORIGINAL PUBLICATION

Universal Design

Universal Design [10] defines a set of 7 principles trying to help in the process of designing and evaluating environments and products in a way that they may be accessed, understood and used to the greatest possible extent, in the most independent and natural manner possible, in the widest possible range of situations and without the need for adaptation, modification, assistive devices or specialized solutions, by any persons of any age or size or having any particular physical, sensory, mental health or intellectual ability or disability [33].

Evaluation criteria

Based on the following principles of universal design [10].

- [10] Principle (1a): Provide the same means of use for all users: identical whenever possible, equivalent when not
- [10] Principle (1d): Make the design appealing to all users
- [10] Principle (3c): Accommodate a wide range of literacy and language skills
- [10] Principle (4a): Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information
- [10] Principle (4d): Provide compatibility with a variety of techniques or devices used by people with sensory limitations
- [10] Principle (7a): Provide a clear line of sight to important elements for any seated or standing user

Themes discussed with two visually impaired participants

- challenges and coping strategies facing road traffic today

- potential future problems and their views on them (electric and hybrid cars, AVAS)
- presentation of various concepts from literature and their view on them

REFERENCES

[1] Regulation No. 540/2014. 2014. Regulation (EU) No 540/2014 of the European Parliament and of the Council of 16 April 2014 on the sound level of motor vehicles and of replacement silencing systems, and amending Directive 2007/46/EC and repealing Directive 70/157/EEC Text with EEA relevance. (2014).

[2] Claudia Ackermann, Matthias Beggiato, Sarah Schubert, and Josef F Krems. 2019. An experimental study to investigate design and assessment criteria: what is important for communication between pedestrians and automated vehicles? *Applied ergonomics* 75 (2019), 272–282.

[3] Pavlo Bazilinskyy, Dimitra Dodou, and Joost De Winter. 2019. Survey on eHMI concepts: The effect of text, color, and perspective. *Manuscript submitted for publication* (2019).

[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] Rupert RA Bourne, Seth R Flaxman, Tasanee Braithwaite, Maria V Cicinelli, Aditi Das, Jost B Jonas, Jill Keeffe, John H Kempen, Janet Leasher, Hans Limburg, et al. 2017. Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. *The Lancet Global Health* 5, 9 (2017), e888–e897.

[6] Chia-Ming Chang, Koki Toda, Takeo Igarashi, Masahiro Miyata, and Yasuhiro Kobayashi. 2018. 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] Vicky Charisi, Azra Habibovic, Jonas Andersson, Jamy Li, and Vanessa Evers. 2017. Children's views on identification and intention communication of self-driving vehicles. In *Proceedings of the 2017 Conference on Interaction Design and Children*. ACM, 399–404.

[9] Michael Clamann, Miles Aubert, and Mary L. Cummings. 2017. Evaluation of Vehicle-to-Pedestrian Communication Displays for Autonomous Vehicles. *Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles* (2017).

[10] BR Connell, M Jones, R Mace, J Mueller, A Mullick, E Ostroff, J Sanford, E Steinfeld, M Story, and G Vanderheiden. 1997. The principles of universal design, Version 2.0, Raleigh, NC. *Center for Universal Design, North Carolina State University* (1997).

[11] Koen de Clercq, Andre Dietrich, Juan Pablo Nunez Velasco, Joost de Winter, and Riender Happee. 2019. External Human-Machine Interfaces on Automated Vehicles: Effects on Pedestrian Crossing Decisions. *Human factors* (2019), 0018720819836343.

[12] Shuchisnigdha Deb, Daniel W Carruth, Muztaba Fuad, Laura M Stanley, and Darren Frey. 2019. Comparison of Child and Adult Pedestrian Perspectives of External Features on Autonomous Vehicles Using Virtual Reality Experiment. In *International Conference on Applied Human Factors and Ergonomics*. Springer, 145–156.

[13] 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.

[14] Shuchisnigdha Deb, B. Warner, S. Poudel, and S. Bhandari. 2016. Identification of external design preferences in autonomous vehicles. In *Proc. IIE Res. Conf.* 69–44.

[15] Debargha Dey, Marieke Martens, Berry Eggen, and Jacques Terken. 2017. The impact of vehicle appearance and vehicle behavior on pedestrian interaction with autonomous vehicles. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. ACM, 158–162.

