Pedestrians and Visual Signs of Intent: Towards Expressive Autonomous Passenger Shuttles

HIMANSHU VERMA, University of Applied Sciences of Western Switzerland (HES-SO), Switzerland
GUILLAUME PYTHOUD, University of Fribourg, Switzerland
GRACE EDEN, Indraprastha Institute of Information Technology Delhi, India
DENIS LALANNE, University of Fribourg, Switzerland
FLORIAN EVÉQUOZ, University of Applied Sciences of Western Switzerland (HES-SO), Switzerland

Autonomous Passenger Shuttles (APS) are rapidly becoming an urban public transit alternative. Traversing populous commercial and residential centers, these shuttles are already operating in several cities. In the absence of a human driver and embedded means of communicating the autonomous shuttle's intent, the task of seamlessly navigating crosswalks and pedestrian-friendly zones becomes a challenging pursuit for pedestrians.

We contribute to the emerging notion of AV–Pedestrian Interaction by examining the context of autonomous passenger shuttles (APS) in real-world settings, and by comparing *four* different classes of visual signals – namely *instructional*, *symbolic*, *metaphorical*, and *anthropomorphic* – designed to communicate the shuttle's intentions. Following a participatory methodology involving local residents and public transport service provider, and working within the framework of inflexible road traffic regulations concerning the operation and testing of autonomous vehicles, we conducted a participatory design workshop, a qualitative, and a survey study. The findings revealed differences across these four classes of signals in terms of pedestrians' subjective perceptions. Anthropomorphic signals were identified as the preferred and effective modality in terms of pedestrians' interpretation of the communicated intent and their perceived sense of attention, confidence, and calmness. Additionally, pedestrians' experiences while judging the intention of *transitionary* vehicular states (starting/slowing) were reported as perplexing and evoked stress. These findings were translated into design and policy implications in collaboration with other stakeholders, and exemplify a viable way for assimilating human factors research in urban mobility.

CCS Concepts: • **Human-centered computing → Interactive systems and tools**.

Additional Key Words and Phrases: Autonomous Passenger Shuttles (APS), Autonomous Vehicles (AVs), AV–Pedestrian Interaction, AV Intentions, Classes of Visual Signals, Comparative Study, Urban Public Transportation

ACM Reference Format:
Himanshu Verma, Guillaume Pythoud, Grace Eden, Denis Lalanne, and Florian Evéquoz. 2019. Pedestrians and Visual Signs of Intent: Towards Expressive Autonomous Passenger Shuttles. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 3, Article 107 (September 2019), 31 pages. https://doi.org/10.1145/3351265

Authors' addresses: Himanshu Verma, himanshu.verma@acm.org, University of Applied Sciences of Western Switzerland (HES-SO), Techno-Pôle 3, Sierre, 3960, Valais, Switzerland; Guillaume Pythoud, University of Fribourg, Boulevard de Pérolles 90, Fribourg, 1700, Switzerland, guillaume.pythoud@unifr.ch; Grace Eden, Indraprastha Institute of Information Technology Delhi, New Delhi, India, grace@iiitd.ac.in; Denis Lalanne, University of Fribourg, Boulevard de Pérolles 90, Fribourg, 1700, Switzerland, denis.lalanne@unifr.ch; Florian Evéquoz, University of Applied Sciences of Western Switzerland (HES-SO), Techno-Pôle 3, Sierre, 3960, Switzerland, florian.evequoz@hevs.ch.

2474-9567/2019/9-ART107 $15.00
https://doi.org/10.1145/3351265

1 INTRODUCTION

In recent years, scientific discourse related to Autonomous Vehicles (AVs) within the domains of Urbanism and Mobility highlight their potential benefits [3, 9–11, 19] and negative consequences [1, 25, 36, 40] for both passengers and the urban landscape. This dichotomy is also reflected in public opinion about the perceived opportunities and challenges concerning AVs, gathered through several surveys (for example [27, 50, 51]). Furthermore, AVs – as a major UbiComp project – have also been scrutinized in terms of their integration in the "messy" urban landscape based upon an analytical framework borrowed from Transportation and Urban Research [1].

From the perspective of pedestrians and other road users (cyclists, skateboarders, and other vehicle drivers), driving is regarded as a "*social phenomenon*" that entails subtle collaboration between road users to ensure safe and navigable traffic conditions [44, 45]. This social dynamics is disrupted with the introduction of AVs, where the passengers are either negligent to traffic situations or engaged in other activities. Furthermore, the increased likelihood of interacting with *zero-occupancy* AVs has been recognized as a concern for both pedestrians and other drivers [1, 45]. This lack of (or limited) human mediation in AVs' functioning raises many ethical, legal, and technological challenges. Although, several vehicle manufacturers and service providers are consistently addressing the underlying technological challenges through exhaustive 'in-the-wild' testing, ensuring the safe operability and risk averseness of these vehicles. Still, the wider acceptability of AVs and their seamless integration into our social and urban fabric entails careful examination of the nuanced and manifold interactions between people and AVs.

HCI and Interaction Design researchers have so far examined and consolidated these interactions in two ways: *a*) in-vehicle interaction with the driver and other passengers (for example, [21, 26, 35]), and *b*) interactions with other road users such as pedestrians, cyclists, other drivers, etc. (for example, [14, 23, 31, 33, 43]). The research presented in this article belongs to the latter class of interactions with the varied road users.

Interactions between pedestrians and drivers – encompassing the need to communicate the latter's intent and awareness of other road users, especially at crosswalks can manifest in subtle and varied ways [43]. Pedestrians leverage several signals including vehicle's movement, speed, size, appearance, and distance to interpret the driver's intention while navigating on roads [15, 16, 41, 47, 57]. In addition, non-verbal indicators such as gaze, gestures, and posture (both of the driver and of pedestrians) are used in the communication process [31, 33]. These signs are demonstrated to induce the feeling of reassurance and confidence amongst the road users [22, 46]. Owing to their risk-averse nature, AVs are considered by experts and manufacturers as a significant step towards a *pedestrian-centered urbanity* [1, 37].

Still, the absence of a human driver and the lack of means of embedded interactions to communicate the intentions or the operational state (slowing down, accelerating, stopping, etc.) – i.e. non-verbal signals from human operators, and their complementary replacements embedded within the vehicle – could in-turn affect trust and overall social acceptance of AVs [7, 31]. Moreover, previous research (predominantly in the domain of Human-Robot Interaction) has demonstrated that the explicit communication of intentions and their respective 'understandability' (or interpretability) are essential prerequisites for the development of trust amongst users [29, 56]. In addition, Thomaz et al. [53] suggest making these intentions transparent, and "*letting the human partner infer the intended target or goal of [Robot's] action*" (p. 160). Casner et al. [12] argue that the presence of varying levels of vehicular automation (from partial to full automation) on streets could further amplify these concerns as the road users might be unaware and ambiguous about identifying and appropriately reacting to a mixed vehicle scenario.

The gap in pedestrians' awareness about the driver's intention – ensuing due to the complete disappearance or reduced driver intervention in AVs – has been the chief design concern for researchers and interaction designers, both within academia and the automobile industry. Prototyped means of filling this gap through embedded communication tools on AVs have been demonstrated and evaluated in the last couple of years. These tools visualize the vehicle's operational state and awareness of pedestrians in multiple ways, including textual and graphical (symbols, pictographs, icons, etc.) representations rendered over embedded LED displays. In addition, anthropomorphism (ascribing human attributes and behavior to inanimate objects) has been leveraged as a design methodology to effectively communicate this awareness and intent, for example, through the rendering of eyes on the vehicle's front surface [5, 13, 33]. Despite their perceived usefulness, interfaces designed to communicate intent have not been reported as effective in facilitating pedestrians' decision-making process [34, 57, 58]. Moreover, Pillai [41] observed that the need for intent communication interfaces is accentuated under special circumstances, especially in poor weather and visibility conditions.

Previous works examining interactions between pedestrians and AVs, especially the ones evaluating the influence of intent communication interfaces, have predominantly focused on private vehicles (cars) in rather constrained and simulated settings (such as parking lots [15, 28] and organizational premises [38]). The work presented in this article, on the other hand, examines interactions between pedestrians and *Autonomous Passenger Shuttles* (APS) which are increasingly being adopted as a public transportation alternative in several cities worldwide. The relatively larger form-factor of APS as compared to private vehicles, and higher levels of anticipated interactivity with the pedestrians at various points of intersection (such as bus stops, sidewalks, crosswalks, pedestrian priority zones) render them different from the previously examined context of private AVs. Moreover, the APS run on a predefined trajectory with designated stops (as part of their operation in the public transportation context), whereas private AVs are relatively free to run on any road and can dynamically plan or modify their trajectory based on external factors such as user demands and traffic conditions. APS are also a *public space* where large numbers of strangers share the ride for a particular period of time. Private vehicles (including AVs), on the other hand, carry small numbers of passengers that may either be family, friends, or as shared taxi commuters. Additionally, APS in their current operational state do not communicate their intent or their awareness of road users to the pedestrians (as discussed in Section 3). This, consequently, manifests as an *awareness gap* for pedestrians, and makes it challenging for them to effortlessly judge the intention of the shuttle and to seamlessly navigate in their proximity. Finally, strict and often inflexible traffic and state regulations concerning the operation of AVs on public roads constrain shuttles' use to either low-risk areas such as airports[1] and university campuses[2], or limit their speed (maximum allowed speed of 20 km/h) drastically to avoid mishaps. These regulations also restrain researchers from conducting ecologically valid evaluations of novel interfaces for communicating the intent of APS to the pedestrians.

In this article, we contribute by extending the previous works on the – relatively new and emerging – notion of *AV–Pedestrian Interaction* by examining the context of APS in real-world settings, which in turn entails maneuvering through the challenges posed in the form of (aforementioned) state regulations. In particular, we design and evaluate effective ways of communicating the intent of APS through a *participatory* effort involving local residents (who have interacted with the APS in their daily commute) and the public transport service provider. Since the space of design possibilities to provide APS' awareness of road users and their intent is extensive and diverse, as a first step, we focus explicitly on the *visual* means of communicating intent. In addition, the relationship between the nature of communicated information (direct *vs.* symbolic *vs.* metaphorical *vs.* anthropomorphic) and its perception and interpretation in different urban scenarios (crosswalks, sidewalks, pedestrian zones, etc.) has so far not been studied in the context of APS. Therefore, we investigate this relationship by comparing different classes of embedded visual signals to communicate the varied set of APS' intentions. We

[1]Driverless Shuttle at Christchurch Airport (New Zealand): https://www.christchurchairport.co.nz/en/about-us/media-centre/media-releases/2017/new-zealand's-first-smart-shuttle-unveiled-in-christchurch/ (last visited on 28th April 2019).
[2]Driverless Shuttle at Nanyang Technical University Campus (Singapore): https://www.straitstimes.com/singapore/transport/ntu-gets-new-driverless-shuttle-bus-to-ferry-students-across-campus (last visited on 28th April 2019).

believe that this knowledge may prove beneficial for the design of signals that can foster an enhanced sense of trust and safety amongst pedestrians concerning APS, and facilitate their wider social acceptability.

2 RELATED WORK

The research presented in this article is situated at the intersection of HCI and Automative-UI, and contributes to the emerging notion of *AV–Pedestrian Interaction*. Although relatively new and a subject of exploration in the past few years, this notion aspires to address the interaction design challenges resulting from the diminishing human intervention in AVs and its subsequent influence on pedestrians. Unlike in-vehicle interaction which focuses on the seamless transfer and sharing of vehicle control between the human driver and AI [21, 26, 35, 42, 54], AV–Pedestrian Interaction seeks to provide a framework for cooperation between pedestrians (and other road users) and AVs.

In this section, we review the relevant research, which can be broadly categorized into two classes: *1*) studies investigating the nature of interactions between pedestrians and AVs, and *2*) systems explicitly designed to communicate AVs' awareness of road users and their intent (current operational state and its transition in the immediate future).

2.1 Pedestrian Behavior and Interactions with Autonomous Vehicles

A 'Wizard-of-Oz' study conducted by Rothenbücher et al. [49] is amongst the first studies to assess pedestrian behavior while interacting with a driverless car. The authors concealed a human driver within the driver's seat, making it appear as if the car was driverless, and subsequently examined pedestrians' reactions while interacting with the vehicle at crosswalks and a roundabout. They observed that road users explicitly seek acknowledgements/signals from a human driver before committing themselves to crossing the street. This seeking behavior underpins the assumption on the part of pedestrians that they were seen by the driver, which simultaneously induces a feeling of trust. Unexpected behaviors (or errors) by the vehicle were also observed to impede the development of trust and confidence amongst road users. In a recent and exhaustive literature review conducted by Rasouli and Tsotsos [45], the authors summarize various pedestrian factors (such as age, gender, social norms, culture, etc.) and environmental factors (such as time and weather conditions, location, speed and distance of vehicle, presence/absence of intent displays, etc.) that influence pedestrian interactions and behaviour in the proximity of autonomous and ordinary vehicles.

Eden et al. [18] conducted a video-based ethnographic study recording the behavior of human stewards (referred as "safety drivers") aboard a self-driving passenger shuttle. Their analysis revealed that while the shuttle was operating autonomously, the stewards proactively gestured and coordinated with pedestrians and other drivers – indicating the self-driving nature of the vehicle, negotiating next moves with pedestrians, and often conveying instructions to other car drivers.

