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Sharing the road with autonomous vehicles: A qualitative analysis of the perceptions of pedestrians and bicyclists

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ABSTRACT

Public perception assessment is important for gaining a better understanding of the acceptance of autonomous vehicles (AVs) and identifying potential ways to resolve public concerns. This study investigated how pedestrians and bicyclists perceived AVs based on their knowledge and road sharing experiences, applying a combined inductive and deductive data analysis approach. Survey responses of pedestrians and bicyclists in Pittsburgh, Pennsylvania, USA collected by Bike Pittsburgh (BikePGH) in 2019, were analyzed in this research. AVs following traffic rules appropriately and AVs driving safer than the human drivers were the most notable positive perceptions towards AVs. Pedestrians and bicyclists showed comparatively fewer negative perceptions towards AVs than positive perceptions. Negative perceptions mostly included a lack of perceived safety and comfort around AVs and trust in the AV technology. Respondents also concerned about AV technology issues (e.g., slow and defensive driving, disruptive maneuver), while sharing the road with AVs. Perceptions of the respondents were significantly influenced by their views on AV safety, familiarity with the technology, the extent respondents followed AV on the news, and household automobile ownership. Regulating AV movement on roadways, developing safety assessment guidelines, and controlling oversights of improper practices by AV companies were the major suggestions from the survey participants. Findings of this study might help AV companies to identify potential improvement needed in AV technology to increase pedestrians and bicyclists acceptance, and policymakers to develop policy guidelines to ensure safe road sharing among pedestrians, bicyclists, and AVs.

1. Introduction

Autonomous vehicle (AV) testing on public roadways started in 2013 (Broggi et al., 2015). In 2018, the state of California permitted Waymo, an AV technology development company, to test AVs on public roadways without a test/safety driver (i.e., pilot and co-pilot who monitor AV operation and ready to take vehicle control due to any AV technical issue) being present in the car (Shoot, 2018). Pilot operation of AVs on public roadways inevitably creates concerns for different roadway users' (e.g., pedestrians and bicyclists) safety. Pedestrians and bicyclists are among the most vulnerable groups of roadway users, as

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pedestrians and bicyclists are relatively unprotected compared to the occupants of AVs or conventional vehicles. In March 2018, a test AV operated by the ride-hailing company, Uber, struck and killed a woman, who was walking with her bike in Tempe, Arizona (Stanton, Salmon, Walker, & Stanton, 2019). This was the first pedestrian/bicyclist fatality caused by AV. Although this AV incident raised questions over the safety and acceptance of AV technology, continuous improvement of AV technology via the testing and performance assessment is critical to make the technology acceptable for mass deployment (Penmetsa, Adanu, Wood, Wang, & Jones, 2019). In these contexts, it is essential to investigate the perceptions of pedestrians and bicyclists on sharing roadways with AVs to improve user acceptance and accelerate safe development of AV technology. An in-depth exploration of the opinions of pedestrians and bicyclists is one of the critical components to understand diverse aspects of AVs sharing roads with pedestrians and bicyclists, which has not been investigated extensively in previous studies (Sursock, 2020).

Pedestrians' and bicyclists' perceptions of AVs depend on their exposure to AVs as pedestrians and bicyclists (Deb, Hudson, Carruth, & Frey, 2018). Practical experiences of sharing the road with AVs could reveal important insights (e.g., sharing the road with AVs could help pedestrians and bicyclists to suggest a safe following distance or right-of-way rules to interacts with AVs). AVs have been tested on public roadways in several states in the USA. The city of Pittsburgh was designated as one of the 10 initial proving grounds for AVs by the USA federal government (BikePGH, 2017). In 2016, AV companies started testing their vehicles on Pittsburgh streets and thus increased the exposure of Pittsburgh bicyclists and pedestrians to AVs. Bike Pittsburgh (BikePGH), an organization located in Pittsburgh, Pennsylvania that works on reducing automobile dependency in the city, conducted two surveys in 2017 and 2019 to document the knowledge, experiences, concerns, and expectations of vulnerable roadway users regarding road sharing with AVs. The BikePGH survey gathered opinions from respondents considering their interactions with AVs only as pedestrian and bicyclist and did not focus on gathering opinions of any other vulnerable road users (e.g., construction workers). In addition to quantitative data, BikePGH collected open-ended responses to understand the reasons for pedestrians and bicyclists' quantitative responses to AV operations in Pittsburgh. This research focused on the open-ended responses to categorize the perceptions of pedestrians and bicyclists towards AVs. In addition, this research analyzed overall responses of a respondent to the open-ended questions and classified his/her responses in one of the three perception classes (i.e., positive/ negative/ mixed). Through chi-squared tests, the authors focused on investigating perception differences among different groups of survey respondents based on their demographics and socio-economic characteristics and exposures to AVs. Perception differences were analyzed separately based on survey respondents' interactions with AVs as pedestrian and bicyclist assuming that their perceptions of AVs could vary considering different travel behaviours and the levels of exposure to AVs. Past public opinion studies revealed the opinions of the public as pedestrians and bicyclists. But those are not always aligned to the opinions of pedestrians and bicyclists based on their real-world road sharing experiences with AVs and open-ended responses. In contrast, the BikePGH survey gathered opinions only from those respondents who had shared the road with AVs at least once as pedestrian or bicyclist or both. In other words, the survey measures the respondents of interest for our research questions. The findings of this research will assist AV policy makers and technology developers in identifying the major perceptions and expected AV related regulations by pedestrians and bicyclists (e.g., regulation in terms AV speed limit, gap requirement with pedestrians and bicyclists, provision of drivers inside pilot AVs) on which they could focus to develop a safe road sharing environment for pedestrians, bicyclists, and AVs.