[16] 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.

[17] Martin J Eppler and Jeanne Mengis. 2004. The concept of information overload: A review of literature from organization science, accounting, marketing, MIS, and related disciplines. *The information society* 20, 5 (2004), 325–344.

[18] 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.

[19] Sylvain Fleury, Éric Jamet, Vincent Roussarie, Laure Bosc, and Jean-Christophe Chamard. 2016. Effect of additional warning sounds on pedestrians' detection of electric vehicles: An ecological approach. *Accident Analysis & Prevention* 97 (2016), 176–185.

[20] 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.

[21] 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).

[22] 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.

[23] Ahmed Hussein, Fernando Garcia, Jose Maria Armingol, and Cristina Olaverri-Monreal. 2016. P2V and V2P Communication for Pedestrian Warning on the basis of Autonomous Vehicles. In *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2034–2039.

[24] Toru Ishikawa, Hiromichi Fujiwara, Osamu Imai, and Atsuyuki Okabe. 2008. Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience. *Journal of Environmental Psychology* 28, 1 (2008), 74–82.

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

[26] 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.

[27] 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.

[28] 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.

[29] 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.

[30] Milecia Matthews, Girish Chowdhary, and Emily Kieson. 2017. Intent communication between autonomous vehicles and pedestrians. *arXiv preprint arXiv:1708.07123* (2017).

[31] Natasha Merat, Tyron Louw, Ruth Madigan, Marc Wilbrink, and Anna Schieben. 2018. What externally presented information do VRUs require when interacting with fully Automated Road Transport Systems in shared space? *Accident Analysis & Prevention* 118 (2018), 244–252.

[32] Nicole Mirnig, Nicole Perterer, Gerald Stollnberger, and Manfred Tscheligi. 2017. Three strategies for autonomous car-to-pedestrian communication: A survival guide. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 209–210.

[33] Government of Ireland. 2005. Disability Act 2005.

[34] Paul E Ponchillia, Eniko C Rak, Amy L Freeland, and Steven J LaGrow. 2007. Accessible GPS: Reorientation and target location among users with visual impairments. *Journal of Visual Impairment & Blindness* 101, 7 (2007), 389–401.

[35] Ryan L Robart and Lawrence D Rosenblum. 2009. Are hybrid cars too quiet? *The Journal of the Acoustical Society of America* 125, 4 (2009), 2744–2744.

[36] Avilash Sahoo, Santosha K. Dwivedy, and P.S. Robi. 2019. Advancements in the field of autonomous underwater vehicle. *Ocean Engineering* 181 (2019), 145 – 160. https://doi.org/10.1016/j.oceaneng.2019.04.011

[37] Andreas Sieß, Kathleen Hübel, Daniel Hepperle, Andreas Dronov, Christian Hufnagel, Julia Aktun, and Matthias Wölfel. 2015. Hybrid City Lighting-Improving Pedestrians' Safety through Proactive Street Lighting. In *2015 International Conference on Cyberworlds (CW)*. IEEE, 46–49.

[38] Helena Strömberg, Ingrid Pettersson, Jonas Andersson, Annie Rydström, Debargha Dey, Maria Klingegård, and Jodi Forlizzi. 2018. Designing for social experiences with and within autonomous vehicles–exploring methodological directions. *Design Science* 4 (2018).

[39] WR Wiener and G Lawson. 1997. The use of traffic sounds to make street crossings by persons who are visually impaired. *Journal of Visual Impairment & Blindness* 91, 5 (1997).

[40] Michael S Wogalter, Raymond W Lim, and Patrick G Nyeste. 2014. On the hazard of quiet vehicles to pedestrians and drivers. *Applied ergonomics* 45, 5 (2014), 1306–1312.

[41] Su Yang. 2017. Driver behavior impact on pedestrians' crossing experience in the conditionally autonomous driving context.

[42] Jingyi Zhang, Erik Vinkhuyzen, and Melissa Cefkin. 2017. Evaluation of an autonomous vehicle external communication system concept: a survey study. In *International Conference on Applied Human Factors and Ergonomics*. Springer, 650–661.

[43] Raphael Zimmermann and Reto Wettach. 2017. First step into visceral interaction with autonomous vehicles. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 58–64.