Dey et al. [16] studied the influence of vehicles' appearance (perceived aggressiveness or friendliness afforded collectively by the vehicle's design, size, and type) on pedestrians' perceived risk of AVs. Their findings reveal that AV's speed and distance to the pedestrians, rather than its appearance, impacts the pedestrians' perceived levels of risk and influences their decision to cross the street. Furthermore, since a vehicle's movement affords subtle cues about the driver's intent (slowing at crosswalks signifies pedestrians' precedence), Risto et al. [47] and Pillai [41] suggest that the vehicle's movement information should be leveraged and assimilated in communicating the AV's intent to road users. In summary, justifying the need to offload the drivers' responsibility for negotiating with pedestrians onto the AVs, these studies guide and structure future discourse in AV–Pedestrian Interaction.

2.2 Influence of Communicating AV's Intent through Embedded Displays on Pedestrian Behavior

Lagström and Lundgren [28] demonstrated *AVIP* – a LED array attached over a car's windshield, designed to communicate awareness regarding its intent (stopping, resting, and starting) and whether or not it was being autonomously driven. Their evaluation of the AVIP interface revealed enhanced confidence amongst pedestrians regarding the usefulness of the LED display, and their interpretation of the symbolic meaning (about AV's intent) conveyed by it. Studies conducted by Clamann et al. [15] and Yang [57], examining the influence of an external display that informed pedestrians whether it was safe to cross the street, revealed, on the contrary, that the display had little influence on the pedestrians' crossing behavior. These conflicting findings necessitate the thorough examination of the effective means of communicating AVs' intent, and possibly through participatory methods that offer opportunities for different stakeholders (researchers, service providers, and pedestrians) to collaboratively ground urban expectations and needs regarding AVs in empirically valid settings. Our research follows this participatory methodology applied within an existing context of autonomous public transport service. Furthermore, the work of Charisi et al. [14] has explored the interfaces that can communicate an AV's intent to child pedestrians and reinforced the necessity of externalizing the autonomous nature of the vehicle. In addition, their findings revealed the use of traditional traffic-signal colors within interfaces to mitigate the instances of misinterpretation amongst children.

Similar means of communicating awareness of road users and the AV's intent through embodied LED displays (distributed across the vehicle's exterior) has also been recently showcased by prominent car manufacturers such as Mercedes Benz[3], Nissan [6], and Jaguar [5]. These interfaces use visual (textual and graphical renderings), auditory, and external (for example, projections on the street) means to coordinate the use of street space with pedestrians. Additionally, anthropomorphic displays – rendering eyes that watch and follow pedestrians (for example, Jaguar [5], Mahadevan et al. [33], Chang et al. [13]), have been designed to induce an enhanced sense of security amongst pedestrians. Chang et al. [13] examined the influence of animated moving eyes on pedestrians' decision making speed, and observed that pedestrians make faster decisions at crosswalks when presented with anthropomorphic intent displays.

More recently, the work of Mahadevan et al. [33] consolidated two distinct aspects of providing awareness to pedestrians: *1*) the nature of information being communicated (visual, auditory, or physical), and *2*) the distribution of this information (on the vehicle, in the surrounding infrastructure, or on personal hand-held devices). Based upon a careful combination of these aspects, the authors presented *four* different interfaces, observing a positive response from participants when making decisions about crossing streets. In addition, their findings offer crucial design implications for these interfaces including simplistic and unambiguous design, avoidance of information overload, and diminished decision-making burden upon pedestrians.

We add to the existing body of research on intent communication in AVs through visual means, with a specific focus on Autonomous Passenger Shuttles (APS) used in public transportation. Previous work related to intent displays have examined several classes of visual signals (including textual instructions, metaphorical pictographs, anthropomorphic animations, etc.), with no apparent consensus on their effectiveness in dynamic urban settings. Clamann et al. [15] observed that informative displays (visualizing AV's operational state including speed and intent) are more effective than advisory displays (which suggest if the pedestrians should cross the street or not). Owing to this diverse set of design possibilities for communicating intent and the varied ways in which they influence pedestrians' perceptions, an immediate transfer of existing design knowledge to our domain (as discussed in Section 3) is not straightforward. Consequently, we also contribute by examining the influence of varying levels of abstraction inherent in different visual signals on pedestrians' perception and ability to interpret these signals.

[3] https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion/ (last visted on 10th February 2019)

3 RESEARCH CONTEXT AND BACKGROUND

In the town of Sion, Switzerland, autonomous passenger shuttles (*Navya Arma*[4] - similar to mini-buses) has been a public transport alternative since June 2016. The City Council, in collaboration with a public transport service provider (PostBus[5]), operate two shuttles everyday between 13:00 and 18:00. It is worth noting that this service is the *first* attempt to integrate autonomous public transport in Switzerland, as well as the *first* in the world to run such a service on public roads. Furthermore, state regulations mandate the presence of a steward within the shuttle at all times, and require them to operate at low speeds (maximum speed of 20 km/h).

Each shuttle is 4.75m long, 2.11m wide, 2.65m high, and weighs 2400 kg when empty. The shuttle resembles a minibus (see Figure 3) that can accommodate 15 passengers (11 sitting and 4 standing), and operates for approximately 9 hours after full battery charge. The shuttle employs LIDAR (Light Detection and Ranging) Sensors, GNSS (Global Navigation Satellite System) Antenna, Cameras, and Odometer for the purpose of obstacle detection and precise positioning. Furthermore, the design of the shuttle is symmetrical with the front and rear of the vehicle being visually similar.

There is a Liquid Crystal Display (LCD) embedded at the front and the rear of the shuttle. These two displays are suspended from the shuttle's ceiling and are visible to the pedestrians through the front and rear windshields. They are used to communicate the shuttle's mode of operation (*manual* or *autonomous*) to the pedestrians. In the manual mode of operation, the on-board steward controls the shuttle using a joystick (similar to controllers used with gaming consoles). Besides indicating its mode of operation, the shuttle does not communicate any other intentions or awareness of pedestrians through the aforementioned displays. Similar to ordinary vehicles, the shuttle also has the turn signals to inform other drivers about the direction it intends on taking. Since its deployment, the shuttle has been involved in two minor accidents with no reported injuries. The cause of these incidents were *a*) malfunctioning of sensors responsible for obstacle detection, and *b*) absence of explicit means to communicate the shuttle's intention to road users. Although the second accident happened shortly after the conclusion of the presented research, still, it stresses the urgent need to communicate the shuttle's intentions to the road users.

Within the framework of "Mobility Lab[6]", which aims to explore innovative and sustainable urban mobility solutions and aspires to extend the autonomous shuttle service in other cities, the public transport provider (PostBus) sought research backed insights about the perception of the shuttles by pedestrians and other road users, including ways of enhancing trust and user experience. Our association with the project fostered a collaboration, where we (HCI researchers) offered to study the experiences of the local community (having already interacted with the shuttle), understand their expectations, and subsequently design and evaluate interfaces to effectively communicate the shuttle's intentions.

In our context, the driverless shuttle operates within the city center, across the main commercial quarter, and its planned trajectory (to-and-from the train station) intersects with pedestrian-heavy zones a few times during a single trip. This results in a high degree of interactivity between the shuttle and pedestrians. Since existing research on AV–Pedestrian interactions (illustrated in Section 2) has predominantly focused on interactions with cars studied at particular zones of interest (such as crosswalks and roundabouts), the immediate transfer, scalability, and applicability of design knowledge to our context (autonomous public transport shuttle) is not a straightforward process. Additionally the variability in information representations across different vehicular intents – textual instructions, graphical symbols, icons and pictographs, interactive awareness, and anthropomorphic signals – provide an extensive set of design possibilities which further complicate the process of making design decisions. Consequently, to address these issues we decided to adopt a participatory methodology from the very beginning.

[4]https://navya.tech/en/
[5]https://www.postauto.ch/en
[6]https://www.mobilitylab.ch/fr/

In the next section, we elaborate the research approach pursued throughout this work and briefly outline the different studies we conducted.

4 RESEARCH APPROACH AND STUDIES

Engaging different stakeholders in a long-term participatory endeavor is the main approach followed in this article. This participatory approach was not limited to a single phase or a study, but spanned the entire research process. It involved local residents, a public transport service provider, and HCI researchers (authors of this article). The following list briefly illustrates the different phases – and a complete research cycle – which constitute the presented work:

- **Phase I** (Section 5): A participatory forum was organized with the local community and representatives of the public transport service provider to understand the resident's experiences and challenges while interacting with the autonomous passenger shuttle (APS) on a daily basis. The findings revealed that the lack of means to communicate APS' intent hindered pedestrians' seamless navigability around the shuttle. Additionally, the forum served as a framework for the service provider to acknowledge the difficulties faced by residents, motivating them to find empirically-informed solutions in collaboration with the HCI researchers.
- **Phase II** (Section 6): Participatory analysis (involving HCI researchers and public transport service provider) of findings from *Phase I* resulted in the identification of viable next steps, which were consolidated into research questions and design rationale.
- **Phase III** (Section 7): The HCI researchers prototyped an Intent Communication Interface, and designed *four* classes of visual signals (*instructional*, *symbolic*, *metaphorical*, and *anthropomorphic*) to communicate the varied APS' intentions which were identified in *Phase I*.
- **Phase IV** (Section 8): A qualitative study was conducted in Quasi Naturalistic manner with the local community, where groups of participants discussed their perceptions and experiences while interacting with a *'single class'* of visual signals (and different APS' intentions).
- **Phase V** (Section 9): Comparative crowd-sourced surveys were conducted with individuals to assess the effectiveness of communicating a *'single APS intent'* by the aforementioned *four* classes of visual signals.
- **Phase VI** (Section 10): Finally, the public transport service provider and the HCI researchers consolidated the findings from *Phase IV* and *Phase V* into executable design and policy decisions, some of which will be implemented in the short term, and others in the long term through collaboration with the vehicle manufacturers and law makers.

Since our work focuses on pedestrians' interaction with the Autonomous Passenger Shuttles (APS) – a sub-class of Autonomous Vehicles (AV). Henceforth, we will use the terms APS to denote autonomous shuttles for public transportation, and AV to denote generic autonomous vehicles.

5 PHASE I. PARTICIPATORY FORUM

The local community has been interacting with the APS on a daily basis – for a year prior to the start of this research work. Consequently, the knowledge of residents' socio-technical experiences, familiarity, and mental models about the shuttle's operation should be considered and grounded within the framework of this research. Therefore, in order to *a*) *engage* representatives of the local community and the public transport provider in a common forum, *b*) *empower* them to inclusively and actively play a part in making design choices, *c*) *gather* knowledge about the experience and expectations of the local community regarding AV–Pedestrian Interaction, and *d*) *acquire* informed insights about the nature of intent information and the means of communicating it, we organized a participatory forum.

Participants were recruited through advertisements in local forums. Twelve subjects (4 females, 8 males) participated in the study. The participants had different professional and educational backgrounds (an architect, a retired engineer, a housewife, a businessman, a social science researcher, a project manager, and six students). Each used a different means of transportation in their everyday life. All of the participants had previously interacted with the APS and rode in it at least once.

The purpose of the forum was to facilitate dialogue between local residents and the representatives of the public transport company, and to elicit their opinions concerning *a*) their lack of awareness about the shuttle's operational states and how it influences their perception of it, *b*) the technological means and channels of representing these intentions and where to situate them, and *c*) the criticality of these representations in different sections of the shuttle's route. During the 2 hour session, participants discussed their experiences when interacting with the shuttle, and evaluated the varied design possibilities for bridging their awareness gap resulting from the lack of driver in the shuttle.

5.1 Procedure and Data Collection

Participants were divided into 4 groups based on their preferred transportation mode (pedestrians, cyclists, skateboarders, and car drivers). Each group was then given 2 sets of cards (see Figure 1a):

(1) *Green* cards corresponding to the 10 different operational states and intentions of AVs (such as stopping, accelerating, obstacle detection, running autonomously, etc.).
(2) *Purple* cards signifying the diverse means of communicating intentions, including representation types (text, pictographs, projections over street, etc.) and technological modalities (sound, beacons, cellphone alerts, etc.). These cards were inspired by an exhaustive exploration of existing signals employed in the domain of road transportation, and previous works on AV–Pedestrian Interaction (particularly [13, 14, 28, 33, 57]). The purple set contained 16 cards.

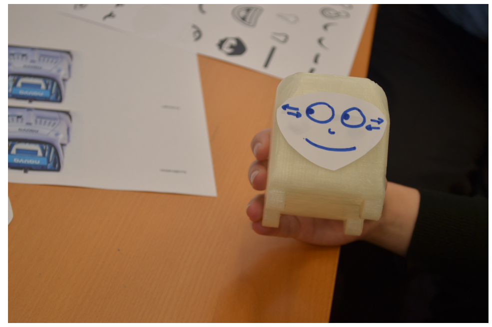
The purpose of providing these cards to groups was to serve as a catalyst for discussions and not to merely act as votes. The groups were also encouraged to include other suggestions they might have on a set of blank cards. In addition, A3-sized sheets containing printed images of the shuttle (and its different sides) and a 3D printed replica of the shuttle were provided along with an annotated map of the shuttle's itinerary, (as shown in Figures 1a and 1b) including crosswalks, roundabouts, and pedestrian zones.