2. Literature review

Several studies have evaluated public perceptions towards AVs focused on general population without focusing on any specific group of roadway users (e.g., Schoettle & Sivak, 2014; Kyriakidis, Happee, & De Winter, 2015), where some studies have evaluated perceptions of motorists towards AVs (e.g., Choi & Ji, 2015; Buckley, Kaye, & Pradhan, 2018). Schoettle and Sivak (2014) analyzed public opinion regarding AV technology by conducting a survey in three countries, the United States of America (USA), the United Kingdom, and Australia. The expectation was high among the respondents in terms of the benefits of AVs. Most respondents expressed their desire to have AVs but did not want to pay extra for the technology. Compared to the respondents of the United Kingdom and Australia, respondents from the USA expressed higher levels of concern in terms of riding AVs, interaction with human driven vehicles, and data privacy. Based on the concerns of 5000 respondents from 109 countries, Kyriakidis et al. (2015) reported that respondents' primary concerns were software hacking/misuse, safety, and legal issues. Respondents with higher incomes, driving mileage, driving frequency, and use of adaptive cruise control were more likely to pay more for AV technology. Choi and Ji (2015) identified factors that might increase public trust in AVs by conducting a survey of 552 drivers. Trust in AVs increased AV acceptance, where system transparency, technical competence, and situation management perceptions of respondents were found to have a positive effect on trust. Using qualitative methods, Buckley et al. (2018) assessed perceptions of motorists towards AVs. Participants emphasized the need to trust AVs (e.g., in terms of mobility and speed management) for wider adoption of the technology. Individual's identity as a driver might act as a barrier to adopt AV, where new technology interest could lead to early adoption.

Few recent studies have assessed the perceptions of non-motorists (i.e., pedestrians and bicyclists) towards AVs. Deb et al. (2017) developed a validated survey questionnaire consisting of three subscales and sixteen survey items to understand the receptivity of AVs by pedestrians. Pedestrians who showed positive crossing behaviours perceived AVs as a safer mode of transportation, whereas pedestrians with aggressive behaviours (e.g., higher levels of violations) showed higher confidence to cross roadways in front of AVs. Reig, Norman, Morales, Das, Steinfeld, and Forlizzi (2018) interviewed 32 pedestrians, who had interacted with Uber AVs to understand the relation between technology perception and individuals' trust in AVs. Individuals' favorable perceptions of AVs were associated with increased trust in AVs. Besides, awareness of the technology and perceptions on the brand (e.g., Uber) also influenced trust. Jayaraman et al. (2018) investigated the interactions between AVs and pedestrians using a simulation-based study and reported that perceived aggressive driving of AVs negatively influenced trust at unsignalized crosswalks but did not affect trust at signalized crosswalks. Pyrialakou, Gkartzonikas, Gatlin, and Gkritza (2020) conducted a stated preference survey among the public of Phoenix, AZ to understand the differences in perceived safety of driving, cycling, and walking near AVs. Cycling near AVs was reported as least safe by the authors compared to walking and driving near AVs. Several studies analyzed BikePGH survey data to understand the perceptions of pedestrians and bicyclists towards AVs. Penmetsa et al. (2019) analyzed the responses of pedestrians and bicyclists separately and found a positive correlation between the levels of AV interactions and perceived AV safety among both groups of roadway users. This study suggested that policymakers should allow more automotive companies to test their vehicles on public roads to increase the interactions of pedestrians and bicyclists with AVs. Das, Dutta, and Fitzpatrick (2020) found that safety expectations from AVs increased with the level of interactions with AVs, applying multiple correspondence analysis technique. The pedestrians and bicyclists who doubted the safety of AVs opposed the use of Pittsburgh streets as an AV proving ground. Perceptions of pedestrians and bicyclists were classified in six categories (i.e., safer AVs, cautious about AVs, negative about AVs, no difference, no experience, and others) and found a marginally significant difference in perceptions between BikePGH members and the general public. Sursock (2020) analyzed the 2019 BikePGH survey data to understand the relationship between AV familiarity with the perceptions of safety and regulation requirements. Increased familiarity of pedestrians and bicyclists showed an improvement in their safety perceptions towards AVs and a decreased demand to impose strict regulations to control AV testing. Pedestrian fatality in the AV involved crash in Tampa, Arizona negatively influenced pedestrians and bicyclists with less familiarity with the technology, where the perceptions of those with higher familiarity with the technology did not change.

As discussed in this section, past studies determined the pedestrians' and bicyclists' perceptions of AVs by analyzing their responses to survey questions with pre-defined strict answer choices and did not explore the qualitative and open-ended responses of pedestrians and bicyclists. For example, past studies (e.g., Schoettle & Sivak, 2014; Deb et al., 2017; Das et al., 2020; Penmetsa et al., 2019; Pyrialakou et al., 2020) reported that survey respondents had positive and negative perceptions about AVs. In these studies, respondents' perceptions did not provide in-depth understandings of AV related concerns, which policymakers and technology developers can use in developing actionable plans to improve AV technology due to analyzing responses to closed questions instead of open-ended questions. Using qualitative data analysis techniques, we attempted to understand pedestrians' and bicyclists' perceptions of AVs in this research by analyzing responses to open-ended questions. Open-ended responses are useful to develop in-depth understanding, as survey participants can provide specific and customized opinions rather than selecting from pre-defined options (Raats, Fors, & Pink, 2020). In addition, open-ended responses help to categorize the perceptions of pedestrians and bicyclists on AVs which cannot be captured by analyzing closed questions (Pettigrew, Worrall, Talati, Fritschi, & Norman, 2019). We hypothesize that the analysis of open-ended questions will reveal comprehensive understanding of perceptions and expected regulations of pedestrians and bicyclists based on their knowledge and road sharing experiences with AVs. Based on the findings of this study, the AV policymakers can develop detailed policy actions (e.g., AV speed limit, gap requirement between AV and pedestrians and bicyclists, potential passenger pick-up and drop off locations, AV data reporting guidelines), and technology developers can advance AV technologies (e.g., addressing AV technology related issues) to facilitate wide-scale adoption and acceptance of AV technology among pedestrians and bicyclists.

3. Methods

3.1. Survey questions and respondent attributes

Survey-based data collection has been widely used to investigate the perceptions of roadway users in various aspects of transportation system engineering research (Das et al., 2020; Gerede, 2015). Although AV technology has been demonstrated promising results in terms of safety improvements, BikePGH as an organization has a healthy skepticism on this (BikePGH, 2019). BikePGH initiated a survey-based platform for pedestrians and bicyclists, where they can share their perceptions regarding AVs. So far, BikePGH conducted two surveys in 2017 and 2019. The surveys were administered via email sent to BikePGH donor members, and via the BikePGH website, social media sites, and news agencies to collect responses from pedestrians and bicyclists in Pittsburgh, PA, which indicates that the collected survey responses was a convenience sample. Considering the involvement of Uber AV in the death of Elaine Herzberg in Arizona, the 2019 survey added a quantitative survey question to understand whether this crash affected the perceptions of Pittsburgh pedestrians and bicyclists on AVs. This study analyzed 2019 survey data consisting of 795 responses. The age distribution among the survey respondents- 18–24 (4.3%), 25–34 (26%), 35–44 (22.3%), 45–54 (16.4%), 55–64 (18.4%), and 65+ (12.4%). Nearly 95% of the survey respondents mentioned household automobile ownership. Most of the respondents had high levels of exposure to AVs. 73% of the respondents paid attention to AV related news to a moderate or large extent. 53% of respondents had high levels of familiarity with AV technology (i.e., mostly or extremely familiar). 60% and 53% of the respondents shared roadways at least once with AVs as bicyclist and pedestrian, respectively, whereas 39% of the respondents shared roadways with AVs as both pedestrian and bicyclist. 60% of the respondents highly rated their perceived safety in terms of road sharing with AVs (rated 4 or 5 on a scale of 1 being very unsafe and 5 being very safe). The 2019 survey questions, which were used for analysis in this study are listed below.

- To what extent have you been paying attention to the subject of AVs in the news? (response category-not at all, to little extent, to some extent, to a moderate extent, to large extent)
- How familiar are you with the technology behind AVs? (response category- not familiar at all, somewhat familiar, mostly familiar, extremely familiar)
- Have you shared the road with an AV while riding your bicycle on the streets of Pittsburgh? (response category- yes, no, not sure)
- Have you shared the road with an AV while walking or using a mobility device in Pittsburgh? (response category- yes, no, not sure)
- Please share any positive experiences that you have had with an AV.[1,2]
- Please share any negative experiences that you have had with an AV.[1,2]
- On a typical day, how safe do you feel sharing the road with AVs? (assessed on a scale of 1 to 5 where 1 being very unsafe and 5 being very safe).
- What is your suggested laws or regulations regarding AVs?[1]
- Demographics and socioeconomic characteristics
  - o What is your age?[2]
  - o Zip code of the living area
  - o Do you (or someone in your household) own an automobile? [2]

These survey questionnaires consisted of both quantitative and qualitative questions. Qualitative survey questions were formulated to understand the perspectives of pedestrians and bicyclists on sharing the road with AVs, which were less interpretable from their responses on quantitative questions. Qualitative questions asked about positive and negative experiences of the survey respondents while sharing roads with AVs, and their recommendations on AVs related regulations to create safer road sharing environments for all roadway users.

3.2. Analysis method

Lack of in-depth understanding of the perceptions of pedestrians and bicyclists on AVs warranted the use of a combination of inductive and deductive approaches for qualitative data analysis. The grounded theory, which requires in-depth responses, could not be applied due to insufficient detailing in the BikePGH survey responses. The inductive approach is used to generate new theory from the data, whereas a deductive approach is used to test a previously developed theory using the data. The methodological framework of this study is presented in Fig. 1.

First, an inductive coding framework was developed from the data, which helped to generate new knowledge on the perceptions of pedestrians and bicyclists (Gabriel, 2013). Inductive coding followed a close reading of the responses, identification of text segment(s) with inherent meaning(s) and assigning text segment(s) to category(ies), which were used to group patterns observed in the data into meaningful units (Thomas, 2003). Then, the categories were revised based on the existing literature on the perceptions of pedestrian and bicyclists towards AVs for broader insights, and to revise the developed inductive coding framework. Finally, a deductive approach was applied to analyze the data. Overlaps and redundancies among the categories were reduced to develop a framework with 3–8 important categories (Creswell, 2002). Responses were coded using a "line-by-line open coding" method to remain open to all possible theoretical directions (Saldana, 2015). Open coding helped to understand the contents and nuances of the data in-depth by breaking down the qualitative data into discrete parts, examining them closely, and comparing the data for similarities and differences.

Survey responses were sampled using quantitative attributes. Attributes included income level (interpreted using zip code responses), age, automobile ownership, safety ratings of AVs, the extent survey respondents follow AVs in the news, and familiarity with AV technology. Respondents were not forced to provide responses to any questions, which resulted in some incomplete responses and were excluded from the analysis. NVIVO 12 software was used to perform both inductive and deductive coding tasks (NVIVO, n.d.). NVIVO is a qualitative data analysis application, which is used to organize, analyze, and visualize unstructured or semi-structured data. Research findings were interpreted based on the categories identified from the data. Moreover, an estimation of the frequency of the related categories was presented. Quantification of qualitative data have been used to impose relative importance on the response categories and to visualize the qualitative data and research findings (Gerede, 2015). Studies of Gerede (2015), Ko et al. (2019), Ta et al. (2020), and Kester, Noel, de Rubens, and Sovacool (2018) used statistical analysis to present qualitative data.