Next, the groups participated in a design phase to discuss and collaboratively *a*) *identify* a prioritized list of up to 5 AV intentions which they believe should be made noticeable, *b*) *annotate* the images of the shuttle or *create* sketches that underline the localized mapping of the aforementioned list of intentions with the technological affordances required to effectively communicate these intentions, and *c*) *illustrate* the sections of the shuttle's itinerary where its interactions with pedestrians – including children and the disabled – are crucial and hence the need for communicating intent is essential. The groups were asked to identify up to 5 AV intentions (and not more) because we wanted them to prioritize (through discussions) and suggest the intentions, whose communication will mitigate the most urgent challenges encountered while interacting with the APS. Furthermore, participants' mapping of the five intentions (for example, starting, slowing, etc.) with different communication modalities (purple cards) allowed us to determine the preferred affordances for communicating with pedestrians.

Following the design phase, each group took turns to present their sketches and elaborate the rationale behind their choices. Finally, we opened the floor for general discussions about participants' experiences when interacting with the APS, and how their perceptions have evolved in the one year since its introduction in terms of their trust and confidence in the shuttle.

We preserved the participants' selection of the most important AV intentions (green cards) and their respective mappings to the technological communication modalities (purple cards). In addition, the annotated maps, sketches, and mock-ups made by the groups served as design suggestions and as sources for identifying regions (segments

(a) A snapshot from the participatory forum where residents collaboratively identified the crucial APS intentions and the preferred means of communicating them to the road users.



(b) A participant displays her mock-up of an anthropomorphic interface for communicating APS intentions, which was attached to the 3D printed replica of the driverless shuttle.

Fig. 1. The Participatory Forum was conducted with the voluntary residents and the representatives of the public transport service. Participants engaged in discussions about their interactive experiences with the driverless shuttle. They also participated in a design session to help identify potential solutions for bridging the awareness gap between APS and pedestrians.

of the shuttle's trajectory) that seek pedestrians' attention or inspire interaction. Group discussions during the design phase and the open discussion were audio recorded, and later transcribed. These were subsequently coded by two researchers to identify road users' *a*) experiences while interacting with the APS, *b*) perceived difficulties due to the lack of awareness about the shuttle's operational state and next actions, *c*) design suggestions for bridging this awareness gap, and *d*) future projections regarding the integration of APS in the urban mobility landscape.

5.2 Results

5.2.1 Different APS Intentions Needing Communication. Participants unanimously indicated their consensus about the different APS intentions that should be explicitly communicated to pedestrians and other road users. The analysis of the audio recordings revealed that participants also reflected upon the attributes of the shuttle's intentions, and what constitutes these intentions. As a result, the current operational state of the shuttle and the subsequent action that the vehicle's AI is planning on making, was assigned as the *intention* of the vehicle – *1*) currently running and will stay running, *2*) currently running but will stop soon, *3*) currently stopped and will stay stopped, and *4*) currently stopped but will start soon. In addition to these four intentions, participants stressed the need for *5)* awareness about the autonomous nature of shuttle's operation, and *6)* the depth of the shuttle's vision i.e. "*what and how far can the shuttle see?*".

5.2.2 Need for Simplistic Representations. The participants highlighted the need for simplistic representations – preferential use of iconography and pictographs rather than text – that are understandable to a wide range of the population, and do not induce additional cognitive load amongst pedestrians. One participant justified this by saying that "*the use of text is overwhelming for the driver, and he does not have the time to follow text on the shuttle, therefore, something simpler would do the job*", and another added that "*the universal pictographs are better than text, imagine reading [textual] intentions in multiple languages*". Also, in their sketches, the participants represented APS intentions using common pictographs which are employed in traffic signals – for example, the *walking man* sign used at pedestrian crossings and the circular red signs prohibiting pedestrian movement.

The use of text to communicate APS intention was further discouraged due to the bilingual demographics of the city, unsuitability for children, and the continuous inflow of international tourists. Furthermore, designing signals which induce a sense of security amongst child pedestrians was expressed by a participant as a necessary design principle – "*Children are the ones who are most scared of crossing. They wait until the vehicle has stopped and that they have been told it's safe to cross.*". Also, existing public transportation uses text to indicate destination and direction of operation. Consequently, the dual use of text (to communicate both destination and intention information) might lead to confusions amongst pedestrians. Hence, the use of graphical representations was advocated.

5.2.3 Use of Multi-Modal Communication and Information Overload. A combination of recurrent multi-modal channels (visual and auditory signs from the vehicle, as well as embedding ambient awareness into the urban landscape) were suggested as a way of rendering the awareness perceptible and readily accessible. However, communicating APS' intentions by sending notifications on hand-held (mobile) and wearable devices was regarded as invasive and annoying by the participants. A participant expressed her annoyance by stating this as a viable scenario: "*Imagine you are sitting at a road-side café and every time the shuttle passes-by you receive a mobile notification*". Participants also discussed the dangers of information overload with the possible proliferation of AVs on urban streets and with different manufacturers using different sets of symbols. One participant stated the problem as "*You don't want them all to become Coca-Cola trucks!*". Consequently, a desire for a standardized universal set of symbols to communicate awareness and intent was expressed by the participants - "*Different AV manufacturers must harmonize how they communicate intent ... if there are 15000 different signals for each vehicle, its going to be a hell!*". The use of traditional traffic light colors in representing these signals was suggested as a way of ensuring clarity and straightforward interpretation by pedestrians (for example, an LED display affixed on to the shuttle showing a GREEN signal might indicate that the shuttle is stopped and pedestrians can cross the street.)

5.2.4 Anthropomorphizing Intent Information. Anthropomorphizing the intent information, for example, by the use of animated faces on the APS front surface, was regarded as a transitory phase leading up to the time when a wider set of population is accustomed to the AV ecosystem, and have established confidence and trust in them. One participant questioned this aspect as "*Humanizing the shuttle (by displaying animated eyes/faces) is a good way to interact with pedestrians who are new to AVs, however is it a practical and functional means of communication in the long term?*". Furthermore, the analysis of sketches and annotations (over the 3D printed replica of shuttle as shown in Figure 1b) generated by the participants revealed the popularity of communicating APS intentions through anthropomorphic means, as three (out of four) groups represented APS intentions using eyes/faces.

5.2.5 How to best represent the APS intent? Considering the manner of representing the aforementioned intentions, however, no agreement was reached, which also led to significant discussions during the open session. Based on past experiences with public transportation and technological expectations, participants offered justifications for choosing one kind of signal over another. They debated the pros and cons of different design possibilities for communicating APS' intentions (such as pictographs, icons, animated eyes, or straightforward instructions), without offering conclusive arguments favoring one kind. Participants also ascribed different priorities to the awareness of various APS intentions owing to the movement of the vehicle. For example, communicating the intent of a shuttle which is moving or slowing down was given a higher precedence as compared to communicating intent of a shuttle that is stationary. Although an agreement was reached regarding the characteristics of these modalities (such as ambient and peripheral awareness, distributing information on the vehicle and the surrounding infrastructure), no consensus was reached concerning the nature of the information itself (instructional *vs.* symbolic *vs.* metaphorical *vs.* anthropomorphic).

Many of these findings are in line with previous works, particularly [14, 33], and the 2019 survey by Rasouli and Tsotos [45] has summarized these findings as crucial design guidelines for AV–Pedestrian Interaction. Still, our effort to engage participants with sufficient prior experience of interacting with an APS in a naturalistic urban setting, and our context of public transportation, are novel aspects which simultaneously extend and reinforce the scope and validity of research on AV–Pedestrian Interaction.

6 PHASE II. CONSOLIDATING RESEARCH QUESTIONS AND DESIGN RATIONALE

Analysis of discussions from the participatory forum emphasized the lack of pedestrians' awareness about the autonomous shuttle's intentions and expressed a unanimous desire for this to be communicated. However, we also observed a gap concerning the adequate manner of communicating this awareness. The extensive set of design choices for visually communicating the APS intentions (textually, symbolically, metaphorically, etc.) coupled with the pedestrians' differentially perceived intensity and ascribed concern (confidence, urgency) with regards to different intentions, complicates the design process for effective intent communication.

Next, we presented our findings to the representatives of the public transport service, and collectively evaluated the subsequent rational steps. As the first step, our transportation partner agreed to establish communication with the APS manufacturer to enable us access to the sensor data stream from the shuttle's LIDAR (Light Detection and Ranging) system, and to facilitate the development of responsive awareness and intent communication interfaces. However, owing to Intellectual Property protections, we were denied access to the shuttle's sensor system. This later influenced our decision to design and evaluate interfaces for communicating APS intentions *only* and not their awareness of pedestrians (see Section 7), and to employ 'Wizard-of-Oz' methodology in our qualitative evaluation in Section 8.

Communicating AVs' awareness and intention to pedestrians, as illustrated by Mahadevan et al. [33], can be achieved in *three* possible ways: *1*) providing awareness in the surrounding urban infrastructure, *2*) notifying pedestrians about the presence and proximity of AV through hand-held mobile and wearable devices, and *3*) displaying information over the vehicle itself. Constraints enforced by the state norms regarding the testing and operation of AVs, especially relevant to the deployment and embedding of signals in the urban environment, ruled out the first option, and limited our choices to the latter two. The second alternative of sending notifications on hand-held devices was previously discouraged by the forum participants as an intrusive and undesired means of communication (see Section 5.2.3). Consequently, we decided to design and study intent communication interfaces that could be attached onto the exterior surface of the APS.

Furthermore, discussions in the participatory forum offered suggestions in favor of combining multi-modal means (both auditory and visual) to enhance the perceptibility and accessibility of communicated information from the APS. Concerning the auditory aspect of communicating shuttle's operational state, the representatives of the public transport service revealed their collaboration with the shuttle's manufacturers to implement auditory signals similar to the ones used by streetcars (trams) – a short ring when the shuttle starts moving or detects pedestrians on the street – ensuring homogeneity in sound signals across the whole region. In addition, the representatives referred to the conventional and popular use of sound signals in public transportation as the primary motivation behind prioritizing the auditory signals over visual signals, and recommended we explore the extensive set of visual signals, and their influence on pedestrians' interactive experiences with the APS.

Finally, analysis of participants' sketches and discussions from the participatory forum revealed that there was a lack of visual awareness related to the APS intentions, and provided us with an extensive set of design choices with varying degrees of abstraction (graphical symbols and icons, metaphorical pictographs, and anthropomorphic animations). Furthermore, past works on *visual* intent displays have either examined the communication of different intentions through a single class of visual signals (for example, [23, 28, 57]) or a combination of a few visual modalities (for example, [33]). These discrete inquiries manifest as a disconnect between the different forms of communicated information and their influence on pedestrians' perceptions, interpretations, and judgments around AVs. Therefore, to form a comprehensive picture and to bridge the gaps in existing design knowledge regarding intent communication for APS, we decided to study the influence of different classes of visual signals on pedestrians' perceptions. This encompasses contrasting the different (classes of) visual signals across the dimensions of *a)* pedestrians' perceived effectiveness in interpreting the APS intentions, and *b)* perceived confidence in their interpretations. Such a comparative analysis might mitigate the instances where pedestrians misconstrue the particular intent being communicated by the APS, and subsequently result in their wider social acceptance. Consequently, with the representatives of the public transport company, we (the HCI researchers) consolidated and formulated the following research questions:

- *What is the relationship between the varying levels of abstraction in visual signals to communicate an APS intentions and their perception by pedestrians?*
- *Which type of visual signal (textual instructions, graphical symbols, metaphorical pictographs, anthropomorphic animations) unambiguously and effectively communicates the different APS intentions?*

7 PHASE III. PROTOTYPING INTENT COMMUNICATION INTERFACE

In order to address these questions, we designed two LED panels with 450 LEDs each (10 rows, 45 columns of `WS2812B` flexible LEDs). The panels were attached below the shuttle's windshield onto its front surface, and stretched across the front and the curved sides of the shuttle, as shown in Figure 3. The dimension of each panel was 150×33 cm^2, where the LEDs were soldered onto a black tarpaulin sheet, and subsequently covered with a translucent plastic to allow sufficient diffusion of the transmitted light and offer protection from rain. We used a

Table 1. The table illustrates the different types of visual signals (instructional, symbolic, metaphorical, and anthropomorphic) that were designed corresponding to the *four* APS intentions (also see Figure 2).

	APS Intentions			
Signal Type	Running NOW and will STAY Running (Running)	Running NOW and will STOP soon (Slowing)	Stopped NOW and will STAY Stopped (Stationary)	Stopped NOW and will START soon (Starting)
Instructions	`'STOP!'` sign *sliding* from the left to the right side of the shuttle.	`'WAIT!'` sign *sliding* from left to right side of the shuttle.	`'CROSS!'` sign *sliding* from left to right side of the shuttle.	Blinking `'CROSS!'` sign *sliding* from left to right side of the shuttle.
Symbolic	Randomized dot pattern *moving* outwards from the center of the shuttle towards the sides at an increased speed.	Randomized dot pattern *yields* as all the dots fall vertically towards the ground.	Randomized dot pattern *oscillates* between the center of the shuttle and the sides.	Randomized dot pattern *moving* outwards from the center of the shuttle, and stopping at the sides.
Metaphorical	Two Lemmings *standing* on the extremities of the shuttle with their hands outstretched.	Two Lemmings *standing* on the sides of the shuttle with their hands outstretched and heads roll from one side to another signalling caution.	Several Lemmings *walk* from both sides of the shuttle as if they are crossing the street in front of the shuttle.	Lemmings *moving* from the left to the right side of the shuttle start running half-way through.
Anthropomorphic	Focused (narrowed) eyes on both sides of the shuttle *gazing* over the street.	Animated eyes *closing* (in a slow blinking manner) on both sides of the shuttle.	Slowly *blinking* eyes that gaze from one side of the street to another.	Animated eyes *opening* wide on both sides of the shuttle.