[1] Open-ended questions
[2] Questions added in 2019 survey

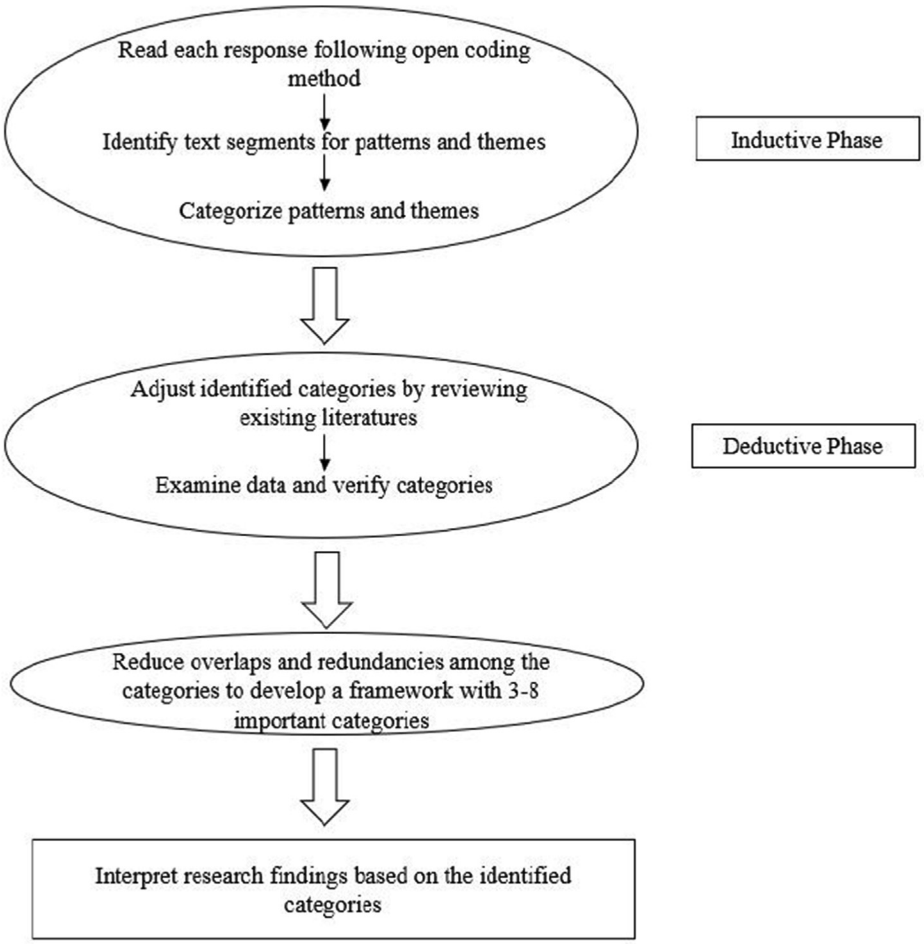

Fig. 1. Methodological framework.

4. Results and discussions

4.1. Perceptions on AVs based on knowledge and road sharing experiences

Positive and negative perceptions of pedestrians and bicyclists on AVs based on their knowledge and road sharing experiences are discussed in the following two subsections.

4.1.1. Positive perceptions

A total of 303 text segments associated with positive perceptions were divided into three major categories by applying a combination of inductive and deductive qualitative data analysis approach. The identified total text segments do not indicate the total number of respondents (i.e., 303 text segments do not indicate 303 respondents). A range of text segments of one to four was extracted from the open-ended response of each survey participant. Gerede (2015) and Ko et al. (2019) also reported the results of their qualitative data analysis by percent frequency of text segments instead of percent frequency by participants. Major categories included in positive perceptions of AVs were- (i) AVs following traffic rules, (ii) AVs driving safer than human drivers, and (iii) the minimum difference between AVs and human driven vehicles. The categories identified within the positive perceptions are summarized in Table 1**(a)**. Approximately 22% of the text segments revealed positive perceptions of AVs in terms of AVs following traffic rules. ‘‘Making a full stop at the stop-controlled intersections” and ‘‘driving within the speed limit” were the most notable traffic rules mentioned by the respondents. Nearly 60% of the text segments reported AVs to be a safer version of human drivers. Respondents perceived that AVs provided more headway or gap while passing than human drivers. Some respondents distinctively highlighted that AVs usually provided at least 4 feet of space while passing or following pedestrians and bicyclists. Also, respondents found that AVs waited longer than human drivers, until it was safe to pass. As stated by one respondent:

Table 1
Categories showing positive and negative perceptions of AVs among pedestrians and bicyclists in Pittsburgh, PA.

(a) Positive perception categories	**Frequency**	**Percent frequency**
Following traffic rules		21.8%
Full stop at stop signs	16	
Stop behind the line marking	1	
Do not cross intersection at red light	6	
Drive within lane	4	
Drive within speed limit	17	
Other traffic rules not distinctly mentioned	22	
Driving safer than human drivers		58.4%
Offer more space than human drivers	30	
Slower driving	25	
Slow down properly to stop at signal	2	
Detect presence of pedestrians and bicyclists better	2	
Yield more to pedestrians and bicyclists	27	
Drive with caution and patience	42	
Do not speed up while passing	3	
Wait longer before passing	1	
More predictable driving	14	
More responsive driving	2	
Lower distraction	8	
Other behaviours not distinctly mentioned	21	
Minimum difference with human driven vehicles	30	9.9%
Others		9.9%
Presence of human drivers	8	
Fascinated with AVs testing in Pittsburgh streets	20	
Environment friendly	2	

(b) Negative perception categories	**Frequency**	**Percent frequency**
Perceived safety issues		47.9%
Feel uncomfortable/unsafe	14	
Not trustworthy	6	
Not predictable	9	
Create distraction	4	
Insufficiently familiar with technology	4	
Technophobic	7	
*Confusion on who is driving (*i.e., *AV technology or human driver)*	4	
Doubt in immature AV technology	8	
Technology issues		45.3%
Disruptive maneuver	7	
Do not stop/yield at crosswalks/signals	7	
Do not allow required gap	7	
Slow/defensive driving	21	
Too fast driving	2	
Driving in wrong lane	3	
Failed to detect pedestrians and bicyclists	3	
Trouble to make maneuver decision	3	
Effect on overall society		6.8%
Might disrupt economy	2	
Increase congestion	5	
Negatively affect pedestrian and bicyclist facilities	1	

> "AVs have never passed me (as a cyclist) until it has been very safe to do so. They have only ever given me well more than 4 feet of clearance and have stayed a safe distance behind me for blocks waiting for a safe time to do so. This is an improvement over many human drivers who drive exceedingly close behind me on my bike while waiting for an opportunity to pass me, which they then do so with less than 4 feet at least some significant amount of the time." *-interacted with AV as a pedestrian and a bicyclist*

Most survey respondents found the driving behaviours of AVs to be defensive (i.e., AVs drove slower than the human drivers). One potential reason could be that AV were authorized to operate below certain speed. Also, AV testing on low-speed roadways contributed to slow driving of AVs. In some cases, their slow driving helped to slow down other aggressive human drivers following AVs, which ensured safer travel for pedestrians and bicyclists. AVs yielded more to pedestrians and bicyclists to avoid potential crashes. They slowed down more than the human drivers to accommodate safe passage for pedestrians and bicyclists. In addition, respondents found AVs to use caution and patience. As stated by two respondents:

> "They have waited behind me where a lot of drivers would have made an aggressive or dangerous pass." *-interacted with AV as a pedestrian and a bicyclist*

"My impression at intersections is that they defer to pedestrians and cyclists more than the average driver would." - *interacted with AV as a bicyclist*

About 5% of positive text segments revealed AV driving more responsive, and to be more predictable than human drivers. As most crashes on roadways happen due to a mistake/distraction of roadway users (e.g., drivers, pedestrians, bicyclists), respondents perceived that AVs would improve safety by eliminating distracted drivers. One respondent stated that:

"AVs don't have a nose buried in a smartphone while driving. With a bit more work they will easily be far safer for everyone on the road than any given driver who is easily distracted."-*interacted with AV as a pedestrian and a bicyclist*

About 10% of text segments mentioned that AV technology resembled human driving perfectly. Some respondents found the presence of test/safety drivers inside the AVs were reassuring in maintaining safe AV operations. Similar findings were reported in (Reig et al. 2018). As stated by two respondents:

"The vehicles I have bicycled next to, behind or in front of had people inside the vehicles which were reassuring." - *interacted with AV as a pedestrian and a bicyclist*
"It's positive that there are actual humans behind the wheel to slow them down manually going through cross walks."- *interacted with AV as a pedestrian and a bicyclist*

Respondents also expressed fascination about witnessing AV testing on Pittsburgh streets. They perceived that AVs could generate new opportunities for people to travel and socialize as well as increase the visibility of Pittsburgh as innovation hub in the world.