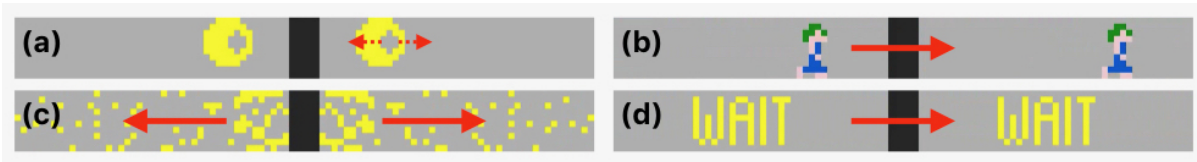


Fig. 2. Images representing different classes of visual signals. The red arrows correspond to the direction of movement in the animation. *(a)* Anthropomorphic - Stopped NOW & will STAY Stopped, *(b)* Metaphoric - Stopped NOW & will START Soon, *(c)* Symbolic - Running NOW & will STAY Running, and *(d)* Instructional - Running NOW & will STOP Soon (see Table 1).

Raspberry Pi 3 (Model B) to light specific sets of LEDs and display the different types of APS intentions. The visual signals were generated on a portable computer, and relayed to the Raspberry Pi and subsequently to the LED panels via a TCP connection.

Table 1 and Figure 2 illustrate the different visual signals that were designed corresponding to the four APS intentions signifying the current operational state and the subsequent action to be taken by the APS. These 4 intentions were collectively identified during the participatory forum (see Section 5.2). Moreover, our particular choices for different classes of visual signals – i.e. instructional, symbolic, metaphorical, and anthropomorphic – were inspired by the participants' preferential selections and discussions (including design sketches and mock-ups) during the participatory forum. In addition, the diverse design solutions for communicating AV's intent, which have been examined in previous works on AV–Pedestrian Interaction were also referred to and influenced our particular design choices for the aforementioned classes – *a*) anthropomorphic [5, 6, 13, 33], *b*) symbolic [23, 28], *c*) metaphorical [14], and *d*) textual [33, 57].

Fig. 3. The Intent Communication Interface attached to the driverless shuttle, and displaying the *Anthropomorphic* signal corresponding to intention *Running NOW & will STAY Running* (see Table 1).

During the participatory forum, participants expressed their preference for graphical representations (icons, pictographs, etc.) over textual signals to express APS intentions. Even so, we included textual signals as a class of visual signal for the sake of thoroughness, and to afford a baseline for comparing other classes of visual signals in terms of their efficacy and interpretability.

The textual *instructions* are a straight-forward means of communicating to the pedestrians whether it is safe to cross the street or not. Instructional signals belong to the class of advisory displays (as opposed to informative displays) [15] – suggesting pedestrians to choose a possible course of action depending on the shuttle's operational state and intention.

The other classes of visual signals constitute the relatively abstract representations of the AV's intentions, with the symbolic class being the most abstract. The *symbolic* category of visual signals featured a randomized dot pattern that would animate over the LED panel emulating the horizontal LED display designed by Lagström et al. [28] and Lundgren et al. [31]. Moreover, we used animated characters from the video-game *Lemmings*[7] to represent the class of *metaphorical* pictographs, which resemble the 'Walking Man' at pedestrian crossings. Similar to the textual instructions, the metaphorical signals used animated allegorical

[7] https://en.wikipedia.org/wiki/Lemmings_(video_game)

narratives (see Table 1) to suggest pedestrians to exercise caution, wait, or cross the street. For example, the signal corresponding to the APS intention of Stopped NOW & will STAY Stopped represents several lemmings walking from both sides of the shuttle, indicating that the pedestrians can cross the street. Finally, the *anthropomorphic* signals comprised of animated eyes that would open/close, blink, or gaze in different directions to indicate the vehicle's intention (see Figure 3). Anthropomorphic signals incorporated the participants' design suggestions for different APS intentions from the Participatory Forum (Section 5), which are also similar to the design solutions examined in previous research [13, 33]. Also, in the domain of Human-Robot Interaction, gaze features are used by robots to signal interpersonal attitudes, and have demonstrated a positive impact on the development of trust and human decision-making process [52]. Our designs for the anthropomorphic signals assimilated these attributes of gaze to signal APS intent.

The universal traffic-light colors (red, green, yellow) were assimilated into the visual signals to facilitate the distinction between different intentions and to homogenize their interpretation with existing road signals. The intentions of Running NOW and will STAY Running and Stopped NOW and will STAY Stopped were visualized in red and green colors respectively to stress that pedestrians shouldn't cross while the shuttle is running. Yellow was used to visualize the *transitionary* intentions where the shuttle was either slowing down or about to start, and to signal caution to the pedestrians.

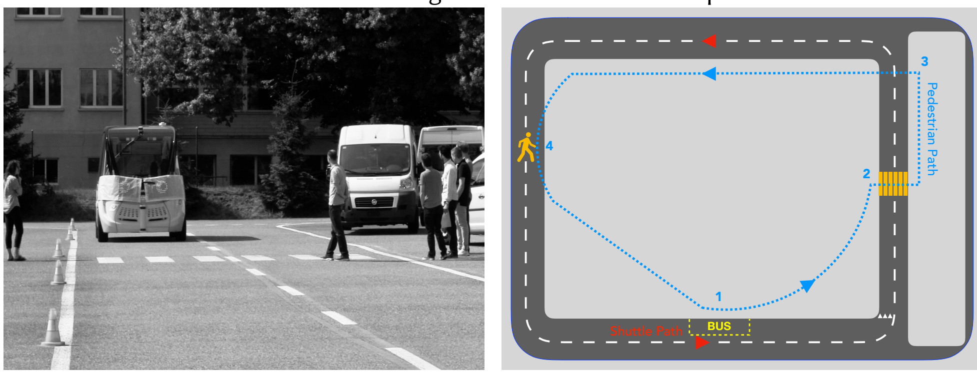
In this article, we primarily focus on evaluating the effectiveness of communicating APS intentions to pedestrians through previously identified (in participatory forum) signal types. Compared to the textual signals the other classes are more implied and abstract representations of the intent information. Moreover, we do not study the influence of inherent abstractness in these classes of signals on pedestrian perceptions. Consequently, the quantification of levels or degree of abstraction is out of scope for this work.

8 PHASE IV. QUALITATIVE STUDY

In order to evaluate the effectiveness of communicating the APS intentions as relatively abstract representations on pedestrians' perception and interpretations, we conducted a qualitative study over two days – *two* sessions on the first day, and *one* on the second – with 14 participants (12 males, 2 females). The objective of the study was to gather subjective evaluations of pedestrians' interpretations and experiences while interacting with the intent communication interface rather than the cognitive and sensory aspects.

The study followed a *between-subjects* design, where each group was presented with different APS intentions corresponding to a *single* visual class only. The study was conducted in a test facility owned by the public transport company because state regulations do not allow testing of autonomous vehicles or new signal modalities on public roads. The test facility is used to train and test new drivers for public transportation vehicles such as buses. Due to the limited availability of both the test facility and the APS (which was brought to the test location thus simultaneously reducing passenger mobility in Sion (Switzerland) as only one APS was operating during the time of the study), there was a constraint in our study-design choices. *Firstly*, we conducted the study with groups rather than individuals, in order to gather more pedestrian perceptions in the limited time we had. However, we did examine individual perceptions across different classes of signals in a comparative crowd-sourced survey study, which is presented in Section 9. *Secondly*, we investigated the influence of different APS intentions on pedestrians' perceptions corresponding to *three* classes of (relatively abstract) visual signals only – i.e. symbolic, metaphorical, and anthropomorphic. We decided to exclude the class of textual *instructions* in this study because participants had previously discouraged the use of text in the participatory forum (see Section 5.2) – primarily due to the perceived higher cognitive load induced by text (see Section 5.2.2), and their limited interpretability for children [14].

Participants were recruited through advertisements in local forums. Depending upon their availability, participants directly signed-up for the specific session (4 participants each in the 1st and 3rd session, and 6 in the



(a) Participants along with an interviewer interacting with the shuttle at the crosswalk during the qualitative study. The shuttle is stationary in this picture and signaling pedestrians to cross using anthropomorphic visual signals.

(b) The planned trajectory of the shuttle (marked with red arrows), and the path followed by participants during supervised walk-through interviews in blue color.

Fig. 4. The Qualitative Study was conducted at the test facility. The participants discussed their perceptions about the shuttle's communicated intentions during supervised walk-through interviews.

2nd session). In each session, the participants interacted with different intentions belonging to a single class of visual signals (Session 1: *Metaphorical*, Session 2: *Symbolic*, and Session 3: *Anthropomorphic*). Upon their arrival at the test facility, two researchers welcomed the participants and introduced them (in groups) to the context and purpose of our study, including a brief recapitulation of our findings from the participatory forum. The participants were, however, not informed about the class of visual signal they were about to experience.

8.1 Procedure

The study was conducted in a Quasi Naturalistic manner [8, 48], where groups interacted with *one* specific class of visual signals during semi-structured supervised walk-through interviews. A predefined script allowed participants to experience all the APS intentions while walking with an interviewer in the test facility track. An autonomous shuttle, mounted with the intent communication interface, was running along a circuit as shown in Figure 4b. A researcher, concealed within the vehicle, controlled the presentation of different APS intentions in a 'Wizard-of-Oz' manner based on an agreed protocol. Groups interacted with the visual signals (representing different APS intentions) at four points of intersection (see Figure 4b): *1*) a bus stop, *2*) a crosswalk (see Figure 4a), *3*) a sidewalk, and *4*) a pedestrian zone without a crosswalk. Participants, simultaneously, discussed amongst themselves and answered questions posed by the interviewer at these intersection points, before moving onto the next one, along a marked path as shown in blue in Figure 4b. Each session lasted for approximately 45 minutes, during which the participants discussed their experience of watching the visual signals for the first time, their interpretations of the communicated intent, and the perceived levels of confidence and urgency in their interactions with the shuttle.

The groups first experienced the intent communication interface affixed onto the APS (with a concealed researcher) at the bus stop, and showing the signal for Stopped NOW *&* will START soon (starting). The interviewer asked participants to interpret the displayed APS intention along with their reasoning behind the interpretation in a think-aloud fashion. In addition, the groups were asked to discuss their subjective experience of the particular signal, such as their perceived confidence in their interpretations, perceived urgency, attention, and insecurity while observing the signal. After a short discussion, and in case of any misinterpretations, the interviewer revealed the intended meaning, and collected participants' feedback regarding difficulties encountered and potential causes for confusions. Next, the participants followed the interviewer at the crosswalk, where they came across the decelerating shuttle (at a distance) and displaying the corresponding signal (Running NOW *&* will STOP soon). The shuttle halted at the crosswalk, signalling groups to cross the street by changing the signal to Stopped NOW *&* will STAY Stopped. After crossing the street, the groups continued their discussion with the interviewer about the aforementioned subjective perceptions. The participants, then proceeded to the sidewalk, where they familiarized themselves with the signal corresponding to Running NOW *&* will STAY Running, followed by the discussions concerning the experienced intention. Finally, the participants walked slowly in the pedestrian-priority zone, where the shuttle passed by them twice, as it visualized the intentions for Running NOW *&* will STOP soon and Running NOW *&* will STAY Running, and again continued their discussions about the generic perceptions regarding the visual signals.

Finally, the participants were thanked for their participation and compensated with 20$. The interviews were audio-recorded, and the participants' interactions with the shuttle were video-recorded.

8.2 Results

During the course of their interactions with the shuttle's intent communication interface, the participants appreciated the explicit communication and effortless accessibility to the shuttle's intentions. In addition, several participants stated that the signals prompted them to confidently make decisions while navigating around APS. One participant concluded this by saying that "*in the end – we have more information as compared to a standard vehicle, which is good!*". Several participants attributed qualities of a traffic companion to the anthropomorphic (animated eyes) and metaphorical (pictographs with Lemmings) categories "*... who is from time-to-time advising me on what to do, whether I should wait or cross the street*". On the other hand, few participants found the visual signals authoritative, as one participant stated "*In pedestrian zones, [pedestrians] have the priority, and looking at the signal it appears that the shuttle is asking me to yield*". Another participant commented that "*I find the shuttle impatient ... it's telling me what to do, but it should be the other way round*".