4.1.2. Negative perceptions

It is necessary to investigate and act on negative concerns of pedestrians and bicyclists to improve the AV technology. A total of 117 text segments with negative perceptions (about one-third of positive perceptions) were identified in the survey responses. Three categories of negative perceptions were detected by applying a combination of inductive and deductive qualitative data analysis approach- (i) perceptions of safety issues, (ii) technology concerns, and (iii) effects on the society. The categories identified within the negative perceptions are summarized in Table 1**(b)**.

Perceived safety issues were prevalent among the negative perceptions (48% of text segments on negative perceptions). Some respondents indicated that they felt uncomfortable/unsafe around AVs, did not trust AVs and were not able to predict their behaviours while sharing the roads. Two conflicting reasons were found from the responses in support of their concerns. The first reason was insufficient knowledge about the AV technology, which indicates that technology-averse people perceived AVs negatively. The second reason was that their awareness of the limitations of under development AV technology created a sense of fear and discomfort. A similar finding was reported in Reig et al. (2018). The two following statements support the conflicting concerns of the respondents:

"Personally, I am not a fan. I am afraid that while the technology may be advanced, I don't see the need for vehicles to drive by themselves on shared roads. The risk of the technology not working is what scares me the most."-*interacted with AV as a pedestrian*
"I know pretty well what they're doing. I had a sense of unease, not because I'm unfamiliar with the tech but because I know its weak points. It's really good at things it's seen before but exceptional circumstances, not so much."-*interacted with AV as a pedestrian and a bicyclist*

Failure to appropriately address these negative concerns could force policymakers to impose unnecessary barriers on AV technology development, testing and operation on public roads, and hamper rapid improvement of AV technology. Continuous investment in education and awareness program could enhance perceived trust, safety, and comfort among pedestrians and bicyclists (Boudway, 2020; Stewart, Musa, & Croce, 2015). Some respondents perceived that the currently tested AV technology increased the perception reaction time of safety drivers in the AVs, as the safety drivers might perceive a false sense of security with AV features. Respondents pointed out the confusion over the transition of vehicle control. AV safety drivers might be distracted or unaware about the right time to take over control to avoid collisions. Schoettle and Sivak (2014) reported significant concerns among 87% of their surveyed respondents regarding the safety issues of immature AV technology. Respondents got distracted with the flashy logos on the body of AVs and outside sensor assembly. Sometimes respondents found it difficult to understand whether the vehicle was driven by a human driver or by itself at the time of their engagement.

Approximately 45% of the negative perceptions were related to AV technology. Respondents identified several aspects of AV technology such as disruptive maneuvers, not stopping/yielding appropriately, driving too fast and over the speed limit, driving in the wrong lane, failed to detect pedestrians and bicyclists, and having trouble making maneuver decisions. Although respondents were concerned about AV technology issues **(**Table 1**(b))**, they were less compared to the respondents with positive perceptions of AV technology **(**Table 1**(a))**. Some respondents recognized that AV technology improved over the years. The following are the responses that indicated concerns about AV technology issues:

"This summer, when I would ride my bicycle in the opposing direction of the Argo AVs on Railroad Street, I did not feel that they were patient enough when I needed to cross the railroad tracks. Most specifically, they did not slow down as I maneuvered to cross the tracks at a ninety-degree angle."-*interacted with AV as a pedestrian and a bicyclist*

"Twice I felt as if I was not recognized as a vehicle while on my bike. I had to get out of its way."-*interacted with AV as a pedestrian and a bicyclist*

"A few times I felt they passed too close (<4'), but that was back in the 'earlier days' of Uber's testing. It seems to me like they have gotten better at that."-*interacted with AV as a bicyclist*

The relatively slow driving of AVs caused both positive and negative concerns among the respondents. Although some respondents acknowledged the safety benefits of slow driving, some highlighted the negative aspects. Slow driving increased the travel time of the vehicles following AVs. Moreover, defensive practices (e.g., waiting at stop-controlled intersections longer than human drivers) resulted confusion and increased travel time, and led to traffic congestion. Respondents mentioned that AVs might be disastrous for the gig economy and could negatively affect the jobs of professional drivers (e.g., taxi drivers). One respondent feared that placing a high priority on AVs might negatively affect the availability and quality of pedestrian and bicycle infrastructures and related improvement/investment in Pittsburgh, PA. A study reported that the pedestrian and bicycle facilities (e.g., sidewalks and crosswalks) might lose funding to special street treatments for AVs (Schmitt, 2019). The percent frequency of the identified positive and negative perceptions of pedestrians and bicyclists on AVs are presented in Fig. 2.

4.1.3. Perception differences based on respondents' attributes

The perceptions of each survey respondent towards AVs were categorized into one of the three classes: positive perceptions, negative perceptions, and mixed perceptions (a combination of positive and negative perceptions). One perception class (i.e., positive, negative, or mixed) has been assigned to each respondent by reviewing his/her overall responses to the open-ended questions. Table 2 summarizes the perceptions of pedestrians and bicyclists towards AVs based on respondents' attributes. Chi-square tests were performed to identify the difference among perceptions. For most of the attributes (except respondents' age), perceptions of respondents did not differ considering their interactions with AVs as a pedestrian or a bicyclist. Respondents who interacted with AVs as a bicyclist, showed a significant difference in perceptions with their age. Younger bicyclists (age 18–34) showed higher mixed perceptions towards AVs compared to the older bicyclists (age 35 +). No difference in perceptions towards AVs was observed among the respondents in terms of age, who interacted with AVs as a pedestrian. Other studies also reported no significant difference in safety perceptions among pedestrians based on their age (Deb et al., 2017; Reig et al., 2018), which is in line with the finding in this study. Among other demographic and socioeconomic characteristics, automobile ownership in the household marginally influenced perceptions towards AVs. Respondents with household automobile perceived AVs more positively than the respondents with no household automobile. Based on household income, no significant differences in perceptions were observed.

Perceptions of the respondents revealed a strong correlation with the assigned safety ratings to AVs. Respondents were asked to rate AV safety while sharing the road with AVs on a scale of 1 to 5 (1 being very unsafe and 5 being very safe). Respondents who provided lower safety ratings (e.g., 1 or 2) had less positive perceptions and more negative perceptions compared to the respondents who rated safety of AVs highly (e.g., 4 or 5). A similar pattern was reported in the studies of (Das et al., 2020; Grush & Niles, 2018; Henaghan, 2018). Based on the 2017 BikePGH quantitative survey data, pedestrians and bicyclists who perceived AVs as less safe were against the use of Pittsburgh as an AV testing ground (Das et al., 2020). Familiarity with the AV technology also influenced perceptions towards AVs. Respondents who were more familiar with the technology had more positive and less negative perceptions than the respondents who were less familiar with the technology. A similar correlation between pedestrians' familiarity and perceptions of AVs was reported in (Reig et al., 2018). AV public demonstration projects, public outreach, and operating and testing on public roadways can increase familiarity with the technology among diverse roadway users (Penmetsa et al., 2019; Das et al., 2020; USDOT, 2018). Respondents who followed AV more in the news, had less positive and more mixed perceptions towards AVs compared to the respondents who followed AV less in the news, as AVs were often featured on news coverage when an AV involved in a crash.

4.2. Perceptions on current and potential future AV regulations

Regulating AV driving on roadways, establishing potential strategies to assess AV safety, and controlling oversights of improper practices by AV companies are the major regulation categories identified from survey responses. Table 3 presents the categories related to AV regulations. Regulating AV movements mainly consisted of speed limit regulations. Respondents were concerned about the slower speed of AVs, which caused congestion or created safety hazards due to speed variation with other traffic. Survey participants were asked whether the speed of AVs should be capped at 25 mph. Currently, speed limits in most roadways used for AV testing are 25 mph in Pittsburgh (Krisher, 2018) and if AV companies want to test their vehicles at higher than 25 mph speed, there must be an extra employee (co-pilot) in the test AV (PennDOT, n.d.). Respondents perceived that the capped speed limit should be selected based on roadway types. AVs driving below 25 mph on roadways with speed limits higher than 25 mph could create safety risk. Some respondents suggested that AVs should drive following the speed limit or match the speed of surrounding traffic. As stated by two respondents:

"I assume max speed is capped at the speed limit. If this is true, however, there are places where they will be traveling significantly slower than most traffic. (For example, on the Rankin Bridge). Not sure what that implies, but does it not create a hazard?" -*interacted with AV as a bicyclist*

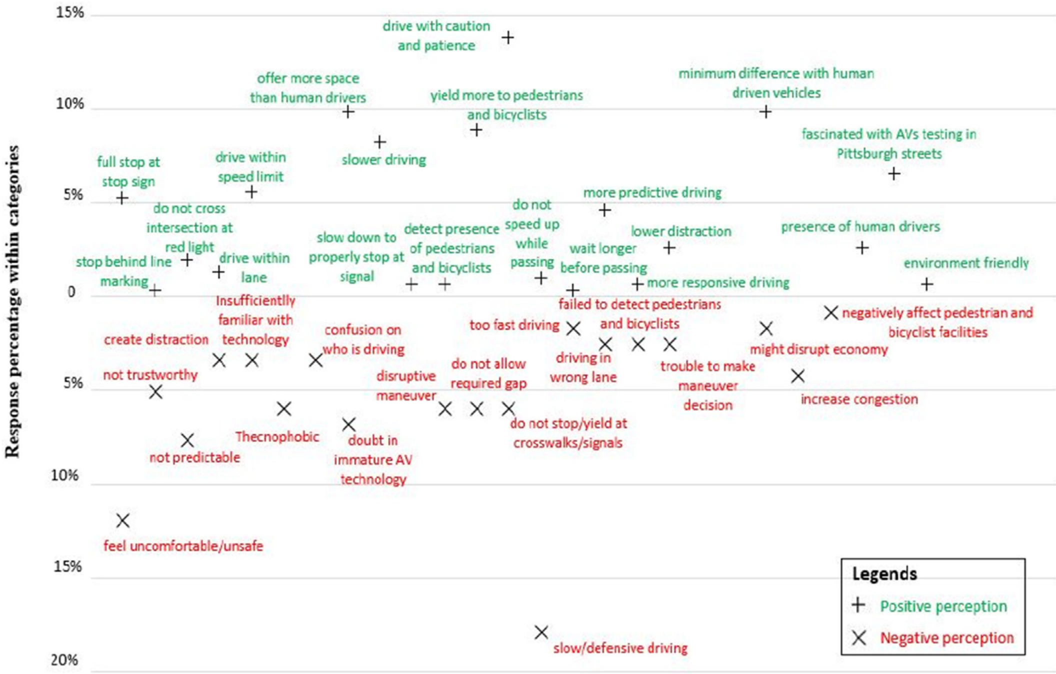

Fig. 2. Percent frequency of the identified positive and negative perceptions of the pedestrians and bicyclists on AVs.

"AVs should drive with the flow of traffic around them -- that means the speed limit should not be capped at 25mph. Inhibiting their ability to drive with the flow of traffic increases safety concerns because it leads to disgruntled drivers around them." *-interacted with AV as a pedestrian*

Respondents also perceived that AV should follow other traffic laws. Pedestrians and bicyclists suggested to develop new regulations to ensure their right of way over AVs. They expected that AVs should maintain a large gap with pedestrians and bicyclists, as some respondents perceived that AVs passed or followed them with less than 4 feet of distance.

In terms of infrastructure for AVs, respondents suggested to develop separate infrastructure. However, separate infrastructure will be difficult to develop due to the scarcity of transportation funding and limited right-of-way in built areas (e.g., Pittsburgh, PA). 7.5% of text segments identified on AV regulations were on regulations to control the movement of AVs in special areas such as banning AV movement or controlling AVs speed limit in school zones. Considering the development stage of current AV technology, respondents wanted to limit AV testing in selected testing areas and hours. Another important regulatory aspect of AVs identified by the respondents was the development of regulation(s) to control passenger pick-up and drop-off points for AVs. Pick-up and drop-off points should not hamper the movements of pedestrians and bicyclists. To address this concern, the existing parking spots might be assigned to multiple AV fleet operators as passenger pick-up and drop-off locations (Duvall, Hannon, Katseff, Safran, & Wallace, 2019).