Furthermore, the analysis of video-recordings revealed that participants in all groups maintained a sustained level of eye contact with the shuttle not only when they initiated the interaction, but most interestingly, as they walked in front of the APS to get to the other side of the road, as seen in Figure 4a. This persistent eye contact could indicate participants' sense of uncertainty that they have actually been *seen* by the shuttle and that the vehicle will act appropriately and yield for the duration of the crossing activity. Eye contact is the most often initiated form of non-verbal communication between pedestrians and drivers [43]. However sustained eye contact during the walk across is not the most common behaviour. Eye contact is made to initiate the interaction and to confirm that road users see each other. Once the pedestrian is confident that they have been seen, they cross looking straight ahead. The enhanced need for awareness related to transitions between the visual signals – signifying the change in intention of the APS – could also be attributed as another explanation for this sustained eye contact with the shuttle.

The use of traffic-light colors to render visual signals was perceived as perplexing and problematic for most of the participants. The limited discernability between the different colors from a distance, especially for color-blind pedestrians, was highlighted as one of the reasons for confusion. "*It takes effort to spot the color from this distance*" said a participant, who suggested superimposing color information over different sets of icons "*why can't you use a big X in red color?*". Furthermore, contrary to traditional traffic signals which are fixed, the visual signals on the shuttle were moving, which interestingly and unexpectedly raised doubts amongst participants about the communicated intent, especially for the metaphorical and symbolic (randomized dot pattern) signals. One participant elaborated her concern as "*The shuttle is stopped and the signal is green, I don't understand if this is a sign for us to move, or if the shuttle wants to move*".

The visual signals were perceived differently at the four intersection points. For instance, participants often misconstrued the shuttle's intentions at the crosswalk, while observing a decelerating shuttle from a distance. The shuttle's movement, although at lower speed, combined with the psychological need for urgent decision making was perceived as stressful and induced extraneous cognitive load at the crosswalk. One participant expressed agitation adding that "*... reading the intent of a heavy moving object and to say with certainty what [the shuttle] will do next, makes you anxious*". In the pedestrian-priority zone, some participants found the shuttle authoritative, due to its demand from pedestrians to yield while encountering the signal for Running NOW *&* will STAY Running. At the bus stop and the sidewalk, however, most (10 out of 14) of the participants correctly identified the displayed intention (starting and running respectively), and expressed high confidence in their interpretations of the shuttle's intentions. This high degree of confidence can be attributed to the nature of expected pedestrian behavior, which demands pedestrians' awareness of the stationary or the running vehicle, but does not involve an urgent need to decide the next course of action.

Regarding the readability of signals and the visibility of the communicated intention represented over the interface, participants encountered problems on the second day of the study due to the brightness of the sunlight. However, the participants did not face any issue on the first day when the weather condition was overcast and rainy. This suggests the use of brighter LEDs and higher resolution displays.

Next, we discuss findings specific to the three classes of visual signals, which were evaluated during the study.

8.2.1 Anthropomorphic Animation (Eyes). Participants reported easily understanding the shuttle's intentions and its level of awareness based upon its eye movements. Moreover, animated eyes were considered as being watchful, being aware of the pedestrians near-by. "*This [signal] is good, the shuttle seems attentive and notices us*". However, a few participants expressed doubt if unlike human drivers, the shuttle was capable of observing pedestrians on both sides of the street. When asked by the interviewer to elaborate, a participant illustrated her observation as "*It's not a problem at all ... I mean ... the signal itself makes me curious if the shuttle can see people on both sides simultaneously*". Anthropomorphic signals could give people a false impression that they are actually being *seen* by the AI within the shuttle when in fact they are not.

8.2.2 Metaphorical Pictographs (Lemmings). Similar to the anthropomorphic signals, pictographs were also easily understood, especially as the characters explicitly consolidated gestures and movement to indicate the future steps pedestrians could follow. However, three (out of 4) participants reported a sense of unease regarding the use of colors. The red colored Lemmings with their hands outstretched (see Table 1) evoked a sense of fear and urgency amongst three participants. One participant articulated this sense of fear as "*This red [Lemming] is slightly scary ... it feels that if I don't step aside and stay clear, the shuttle will run over me*".

8.2.3 Symbolic Representations (Randomized Dots). Both the interviews and the video-recordings revealed that participants exhibited confusions and misinterpretations while interacting with this class of visual signals. "*I had to glance at it three times, and even then I am not sure what this movement [of dots] suggests*" said one of the participants. The interviewers had to explicitly describe the shuttle's intention to the participants, and the rationale behind the particular movement of dots. Furthermore, due to the symmetric shape of the shuttle (front and back look alike) and the use of colors, a participant upon first glance confused the intent communication interface with the tail (brake) lights. Hesitations by the participants while crossing the street, and their low confidence in the interpretation of different intentions highlights that symbolic representations could impede pedestrians' trust in APS.

8.3 Summary of Findings

To conclude this section, we summarize the findings from the qualitative study.

- Participants demonstrated a positive disposition and appreciation for the explicit communication and effortless accessibility to the shuttle's intentions via the embedded interface. This overall positive evaluation reinforces the previous contributions to the notion of AV–Pedestrian Interaction (specifically [23, 28, 33]).
- Anthropomorphic signals were well perceived and understood by participants, who attributed the quality of '*watchfulness*' to this class of visual signal. On the other hand, symbolic signals were often misconstrued and evoked confusions.
- Participants maintained persistent eye contact with the shuttle – not only when they initiated an interaction, but also while traversing in front of the shuttle.
- Contrary to the design suggestion of Charisi et al. [14], the use of traffic light colors to communicate shuttle's intentions was perplexing for participants because they are accustomed to stationary traffic-light signals.
- Intersections affording high levels of interactivity between the APS and the pedestrians – crosswalks and pedestrian-priority zones, and which also elevate the pedestrians' need to negotiate the use of street space with moving APS, were reported as stressful and anxiety inducing by some participants.

The qualitative study evaluated the three classes of visual signals across the dimensions of pedestrians' interpretability and subjective perceptions. Still, we lack a comprehensive understanding of the relationship between pedestrians' subjective experiences and how they change across the different classes of visual signals. In addition, the smaller sample size of participants, and individuals' tendency to conform to their peers in group discussions (conformity bias) limits our ability to reach a conclusive argument. Therefore, we conducted a comparative crowdsourced study with individuals, as presented in the next section.

9 PHASE V. COMPARATIVE CROWDSOURCED SURVEYS

Following the individual assessment of visual signals in the qualitative study, we conducted a comprehensive crowdsourced survey to compare and examine the differences across the different classes of visual signals in effectively communicating the APS intentions. Unlike the qualitative study, where each group interacted with different intentions belonging to a *single* class of signals, in the survey study, each participant interacted with only a *single* APS intention and its different manifestations from the four classes of signals. We included the class of textual *instructions* (see Table 1) in the surveys, as a baseline condition, for the sake of completion and to establish a comparative standing of different classes of visual signals in terms of pedestrians' interpretability and subjective perceptions.

9.1 Procedure and Data Collection

We designed 16 different surveys for 4 APS intentions illustrated in Table 1 (i.e. 4 surveys for each APS intention). The aim of each survey was to compare the different classes of visual signals (instructional *vs.* symbolic *vs.* metaphorical *vs.* anthropomorphic) corresponding to a single APS intention. Within the group of 4 surveys related to a specific intent, we counterbalanced the presentation order of the signal type, and retained the nature of questions asked from the participants. The rationale behind designing 16 different surveys was to create smaller sub-tasks that can be easily disseminated over crowdsourcing platforms. We used SurveyMonkey[8] to design the surveys, and used Prolific[9] as the crowdsourcing platform. Each survey took approximately 7 minutes to answer, and a registered participant received only one survey. Finally, the survey was conducted in Switzerland.

Each survey initially presented an animated GIF of the autonomous shuttle displaying a visual signal for one of the intentions. The animated GIF (images) showed the front face of a stationary autonomous shuttle with the (animated) intent communication interface attached under the windshield, and resembling the arrangement from

[8] https://www.surveymonkey.com/
[9] https://prolific.ac/

the qualitative study as shown in Figure 3 and 4a. We did not use the traffic-signal colors in rendering the signals because of the confusions evoked by their use during the qualitative study. All the signals were presented in a neutral mustard yellow color.

The survey started with a summary of the study's purpose and the tasks required from the participant. Next, we collected basic demographic data from the participants such as their gender, age group, and familiarity with APS. Following this step, the participants were asked to interpret the intention communicated by the presented visual signal, displayed as an animated GIF of the intent communication interface mounted over the autonomous shuttle. Upon answering, the survey revealed the correct intention communicated by the previous animation despite the (correct or wrong) interpretation provided by the participant. After this step, the participant was shown two *side-by-side* animated GIFs related to the previously revealed (*first*) intention, and to facilitate pairwise comparison a new class of visual signal (*second*) was introduced alongside the previously shown animation. The participants, then, registered their preferences and perceived ease in interpreting the two different signals in a pairwise manner. In addition, the participants also recorded their perceived confidence, urgency, insecurity, and attention while encountering the presented visual signals on a 5-point Likert Scale. The survey continued by introducing a new class of visual signal (*third*) by presenting it next to the previously presented (*second*) animation, and asking them aforementioned questions about their perceptions and ease of interpretation. Finally, the participants registered their preferences by comparing the *third* and the *fourth* class of visual signal. The rationale behind revealing the correct interpretation of the presented signal *initially* was to avoid propagation of misunderstandings in the next step – i.e. pairwise comparisons between different classes of signals, and to gather participants' subjective assessments concerning the effectiveness of communicating a *known* intention by different representations.

350 participants (198 females, 148 males, and 4 unspecified) completed the surveys, and each of the 16 different questionnaires was completed by at least 20 participants. Six participants stated some form of color blindness. Moreover, in terms of familiarity with APS, 282 (80.57%) participants stated no familiarity, 39 (11.14%) reported seeing an APS in their proximity, and 29 (8.28%) participants mentioned riding in one.

9.2 Analysis and Results

9.2.1 Participants' Interpretation of the Communicated Intent. At the beginning of each survey, the participants were initially asked to interpret the APS intent being communicated by the particular visual signal. Upon examining these responses corresponding to the different APS intentions, we observed that participants largely misconstrued the intent communicated by these visual signals as shown in Table 2. Furthermore, the intention corresponding to the *transitionary* state of Running NOW and Stopping SOON (slowing down) was misunderstood by the most number of participants (86.91%).

One possible explanation for such low proportion of correct interpretations could be that 80.57% of survey participants reported no familiarity with the APS and never encountered the autonomous shuttle. However, the Chi-Square test of independence revealed no significant relationship between visual signals' interpretability and participants' familiarity with autonomous shuttles ($\chi^2(2)=0.07$, $p>.05$). Since the participants were encountering the signals for the first time and we did not compensate for learning effects, this might explain the low interpretability of presented intentions and is a limitation with our study. Another rational explanation behind this observed phenomenon (low rates of interpretability) can be the inherent similarity between some of the response choices (corresponding to the different APS intentions presented in multiple-choice manner) encountered by the participants. For example, the APS intentions of Running NOW and will STAY Running and Running NOW and will STOP Soon are similar in the sense that both intentions correspond to a moving shuttle, despite the latter signifying a decelerating shuttle. This similarity in choices might have confused participants, and consequently led to lower interpretation rates. Participants' erroneous judgments while encountering similar

Table 2. The table illustrates the correct interpretations of the different APS intentions in the crowdsourced survey.

APS Intentions	Correct Interpretations	Correct Interpretations across Signal Types			
		Anthropomorphic	Instructional	Metaphorical	Symbolic
Running NOW and will STAY Running	38.55%	45.00%	28.57%	19.05%	61.90%
Running NOW and will STOP soon	13.09%	30.43%	4.76%	0.00%	15.79%
Stopped NOW and will STAY Stopped	23.17%	10.00%	57.14%	9.52%	15.00%
Stopped NOW and will START soon	31.68%	38.09%	29.41%	27.27%	33.33%
	26.93%	30.95%	29.89%	14.28%	32.14%

choices have been extensively studied in the domain of Psychology (for example, [4, 39]), and specifically within the context of multiple-choice questionnaires (such as ours). More recent research works in the domain of Neuroscience [20] and Information Visualization [24] have also examined the misjudgments exhibited by participants while faced with similar choices (or choices with subtle differences). In order to mitigate these low interpretation rates, visualizations for the transitionary APS states (slowing/starting) could be complemented with additional information (shown alongside the visualized information) to make them more salient, for example, by visualizing deceleration as a decreasing animated bar for the APS intent of *slowing*, and a timer indicating when the APS will start for the intent of *starting*.

We found only two instances where the majority of the participants correctly interpreted the communicated intent, upon separate examination of the different classes of visual signals: *1*) Textual Instructions were correctly interpreted by 57.14% of the participants in surveys designed to compare the APS intent of Stopped NOW and will STAY Stopped (stationary); and *2*) Symbolic class of visual signals were correctly interpreted by 61.90% of the participants who completed the surveys for the intention of Running NOW and will STAY Running (running). One possible explanation for these relatively high proportions of correctly interpreted responses could be the confluence of factors including the *invariable* state of the APS (the vehicle either stays stationary or continues running) and the subsequently low levels of attention required on the part of pedestrians to seamlessly navigate around APS. This low level of perceived attention could in turn reduce the extraneous cognitive load amongst the pedestrians and might reduce the uncertainties regarding the intent of the APS. We also found statistically significant differences in the perceived levels of attention corresponding to these invariable APS states as compared to the transitionary states (Kruskal-Wallis: χ^2=10.40, df=1, p=.001, ε^2=.03). In addition, participants also reported lower levels of perceived stress corresponding to these invariable states, and this difference was found to be marginally significant (Kruskal-Wallis: χ^2=3.19, df=1, p=.07, ε^2=.01). We also observed similar results in the qualitative study, where participants reported high confidence and low sense of stress at the bus stop and the sidewalk while encountering the shuttle in these aforementioned invariable states (stationary and running).

In the case of transitionary states (Running NOW and will STOP soon and Stopped NOW and will START soon), anthropomorphic signals were correctly interpreted by a higher number of participants as compared to other signal types (see Table 2). This relatively higher proportion of correct interpretations for anthropomorphic signals could be attributed to their perceived watchfulness (as revealed in the qualitative study), and participants' tendency to seek for human-like signals (such as gaze) from drivers [7].

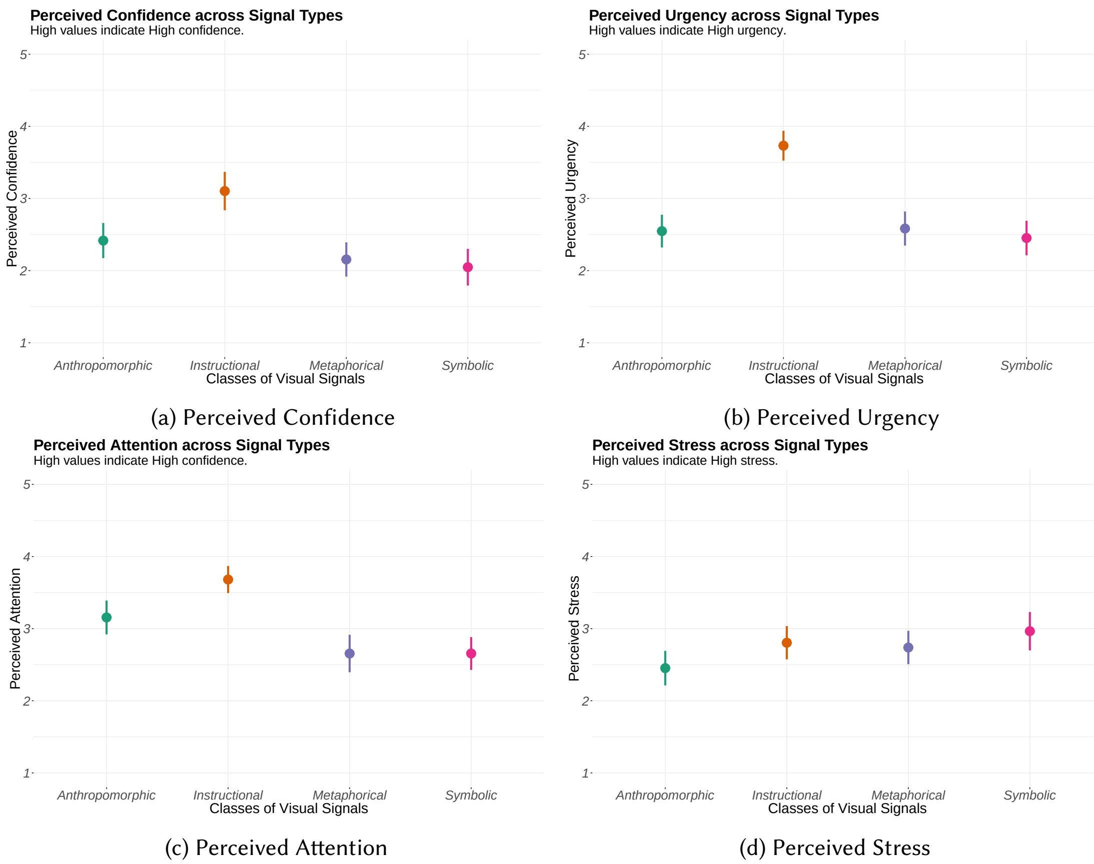


Fig. 5. Mean Plots showing the mean and confidence interval values for the user perceptions corresponding to the different classes of visual signals. These perceptions were recorded in the crowdsourced comparative surveys.

The Chi-Square test of independence revealed a statistically significant relationship between the classes of visual signals and participants' ability to correctly interpret the communicated APS intentions ($\chi^2(3)$=9.11, p=.027). Furthermore, although only 26.93% of the participants correctly interpreted the communicated intention from the visual signals, we did not find significant differences in percentages of correct interpretations between the different categories of visual signals (Instructional: 29.89%, Anthropomorphic: 30.95%, Metaphorical: 14.28%, and Symbolic: 32.14%). This finding also demonstrates that the class of metaphorical pictographs was reported as the least understood signal. In addition, no significant relationship of visual signals' interpretability was observed with participants' gender ($\chi^2(2)$=1.07, p>.05).

9.2.2 Preferences and Perceptions. In this section, we will present the results from the *second* part of the questionnaires, which focused on pairwise comparison of participants' perceptions across the different visual signal types. We found statistically significant differences across the different classes of visual signals (see Figure 5) in terms of participants' *1*) perceived level of attention while encountering the visual signal (Kruskal-Wallis: χ^2=52.95, df=3, p<.001, ε^2=.15), *2*) perceived confidence in their interpretation of the communicated intent (Kruskal-Wallis:

χ^2=37.28, df=3, p<.001, ε^2=.11), *3*) perceived sense of caution experienced while regarding the visual signal and the communicated intent (Kruskal-Wallis: χ^2=71.01, df=3, p<.001, ε^2=.20), and *4*) perceived levels of stress induced while gazing at the visual signal (Kruskal-Wallis: χ^2=8.73, df=3, p=.03, ε^2=.02).

Textual instructions – the most objective and straightforward means of communicating APS intentions, were reported as the preferred visual signal by the participants. Furthermore, the participants ascribed higher confidence, attention, and sense of urgency while engaging with the instructional signals. Anthropomorphic signals (animated eyes), on the other hand, were the second preferred signal with regards to the perceived levels of attention and confidence in participants' interpretation of the communicated intents. In addition, anthropomorphic signals were assigned a lower rating for participants' perceived sense of urgency, and received the least average rating for evoking stress. Both the metaphorical (Lemmings - pictographs) and symbolic (randomized dot pattern) visual signals were the least preferred means of communicating APS intentions, and these two categories did not differ significantly across the variables registering participants' perceptions.

It is worth noting that the participants reported significantly low levels of perceived urgency while interacting with the abstract forms of visual signals (anthropomorphic, metaphorical, and symbolic) as compared to the instructional signals (p<.001, Pairwise Wilcoxon Rank Sum Test). However, we did not observe any significant difference between these three categories of abstract visual signals. Finally, the symbolic signals were found to incite higher levels of stress amongst the participants, closely followed by the instructional and metaphorical classes of signals. The anthropomorphic signals were reported as the least stressful signal by the participants.

Anthropomorphic signals were reported as the second preferred alternative for communicating APS intentions in the survey study. Still, their improved interpretability in relation to *transitionary* APS states (see Section 9.2.1) and the significantly lower levels of evoked stress by them, makes them a rational choice for communicating shuttle's intentions in safety-critical traffic scenarios. This finding is contrary to the observations of Mahadevan et al. [33], who reported that visualizing human-like features through animated eyes and faces was not well perceived by their participants.

9.3 Summary of Results

To conclude this section, we summarize the key findings from the crowdsourced survey study.

- Relatively higher proportion of participants misinterpreted the APS intention communicated by different classes of visual signals.
- The *transitionary* vehicular states – when the autonomous shuttle is slowing down or starting – were particularly misunderstood by most participants as compared to the *invariable* vehicular states (stationary or running APS).
- The *invariable* APS states induced a higher sense of confidence and lower levels of stress amongst the participants.
- *Instructional* (textual) signals were the preferred and well perceived class of visual signals for communicating APS intentions, and were rated high in terms of perceived attention, confidence in pedestrians' interpretation, and perceived urgency.
- *Anthropomorphic* signals were the second preferred class of visual signals in terms of pedestrians' perceived attention and confidence. In addition, anthropomorphic signals evoked the least stress amongst the participants.
- The *Symbolic* class of visual signals – embodying the highest level of abstraction – was perceived as the most stressful by the participants.
- Anthropomorphic, symbolic, and metaphorical signals (the abstract forms of communicating APS intentions) evoked the least sense of urgency amongst the participants. However, the instructional signals were perceived as the most urgent.

– The Metaphorical class of signals was the least preferred category in terms of pedestrians' interpretability and perceptions.

10 PHASE VI. IMPLICATIONS AND FUTURE STEPS

Following both the qualitative and survey study, we presented our findings to the representatives of the public transport service provider, and discussed next logical steps. Upon reviewing the findings, the representatives appreciated our efforts in investigating the effectiveness of communicating driverless shuttle's intentions to the pedestrians by comparing different classes of visual signals. In addition, the representatives also acknowledged evidence of restrictions that impeded such research endeavor due to the lack of cooperation from the vehicle manufacturer and regulating authorities. Consequently, we collectively devised next strategic moves, which we describe hereafter, to foster the development of trust amongst road users regarding autonomous shuttles, and to support the amalgamation of autonomous public transportation within the ecosystem of urban transportation.

Regarding the choice of appropriate class of visual signal to communicate shuttle's intentions, we chose the *anthropomorphic* animations over textual *instructions*, even though the latter was rated as the most preferred alternative in the surveys. The driverless shuttle, in its current state, already uses a display (affixed at the top of its windshield as seen in Figure 3) to communicate the direction and the autonomous/manual mode of operation to the pedestrians using text. The second use of text to communicate the shuttle's intentions was deemed as confusing and error-inducing for the pedestrians. Additionally, the shuttle operates in a multilingual country and using text (in translated form) might lead to information overload thus rendering the signals ineffective for children and tourists. Furthermore, anthropomorphic signals, although, perceived as attention seeking, watchful, and inducing a high sense of confidence, were also perceived as least stressful, which makes them an ideal choice for the safety-critical context of urban transportation. The representatives also stated their resolution to share this design specification with the vehicle manufacturer, and to demand the seamless embodiment of anthropomorphic animation in the future.

Since our study only involved adult pedestrians, the representatives considered it a priority to engage children in the design process (as examined by Charisi et al. [14]), and to educate them about the functionality of APS and the appropriate ways of responding while encountering one. In order to achieve this, we decided to collaborate with the regional police department which currently organizes 'Road Traffic Awareness Days' in schools to disseminate awareness amongst children about the interpretation of traffic signals, and safe ways of navigating on city roads. The representatives, additionally, suggested bringing the driverless shuttle with its intent communication interface to the school premises, or to bring children on a field trip to the test facility. This way the representatives of the police department can demonstrate the operational behavior of APS to the children, acquaint them with the different signals that communicate its intentions, and evaluate the effectiveness of signals with children followed by assimilating their suggestions in designing effective universal signals.

Regardless of their temporal and functional familiarity with the APS (qualitative study participants were familiar with the autonomous shuttle, however the majority of survey participants were not), participants encountered challenges in successfully interpreting the shuttle's intentions. Therefore, consolidating these difficulties faced by the participants, especially corresponding to the *transitionary* states of the shuttle, and despite participants' familiarity with the APS, we formulated a *three* step agenda to foster road users' awareness regarding the readability and interpretability of APS intentions:

(1) In the *short* term, the public transportation service provider will disseminate information to increase pedestrian awareness about the shuttle's intentions and the signals used to communicate them through informative posters, advertisements, or animations exhibited at the bus stops and within the shuttle.
(2) We decided to implement a series of awareness programs in the *medium* term, especially in collaboration with police and road transportation officials to educate pedestrians (including children) and adults who are

in training for gaining a driving permit, and to enhance the general awareness regarding the operational behavior of APS.

(3) Finally, in the *long* term, we (the HCI researchers) proposed to form a consortium with regulators, manufacturers, researchers and service providers to facilitate the rapid infusion of research findings and design implications, and their standardized implementation in empirically valid contextualized urban settings.

11 DISCUSSION

In this section, we discuss the presented findings from both the qualitative and survey study, and explain their implications for our project context and AV-Pedestrian Interaction research in general.

11.1 Towards Effective and Expressive Visual Signals

Communicating autonomous passenger shuttle's (APS) intentions in a direct and straightforward manner, through textual instructions was observed to be an effective and preferred class of visual signals in the survey study. Besides effectively capturing participants' attention and evoking an enhanced sense of confidence regarding their interpretation of shuttle's intentions, this class of visual signals also induced a feeling of urgency amongst participants. Based on these results, the attributes and observed behaviors of instructional signals ostensibly make them a clear choice for designing APS intent communication interfaces. However, their generalizability to urban contexts where people might speak different languages, and their suitability for a diverse population of pedestrians including children is questionable. Furthermore, their use was discouraged in the participatory forum with the local residents, who in turn preferred allegorical and illustrative means of communicating shuttle's intentions while reducing (if not eliminating) the need for conscious reflection on the part of pedestrians.