In terms of the number of test/safety driver in the AV testing vehicles, respondents did not want more than one safety driver on board, as multiple persons might cause distraction. One respondent suggested to regulate the hours of service of drivers and to alter drivers after a period to avoid supervising AV driving with fatigue. Respondents mentioned difficulties in identifying AVs among human driven vehicles and understanding whether the AVs were driving in AV mode or not. A similar observation was reported in (Reig et al., 2018). Strategies such as using a distinct light indicator on the roof of the AV as the indicator of autonomous mode were suggested by the respondents.

Approximately 20% of the text segments on AV regulations were to regulate AVs through comprehensive safety assessment guidelines. Respondents urged policymakers to develop standardized sets of criteria for AV testing on public roadways. Standardized vision testing was suggested by the respondents to assess the accuracy of AVs detecting objects to drive safely in all possible roadway types, weather, and traffic conditions. AVs should be able to detect all expected and unexpected human behaviour scenarios, especially pedestrians and bicyclists. Respondents expected AV companies to submit formal and comprehensive safety and security measures when applying for test permits. One respondent suggested maintaining a log of events encountered by AVs to properly track potential safety issues and performances of AVs. As stated by one respondent on developing regulations regarding AV safety assessment:

"AVs should have to pass a 'driving test', similar to driver's license requirements. AVs should be tested for the sensing capabilities—should sense and stop for pedestrians, bicycles, etc. even when they move in a non-standard way (stepping into traffic mid-block, etc.)."*-interacted with AV as a bicyclist*

Table 2
Perceptions of pedestrians and bicyclists towards AVs based on respondents' attributes.

Road user	Attributes	Open-ended responses (in percentages)			
		Positive perception	*Negative perception*	*Mixed perception*	*p-value*
	AV safety rating				
Pedestrian	1 or 2 (n = 33)	30	64	6	$\leq$0.001***
	3 (n = 53)	57	24	19	
	4 or 5 (n = 237)	84	3	13	
Bicyclist	1 or 2 (n = 33)	27	61	12	$\leq$0.001***
	3 (n = 42)	62	19	19	
	4 or 5 (n = 229)	81	2	17	
	Familiarity with AV				
Pedestrian	Less familiar (n = 123)	69	17	14	0.08*
	More familiar (n = 197)	79	9	12	
Bicyclist	Less familiar (n = 120)	67	16	18	0.06*
	More familiar (n = 183)	77	8	15	
	Follow AV on news				
Pedestrian	Less (n = 56)	86	11	3	0.05**
	More (n = 267)	72	13	15	
Bicyclist	Less (n = 54)	85	9	6	0.05**
	More (n = 249)	70	11	19	
	Automobile ownership				
Pedestrian	Yes (n = 300)	76	12	13	0.08*
	No (n = 19)	53	21	26	
Bicyclist	Yes (n = 387)	74	10	16	0.05**
	No (n = 21)	47	24	29	
	Age				
Pedestrian	18–34 (n = 107)	76	8	16	0.57
	35–54 (n = 131)	73	15	12	
	55+ (n = 83)	73	15	12	
Bicyclist	18–34 (n = 101)	69	6	25	0.03**
	35–54 (n = 130)	73	13	14	
	55+ (n = 72)	76	14	10	
	Income				
Pedestrian	Lower Income (n = 148)	75	9	16	0.46
	Higher income (n = 114)	77	12	11	
Bicyclist	Lower income (n = 143)	73	10	17	0.92
	Higher income (n = 114)	75	8	17	

Chi-square test showed significant correlation between respondent attributes and perceptions in the following levels: *= $p \leq 0.10$; **= $p \leq 0.05$; ***= $p \leq 0.001$.

Table 3
Categories within expected regulations on AVs among Pittsburgh pedestrians and bicyclists.

Categories	Frequency	Percent frequency
Regulations on AV movement		39.7%
Regulate speed limit	18	
Regulate typical traffic laws	3	
Separate autonomous infrastructure	3	
Enough gap with pedestrians and bicyclists	2	
Right of way to pedestrians and bicyclists	2	
Limit movement in sensitive areas	3	
Regulate AV pick up and drop off locations	3	
AV indicator	10	
Driver inside the vehicles	10	
Restrict AV testing	4	
Rigorous safety assessment	29	19.8%
Control oversights of AV companies		22.0%
Comprehensive data reporting guidelines	12	
Transparency of AV companies with public	15	
Enforce violations	1	
Force to reimburse for any damage	4	
Reinvestment in public infrastructure	8	5.5%
Discard AV	11	7.5%
Others		5.5%
Force to build electric AVs	2	
AV friendly infrastructure	1	
Consistency in regulations	2	
Regulate in the process of technology development	3	

A law passed by the U.S. House of Representatives requires manufacturers of AVs to demonstrate National Highway Traffic Safety Administration (NHTSA) how their AVs address safety issues (Canis, 2018). On transparency issues, the same law requires manufacturers to publish their cybersecurity and data privacy plans.

A moderate percentage of text segments identified on AV regulations (22%) were on controlling and monitoring the actions of AV companies. Some respondents feared that AV companies might take advantage of technology advancement and compromise safety and security of roadway users. Respondents asked for regulations to increase the transparency of AV companies with the public. Respondents asked for transparency on testing procedures, testing performances, and potential safety issues irrespective of crash occurrence. Federal guidance included in the "Preparing for the Future of Transportation: Automated Vehicles 3.0" required companies to develop and deploy AV technology maintaining transparency on vehicle safety performance (USDOT, 2018). AV testing companies in California need to submit an annual report to the Department of Motor Vehicles (DMV) on the instances when test/safety drivers had to take over the control of driving from the AV system (Baron, 2018). Although some respondents perceived that public transparency could affect the competitiveness among AV companies, they perceived that transparency is important to ensure public safety and security. In addition, respondents asked for specific guidelines on how AV companies should use the collected data considering the necessity of privacy protection. Oversights of AV companies could be captured through comprehensive data reporting guidelines. Respondents suggested making the collected data open source and anonymizing personal information. One respondent suggested to report data quarterly in an aggregated format to the public, as real time raw data might not make much sense to the public. Currently, companies testing their AVs in Pittsburgh streets need to submit operational reports twice in a year to the Penn DOT (PennDOT, n.d.). Based on the reports, Penn DOT issues public report once in a year (Bauder, 2019). However, some respondents suggested to relax the extent of data reporting to reduce barriers towards the rapid progress of AV technology. As stated by one respondent:

> "Don't overregulate. I don't necessarily agree with any of those companies being forced to share every metric possible."- *interacted with AV as a pedestrian and a bicyclist*

In terms of liabilities, traffic rules should regulate AV companies to pay for incidents and property damage due to the fault of AVs. Respondents suggested that AV companies should maintain an account from which violation, collision or property damage fees might be collected automatically and reimbursed to the appropriate authorities.