Anthropomorphic animation of eyes, manifested as an optimal middle ground, and was collectively chosen as the candidate class to communicate the shuttle's intentions by the local residents and the service provider. Anthropomorphic signals were appreciated and liked by the participants for their ascribed quality of being "*watchful*" – aware of pedestrians. Attributing this quality of watchfulness to APS was specific only to the class of anthropomorphic signals, which seemingly and notably, offloads onto APS the role of a human driver of staying vigilant, and could explain why they were perceived as calm, and invoking the lowest levels of perceived stress amongst the survey participants. These findings complement and extend the work of Chang et al. [13] who reported observing faster decision making process by the pedestrians when interacting with animated eyes displayed upon an AV. However, in terms of pedestrians' subjective perceptions, our participants (in both the qualitative and survey study) appreciated the anthropomorphic signals, which was not the experience reported by Mahadevan et al. [33].

Other abstract classes of visual signals – metaphorical and symbolic, were not well perceived because of their poor discernability from a distance and the ensuing confusions amongst pedestrians while interpreting them. Furthermore, the use of traffic-light colors to render visual signals should be avoided because road users are accustomed to stationary traffic-light signals. The superposition of vehicle's movement and the use of traffic-light colors was reported as an unusual combination (as opposed to the design suggestions presented by Charisi et al. [14]) resulting in uncertainties while trying to understand the communicated intention.

It is essential to reemphasize that this research has focused solely on people's perception of signals that are displayed over the APS, rather than those that can be distributed in the urban infrastructure or disseminated through personal hand-held devices as illustrated by Mahadevan et al. [33]. The latter means of delivering intent information was regarded as disruptive and undesirable by local residents. Moreover, strict state regulations related to the testing and use of non-standard signals embedded within an urban context limited our ability to examine the complementarity of signals which are accessible both via urban infrastructure and APS. Still, we believe this complementarity might mitigate the need for sustained eye contact resulting from pedestrians' uncertainty about the change in shuttle's operational state, and which the pedestrians demonstrated in our study.

In this article, we have explicitly focused on signals that communicate the autonomous shuttle's intentions and not its awareness of pedestrians. This awareness about "*what and how far does the shuttle see?*" was also expressed by local residents in the participatory forum (Section 5). Despite our numerous efforts to establish collaboration with the vehicle manufacturer, we were denied requests to access the shuttle's LIDAR sensor stream, which in-turn hindered our plans to design visualizations that represent this awareness. A limitation in our research, this scenario is a consequence of the inherent 'stiffness' in the context of urban mobility (as discussed in Section 11.4). Furthermore, the communication of AV's awareness of road users also raises relevant open questions such as *1*) How to design and represent the awareness information?, *2*) How should we design the interplay between the communication of AV's intentions and its awareness of pedestrians?, and *3*) How does this aforementioned interplay affect the road users' perceptions, experiences, and judgements? In our future work, we aim to investigate these aspects related to the communication of AV's awareness of road users.

Finally, the limited availability of the test facility and of the driverless shuttle restricted us in performing qualitative evaluations of all the four classes of visual signals (we only evaluated three abstract categories), and to gather participants' subjective perceptions while comparing different kinds of visual signals. Although, we complemented the qualitative evaluations with comparative crowdsourced surveys which revealed the relationship between pedestrians' perceptions and different classes of visual signals (including textual instructions). Still, our findings related to textual instructions are specific to our multi-lingual context, and do not aspire to be generalizable in other cultures and contexts.

11.2 "One Signal to Rule Them All!?"

Pedestrians' levels of confusion while interpreting the meaning of communicated visual signals differed across different APS intentions. *Transitionary* vehicular states – when an APS is slowing down or about to start – were particularly misinterpreted by the participants as compared to the other *invariable* states. Moreover, these high levels of misinterpretations could be attributed to the extraneous cognitive load resulting from pedestrians' enhanced sense of stress while judging the vehicle's changing state. This extraneous cognitive load might also explain the sustained eye contact maintained by pedestrians while reading the signal and steering themselves in the proximity of autonomous shuttle. Pedestrians' confusions and misinterpretations could also be attributed to the novelty of these interfaces and could diminish over time as pedestrians become accustomed to these types of new visual signals. In our future work, we intend to examine the pedestrians' evolving perceptions as a consequence of extended exposure to the intent communication interface (and visual signals). This is a necessary step towards the standardization of signals for communicating AVs' intentions and awareness of pedestrians, which leverages the sensory and cognitive qualities in supporting pedestrians' negotiations and not only the subjective perceptions.

Unlike the qualitative study where participants experienced the intent communication interface affixed onto a moving shuttle, in the crowdsourced surveys, this movement information was missing and the participants were asked to interpret the communicated APS intention solely based on animated GIFs of the driverless shuttle. Furthermore, the question demanding participants' interpretation presented them with multiple choices with subtle differences between intentions (running *vs.* slowing and stopped *vs.* starting). These factors might have made the interpretation process relatively harder, and might have resulted into less accurate judgments regarding different APS intentions as observed in Section 9.2.1. These low interpretation rates suggest that there is still further work to be done to create *explainable AI interfaces* within the AV domain that are easily understandable. An emerging new field of research, *Human-Centered AI* (HAI), aims to investigate and address these and similar challenges for explaining the intentions and actions of AI systems [55]. This is especially true when designing interfaces that communicate probabilistic behaviors where multiple outcomes are possible in any given interaction [2]. For instance, when AVs encounter varied road users on public roads, factors such as weather, time of day, and road congestion will influence how it will respond. Long et al. [30] suggest engaging in co-design activities with the general public (similar to our research efforts in this article, also see Section 11.5) to design interfaces that are immediately understandable and afford improved user experience within the greater social milieu. Moreover, through this research work and our collaboration with different stakeholders, and also through the emergent real-world insights about pedestrians' interactions with APS and the varied intent signals, we are simultaneously reinforcing the significance of problems addressed by HAI.

For this project, the intent communication interface was situated on the front surface of the driverless shuttle, which affords interactions with pedestrians who encounter the shuttle face-to-face. However, road users (for example, cyclists and drivers) often interact with public transport vehicles from the rear or the side, and utilize the information communicated by tail lights and turn signals to navigate in traffic situations, especially in vicinity of bus lanes. However, the presence of autonomous passenger shuttles does not diminish the road users' need for intentions, it augments the scope of the design space by adding a few crucial attributes – such as rapid perceptibility of AVs' intention, leveraging peripheral vision, reduced extraneous cognitive load, and seamless guiding behavior via the intent communication interfaces.

The driverless shuttle, which resembles a mini bus suitable for 11–15 passengers and is larger than private cars, was the subject of our study. Our findings have demonstrated the generalizability and scalability of intent communication interfaces on vehicles of larger sizes as compared to the ones that were examined in previous works on AV–Pedestrian Interaction. Consequently, our contributions have extended and reinforced the utility of communicating AVs' intentions and their influence on pedestrians' perceptions and experiences while interacting with AVs (as previously examined in [34, 41, 45, 58]).

11.3 Multiple Phase *in-the-wild* Research Approach

The uniqueness of our research context (a fully-functioning autonomous passenger shuttle (APS) on public roads and local residents with prior experiences of interacting with the shuttle) and our collaboration with the public transport service provider influenced our particular choice of the employed research approach. This research approach manifested as a design-research effort and a complete research cycle spanning across multiple phases – from co-design, to prototyping, to two evaluations (naturalistic evaluation in a test facility, and crowdsourced surveys with a wider audience), to the development of design and policy implications. Our contributions to the notion of AV–Pedestrian Interaction and the domain of Ubiquitous Computing are two-fold: *a*) We studied pedestrians' interactions with an Autonomous Passenger Shuttle (APS) – which are rapidly becoming an urban public transit alternative and are already operating in several cities worldwide, and examined the different visual signals in order to effectively communicate the intentions of APS to pedestrians; and *b*) Through *in-the-wild* studies which engaged different stakeholders, we demonstrated a viable methodology for extending the scope and impact of human factor research on AVs, and their seamless integration in the messy urban landscape.

Rogers [48] argues that "*carrying out in-situ user studies, sampling experiences, and probing people [in their daily lives]*" could lead to the development of "*full inter-dependencies between design, technology, and behavior*", which is not possible in traditional lab settings or simulated/virtual environments – which has (so far) been the approach of examining the intricacies of AV–Pedestrian Interaction. In addition, the contributions emerging from 'in-the-wild' research promise empirical-validity, and a broader impact which extends beyond a specific problem or a single domain. On the other hand, the use of simulated environments (for example, the Virtual Reality based immersive pedestrian simulator [32]) could mitigate many of the issues which currently impede research on AV–Pedestrian Interaction (such as the availability of AVs, regulatory restrictions regarding public testing, etc.). Furthermore, these approaches facilitate the process of rapid prototyping and evaluation while affording a better control over diverse study variables. An example of the generated insight which emerged from our research, was our exposure to the 'stiffness' in the domain of urban mobility (discussed in detail in the next section). Such insights cannot be uncovered solely with alternative (simulation) approaches, and hence they should be complemented with in-the-wild approaches in order to permeate the extensive, complex, and multi-stakeholder context of urban public transportation.

Moreover, since the local residents are the ultimate beneficiary of this research endeavour (improved interactive experiences with the APS while also affording a safe public transportation infrastructure), engaging them in a participatory effort enabled us to leverage their intrinsic motivation to participate and co-design the different visual signals. Additionally, collaboration with the public transport service provider, in the same way, would result into new, innovative, and improved services which can be beneficial for their business as their services will be well perceived by the users. We believe that the aforementioned aspect of intrinsic motivation is an essential ingredient for conducting research on disruptive and safety-critical context of AVs, and which is not easy to emulate in lab settings.

Finally, engaging local residents and the representatives of the public transport company in different stages of the design-research process (from designing, to prototyping, to evaluating) provides a framework where users' initial design expectations can be challenged in the later stages. This not only provides a fertile ground for collectively reflecting why certain design aspects work or don't work and why, but also leads to iterative design improvements which are more likely to work in the chaotic and messy real-world settings [8]. For example, the residents initially suggested using traffic-light colors in the visualization of different intent signals, however, the evaluations in the road test facility (see Section 8.2) demonstrated that the use of colors led to readability problems and confusions amongst participants.

11.4 The Stiffness in Urban Mobility

Our collaboration with the public transport service provider exposed us to the inherent *stiffness* in the domain of road transportation and urban mobility. Comprised of different stakeholders including vehicle manufacturers, service providers, and regulators, the domain of urban mobility has not changed significantly in the last decades. Although, research in urban mobility and automobiles has made road transportation more efficient, safe, and user friendly, much of the available knowledge about mobility exists as normative regulations and laws. This leaves very little room for risk taking and experimentation (hence the 'stiffness'), especially relevant to the disruptive changes brought forward by the predicted proliferation of autonomous vehicles. In addition, the lack of available regulatory "instruments" to conduct empirically valid research with AVs, makes it significantly more difficult to apply research findings and design implications, which will eventually re-calibrate the normative (regulatory) knowledge.

This stiffness, on the one hand, influenced our many study choices, such as the use of signals affixed onto the APS and not the evaluation of signals distributed in the urban settings. On the other hand, it also uncovered a disconnect in human factor research in urban mobility and its wider applicability owing to the lack of consolidated efforts between manufacturers, service providers, lawmakers, and researchers (also illustrated by Eden [17]). In our context, the collaboration with the public transport service provider, provided a framework to collectively ground the pedestrians' difficulties while interacting with the driverless shuttle and their expectations, and to find rational solutions in a participatory manner. Such a framework, finally, convinced the service provider of the merit in our collaborative efforts, and they agreed to engage and involve law makers and manufacturers in our collective effort to mitigate the effect of the aforementioned stiffness on the human factor research in AV–Pedestrian Interaction.

11.5 Bringing Participatory Approaches to Urban Mobility

Our engagement with different stakeholders, particularly local residents and the representatives from the public transport service, manifested as a participatory effort since the beginning of the project. Starting with *a*) a collective understanding of residents' experiences while interacting with the driverless shuttle, to *b*) the identification of the awareness gap with regards to shuttle's intentions and awareness of road users, *c*) a comparative evaluation of different classes of visual signals, and *d*) the transformation of findings into design and policy implications, we adopted a recurrent participatory method to ground the experiences and expectations of different stakeholders in an ecologically valid setting.

Through these comprehensive concerted efforts, that bring together not only the urban population and the mobility experts, but also designers, researchers, lawmakers, and vehicle manufacturers, is how we believe that AVs can successfully permeate the urban landscape. Furthermore, this cooperative approach to addressing design and trust issues relevant to AVs, is the rational methodology to establish standardized means of informing pedestrians about AV's intentions and their awareness of road users.

12 CONCLUDING REMARKS

While navigating through traffic, pedestrians' interpretation and assessment of vehicle's (both autonomous and traditional) intentions pursues a holistic approach consolidating sensory aspects (vision, sound, movement, etc.), mental models, and socio-technical experiences. Still, vision remains a significant contributor to their decision making process, and underpins the essential need for interfaces which foster meaningful cooperation between pedestrians and autonomous vehicles (AVs). In this article, our contributions to the emerging notion of AV-Pedestrian Interaction manifest in the comparison of effective means for *visually* communicating autonomous passenger shuttle's (APS) intentions to pedestrians, and design implications emanating from these comparisons. We studied differences across *four* classes of visual signals – instructional, anthropomorphic, metaphorical, and symbolic, which exemplify varying levels of abstraction in communicating different AV intentions. Anthropomorphic signals were chosen as the ideal candidate for communicating APS intentions because this class of signals was perceived as attention seeking and induced a feeling of confidence, calm, and watchfulness amongst pedestrians.

The presented research has examined the context of Autonomous Passenger Shuttles (APS) in real-world settings. These shuttles are increasingly being adopted in cities worldwide as a public transportation alternative. However, in their current state these APS do not communicate their intentions to the varied road users, creating a gap in pedestrians awareness about the vehicle's intentions, and consequently making it challenging for them to navigate in their proximity. Furthermore, the domain of urban mobility and road transportation (comprising of vehicle manufacturers, regulators, and service providers) limits the opportunities for ecologically-valid testing of Autonomous Vehicles (AVs), and consequently underlines the disconnect between human factor research on AVs, and its wider applicability. Through our contribution, we exemplify how our participatory methodology to engage the local community and public transport service providers in a participatory endeavor facilitated the development of design solutions which impact the immediate concerns of pedestrians while interacting with APS, and provided a grounding for the development of local trust and confidence in APS' capabilities. This participatory approach also demonstrated a persuasive and viable way forward for extending the scope and influence of human factor research in the inflexible domain of urban mobility.

ACKNOWLEDGMENTS

We would like to thank our colleagues from PostBus and Mobility Lab (Switzerland) including Anne-Clair Pliska, Lukas Krienbühl, Jürg Michel, and Flavien Claivaz who collectively contributed throughout the different phases of this work. The anonymous reviewers deserve special appreciation for their constructive suggestions and detailed feedbacks, which enabled us to significantly improve the quality of our work. Finally, our special thanks to the local residents who participated in our studies.

REFERENCES

[1] Hamed S. Alavi, Farzaneh Bahrami, Himanshu Verma, and Denis Lalanne. 2017. Is Driverless Car Another Weiserian Mistake?. In *Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems (DIS '17 Companion)*. ACM, New York, NY, USA, 249–253. https://doi.org/10.1145/3064857.3079155

[2] Saleema Amershi, Dan Weld, Mihaela Vorvoreanu, Adam Fourney, Besmira Nushi, Penny Collisson, Jina Suh, Shamsi Iqbal, Paul N. Bennett, Kori Inkpen, Jaime Teevan, Ruth Kikin-Gil, and Eric Horvitz. 2019. Guidelines for Human-AI Interaction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, Article 3, 13 pages. https://doi.org/10.1145/3290605.3300233

[3] James M Anderson, Kalra Nidhi, Karlyn D Stanley, Paul Sorensen, Constantine Samaras, and Oluwatobi A Oluwatola. 2014. *Autonomous vehicle technology: A guide for policymakers.* Rand Corporation.

[4] F Gregory Ashby and Nancy A Perrin. 1988. Toward a unified theory of similarity and recognition. *Psychological review* 95, 1 (1988), 124.

[5] Jimi Beckwith. 2018. Jaguar Land Rover gives driverless pods 'eyes' to signal road users. https://www.autocar.co.uk/car-news/new-cars/jaguar-land-rover-gives-driverless-pods-eyes-signal-road-users. [Online; accessed 3-September-2018].

[6] Brett Berk. 2015. How Nissan's Using Anthropology to Make Autonomous Cars Safe. http://www.thedrive.com/tech/999/how-nissans-using-anthropology-to-make-autonomous-cars-safe. [Online; accessed 3-September-2018].

[7] The League of American Bicyclists Bikeleague. 2014. Autonomous and Connected Vehicles: Implications for Bicyclists and Pedestrians. https://bikeleague.org/sites/default/files/Bike_Ped_Connected_Vehicles.pdf. [Online; accessed 26-April-2019].

[8] Laurens Boer and Jared Donovan. 2012. Provotypes for participatory innovation. In *Proceedings of the designing interactive systems conference.* ACM, 388–397.

[9] Patrick M Boesch, Francesco Ciari, and Kay W Axhausen. 2016. Autonomous vehicle fleet sizes required to serve different levels of demand. *Transportation Research Record: Journal of the Transportation Research Board* 2542 (2016), 111–119.

[10] Patrick M Bösch, Felix Becker, Henrik Becker, and Kay W Axhausen. 2018. Cost-based analysis of autonomous mobility services. *Transport Policy* 64 (2018), 76–91.

[11] Lawrence D Burns. 2013. Sustainable mobility: a vision of our transport future. *Nature* 497, 7448 (2013), 181.

[12] Stephen M. Casner, Edwin L. Hutchins, and Don Norman. 2016. The Challenges of Partially Automated Driving. *Commun. ACM* 59, 5 (April 2016), 70–77. https://doi.org/10.1145/2830565

[13] 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 (AutomotiveUI '17)*. 65–73.

[14] 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 (IDC '17)*. ACM, New York, NY, USA, 399–404. https://doi.org/10.1145/3078072.3084300

[15] Michael Clamann, Miles Aubert, and Mary L Cummings. 2017. *Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles.* Technical Report.

[16] 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 (AutomotiveUI '17)*. ACM, New York, NY, USA, 158–162. https://doi.org/10.1145/3131726.3131750

[17] Grace Eden. 2018. Transforming Cars into Computers: Interdisciplinary Opportunities for HCI. In *Proceedings of 32nd BCS HCI Conference, Belfast, UK, 2018.* British Human Computer Interaction (BHCI).

[18] Grace Eden, Benjamin Nanchen, Randolf Ramseyer, and Florian Evéquoz. 2017. On the road with an autonomous passenger shuttle: integration in public spaces. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems.* ACM, 1569–1576.

[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] Moran Furman and Xiao-Jing Wang. 2008. Similarity effect and optimal control of multiple-choice decision making. *Neuron* 60, 6 (2008), 1153–1168.

[21] Nikhil Gowda, Wendy Ju, and Kirstin Kohler. 2014. Dashboard Design for an Autonomous Car. In *Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.* ACM, 1–4.

[22] Nicolas Guéguen, Sébastien Meineri, and Chloé Eyssartier. 2015. A pedestrian's stare and drivers' stopping behavior: A field experiment at the pedestrian crossing. *Safety science* 75 (2015), 87–89.

[23] Azra Habibovic, Victor Malmsten Lundgren, Jonas Andersson, Maria KlingegÃěrd, Tobias LagstrÃűm, Anna Sirkka, Johan FagerlÃűnn, Claes Edgren, Rikard Fredriksson, Stas Krupenia, Dennis SaluÃďÃďr, and Pontus Larsson. 2018. Communicating Intent of Automated Vehicles to Pedestrians. *Frontiers in Psychology* 9 (2018), 1336. https://doi.org/10.3389/fpsyg.2018.01336

[24] Jeffrey Heer and Michael Bostock. 2010. Crowdsourcing graphical perception: using mechanical turk to assess visualization design. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 203–212.

[25] Kyeil Kim, Guy Rousseau, Joel Freedman, and Jonathan Nicholson. 2015. The travel impact of autonomous vehicles in metro atlanta through activity-based modeling. In *The 15th TRB National Transportation Planning Applications Conference*.

[26] Jeamin Koo, Jungsuk Kwac, Wendy Ju, Martin Steinert, Larry Leifer, and Clifford Nass. 2015. Why did my car just do that? Explaining semi-autonomous driving actions to improve driver understanding, trust, and performance. *International Journal on Interactive Design and Manufacturing (IJIDeM)* 9, 4 (2015), 269–275.

[27] Miltos Kyriakidis, Riender Happee, and Joost CF de Winter. 2015. Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transportation research part F: traffic psychology and behaviour* 32 (2015), 127–140.

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

[29] John D Lee and Katrina A See. 2004. Trust in automation: Designing for appropriate reliance. *Human factors* 46, 1 (2004), 50–80.

[30] Duri Long, Mikhail Jacob, and Brian Magerko. 2019. Designing Co-Creative AI for Public Spaces. In *Proceedings of the 2019 on Creativity and Cognition (C&C '19)*. ACM, New York, NY, USA, 271–284. https://doi.org/10.1145/3325480.3325504

[31] Victor Malmsten Lundgren, Azra Habibovic, Jonas Andersson, Tobias Lagström, Maria Nilsson, Anna Sirkka, Johan Fagerlönn, Rikard Fredriksson, Claes Edgren, Stas Krupenia, et al. 2017. Will There Be New Communication Needs When Introducing Automated Vehicles to the Urban Context? In *Advances in Human Aspects of Transportation*. Springer, 485–497.

[32] 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 (DIS '19)*. ACM, New York, NY, USA, 475–486. https://doi.org/10.1145/3322276.3322328

[33] 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 (CHI '18)*. ACM, New York, NY, USA, Article 429, 12 pages. https://doi.org/10.1145/3173574.3174003

[34] Milecia Matthews, Girish Chowdhary, and Emily Kieson. 2017. Intent Communication between Autonomous Vehicles and Pedestrians. *arXiv preprint arXiv:1708.07123* (2017).

[35] Alexander Meschtscherjakov, Alina Krischkowsky, Katja Neureiter, Alexander Mirnig, Axel Baumgartner, Verena Fuchsberger, and Manfred Tscheligi. 2016. Active corners: Collaborative in-car interaction design. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. ACM, 1136–1147.

[36] Jonas Meyer, Henrik Becker, Patrick M Bösch, and Kay W Axhausen. 2017. Autonomous vehicles: The next jump in accessibilities? *Research in Transportation Economics* 62 (2017), 80–91.

[37] Adam Millard-Ball. 2018. Pedestrians, Autonomous Vehicles, and Cities. *Journal of Planning Education and Research* 38, 1 (2018), 6–12.

[38] Sina Nordhoff, Joost de Winter, Ruth Madigan, Natasha Merat, Bart van Arem, and Riender Happee. 2018. User acceptance of automated shuttles in Berlin-Schöneberg: A questionnaire study. *Transportation Research Part F: Traffic Psychology and Behaviour* 58 (2018), 843–854.

[39] Robert M Nosofsky. 1986. Attention, similarity, and the identification–categorization relationship. *Journal of experimental psychology: General* 115, 1 (1986), 39.

[40] Enrica Papa and António Ferreira. 2018. Sustainable Accessibility and the Implementation of Automated Vehicles: Identifying Critical Decisions. *Urban Science* 2, 1 (2018), 5.

[41] Anantha Krishna Pillai. 2017. Virtual Reality based Study to Analyse Pedestrian attitude towards Autonomous Vehicles.

[42] Ioannis Politis, Stephen Brewster, and Frank Pollick. 2015. Language-based Multimodal Displays for the Handover of Control in Autonomous Cars. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '15)*. ACM, New York, NY, USA, 3–10. https://doi.org/10.1145/2799250.2799262

[43] Amir Rasouli, Iuliia Kotseruba, and John K Tsotsos. 2017. Agreeing to cross: How drivers and pedestrians communicate. In *Intelligent Vehicles Symposium (IV), 2017 IEEE*. IEEE, 264–269.

[44] Amir Rasouli, Iuliia Kotseruba, and John K Tsotsos. 2018. Understanding pedestrian behavior in complex traffic scenes. *IEEE Transactions on Intelligent Vehicles* 3, 1 (2018), 61–70.

[45] 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).

[46] Zeheng Ren, Xiaobei Jiang, and Wuhong Wang. 2016. Analysis of the Influence of Pedestrians' eye Contact on Drivers' Comfort Boundary During the Crossing Conflict. *Procedia engineering* 137 (2016), 399–406.

[47] Malte Risto, Colleen Emmenegger, Erik Vinkhuyzen, Melissa Cefkin, and Jim Hollan. 2017. Human-Vehicle Interfaces: The Power of Vehicle Movement Gestures in Human Road User Coordination. (2017).

[48] Yvonne Rogers. 2011. Interaction design gone wild: striving for wild theory. *interactions* 18, 4 (2011), 58–62.

[49] Dirk Rothenbücher, Jamy Li, David Sirkin, Brian Mok, and Wendy Ju. 2016. Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles. In *Robot and Human Interactive Communication (RO-MAN), 2016 25th IEEE International Symposium on*. IEEE, 795–802.

[50] Brandon Schoettle and Michael Sivak. 2014. Public opinion about self-driving vehicles in China, India, Japan, the US, the UK, and Australia. (2014).

[51] Brandon Schoettle and Michael Sivak. 2014. A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia. (2014).

[52] Christopher Stanton and Catherine J Stevens. 2014. Robot pressure: the impact of robot eye gaze and lifelike bodily movements upon decision-making and trust. In *International Conference on Social Robotics*. Springer, 330–339.

[53] Andrea Thomaz, Guy Hoffman, Maya Cakmak, et al. 2016. Computational human-robot interaction. *Foundations and Trends® in Robotics* 4, 2-3 (2016), 105–223.

[54] Marcel Walch, Kristin Lange, Martin Baumann, and Michael Weber. 2015. Autonomous Driving: Investigating the Feasibility of Car-driver Handover Assistance. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '15)*. 11–18.

[55] Wei Xu. 2019. Toward human-centered AI: a perspective from human-computer interaction. *interactions* 26, 4 (2019), 42–46.

[56] Rosemarie E Yagoda and Douglas J Gillan. 2012. You want me to trust a ROBOT? The development of a human–robot interaction trust scale. *International Journal of Social Robotics* 4, 3 (2012), 235–248.

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

[58] 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 (AutomotiveUI '17)*. ACM, New York, NY, USA, 58–64. https://doi.org/10.1145/3122986.3122988