Automotive companies should also cover the cost if there is the necessity of building new infrastructures or modifying current infrastructures for AVs. As stated by two respondents:

> "The City should extract commitments to improve city streets. AV companies should be paying for our road repairs and bike lanes in exchange for access to our city"- *interacted with AVs as a pedestrian*
> "Perhaps AV companies should pay impact fees to cover roadways that they use as testing grounds and should pay for any road modifications that are demanded by AV technology."-*interacted with AV as a pedestrian* and a bicyclist

Duvall et al. (2019) also envisioned that AV companies should bear infrastructure expenses if they operate AVs. In contrast, if AVs are deployed as public AV fleets (like current public bus systems), public authorities should bear all infrastructure expenses.

Although 7.5% of text segments identified on AV regulations were on AV ban in Pittsburgh roadways, most respondents were in favor of AVs. Additional regulations identified by survey respondents were: (i) AV companies should build and test electric AVs considering the environmental benefits; (ii) New developments and current infrastructures should ensure proper accommodations for AVs (i.e., signs and markings). Reports from AV companies to the California DMV included poorly marked lanes as one of the limitations of the current roadway infrastructures to operate AVs (Baron, 2018); (iii) Regulations applied for AVs should be uniform across different areas in Pittsburgh; and (iv) As AV technology currently is in the development stage, regulation processes should be flexible, and policy makers should be open to modify, add, or remove regulations.

5. Conclusions

This study investigated vulnerable roadway users' (i.e., pedestrian and bicyclist) perceptions about AVs by applying qualitative data analysis technique. The qualitative data analysis techniques developed in-depth understating of pedestrians' and bicyclists' perceptions. The outcomes of this study are mostly consistent with previous research. Compared to past studies, the current study analyzed open-ended responses of pedestrians and bicyclists who had real-world road sharing experiences with AVs. The major contribution of this study is the categorization of pedestrians' and bicyclists' perceptions and expected regulations regarding AVs by analyzing their open-ended responses. The analysis revealed that the pedestrians and bicyclists appreciated the AVs for following traffic rules and being a safer version of human drivers. Familiarity with AV technology was found to improve positive perceptions on AVs among pedestrians and bicyclists. Slow driving of AVs, although perceived as safety benefits of AVs by some respondents, the slower AVs (compared to the speed of surrounding vehicles) could create safety hazard and congestion. Respondents perceived a lack of safety and comfort around AVs and trust in AV technology. Respondents also concerned about AV technology issues (e.g., slow and defensive driving, disruptive maneuver). To improve perceived safety and comfort around AVs and trust in AV technology, awareness program/campaign and AV technology demonstration projects can be implemented. In terms of regulating AV operations, respondents suggested controlling AV operations on Pittsburgh's roadways, assessing the safety performances of AVs, and controlling oversights of improper practices by AV companies. Data reporting of AV companies was emphasized to ensure public transparency. It was mentioned to revise the AV related regulations over time, as AV technology has been maturing over time and new challenges may appear in future. From chi-squared tests, it was observed that the AV perception differences among different groups of respondents (by demographics, socio- economic characteristics and AV exposures) mostly did not change based on their interactions with AVs as pedestrians or bicyclists. To understand the AV related perceptions and regulation expectations among pedestrians and bicyclists, conducting surveys in the areas where AVs have been tested and operated on public roadways (e.g., Phoenix, AZ; Pittsburgh, PA; San Francisco, CA) are immensely important, as pedestrians and bicyclists in those areas have direct exposure to AVs. The findings of this research will assist AV policy makers and technology developers in identifying and understanding major AV-related positive and negative perceptions and regulation expectations from the viewpoint of pedestrians and bicyclists who encounter AVs during their everyday travel. Measures (e.g., policy and technology solutions to address the concerns) could be adopted accordingly to promote AV technology testing and deployment on public roadways and enable a safe road sharing environment for pedestrians and bicyclists.

The current study is not without limitations. First, the surveyed data collection method used in this study produced responses with insufficient depth to apply the classic grounded theory of qualitative data analysis (Glaser & Strauss, 1967). Grounded theory requires extensive and repeated gathering and examination of the data, suitable generally with interview-based data collection methods. Although interview-based methods require more resources (e.g., time, manpower), those methods could be helpful to generate deeper understandings of pedestrians' and bicyclists' perceptions while sharing roadways with AVs. More in-depth data collection using interview-based methods may be used to validate the findings of this study. Second, the survey sample was limited to Pittsburgh, which might not represent the perceptions of pedestrians and bicyclists of other areas. Third, it is unknown whether the survey sample were representative of all pedestrians and bicyclists in Pittsburgh, as some targeted platforms (i.e., email list, BikePGH website, selected social media sites and news agencies) were used to collect survey responses (i.e., convenience sampling). Fourth, respondent's attributes (e.g., levels of familiarity with AV technology, age groups) were not factored in the analysis to identify perceptions and AV regulations of different groups of pedestrians and bicyclists and should be explored in future research. Identification of perceptions and expected regulations for different groups of pedestrians and bicyclists would help policy makers target specific population groups and use unique measures to improve their road sharing experiences with AVs. Fifth, past studies reported that use of advanced vehicle technologies (e.g., adaptive cruise control, lane keeping assistance, automatic braking while skidding, parking assistance, blind spot and collision warning systems), gender, household income, and education level influenced perceptions about AVs (Kyriakidis et al., 2015; Pettigrew et al., 2019; Pyrialakou et al., 2020). BikePGH survey did not collect data related to the use of advanced vehicle technologies or AVs by survey participants, survey participants' gender, education levels, and annual household incomes, which should be explored in future research. Sixth, future research could perform frame analysis to compare the perceptions of pedestrians and bicyclists who have road sharing experiences with AVs and the AV related perceptions documented in the past public opinion studies. Such analysis might strengthen the need to understand the opinions of pedestrians and bicyclists based on their real-world exposures to AVs. Finally, the interpretation of the responses can have the coder's bias.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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