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Technological perception on autonomous vehicles: perspectives of the non-motorists

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ABSTRACT
This study investigated a less explored autonomous vehicle (AV) related topic (non-motorists and AVs) through the following two research questions: (1) Does the perception towards AVs differ in non-motorists based on stakeholder nature? and (2) Does prior interaction with AVs alter perception on AVs? The present study examined survey data collected by BikePGH in Pittsburgh, Pennsylvania. This study used multiple correspondence analysis (MCA) to identify the response patterns of participants and sort the responses into several clusters. The results show that perception measures vary among participants based on the nature of the stakeholder. The reception of AVs among the participants was mixed. The results also show that participants with real AV interactions have higher expectations and interest in AVs than the participants with no experience. Additionally, the findings show that participants who see no safety potentials for AVs are also against using Pittsburgh as an AV proving ground. It is anticipated that the results will help in improving the strategic management of AVs to make non-motorist mobility safer.

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Autonomous vehicles; pedestrians; bicyclists; perception; multiple correspondence analysis

1. Introduction

In recent years, the initiation of autonomous vehicles (AVs) has gained worldwide attention. Emerging technologies have transformed the transportation system, particularly in regard to safety and mobility. Full automation level AVs can handle different traffic conditions without human input, thus reducing the number of crashes caused by human error. The widespread implementation of AVs will also reduce traffic congestion and air pollution. It is important to understand end-users' knowledge of and attitude towards AVs to ensure that consumers are aware of these many benefits.

Non-motorised traffic fatalities are on the rise. In 2016, pedestrian fatalities made up 16 per cent (5987 in count) of all traffic fatalities, and bicyclist fatalities made up 2.3 per cent (852 in count) of all traffic fatalities (NHTSA 2018, 2019). In crashes involving a vehicle and a non-motorised roadway user, the non-motorised user is more likely to be killed or injured. Studies have shown that AVs will make roadways safer overall. However, in recent news, an AV was in full automation mode when a crash occurred and resulted in a pedestrian fatality. This incident gained international media attention and has brought forth potential safety concerns in unexplored research areas such as the interactions between AVs and non-motorised users on the roadways. The surveys and relevant studies are very limited due to absence of data. Prior studies have shown that stakeholders' roles and their familiarity

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with AV technologies contribute to AV perception measures. This study aims to answer two research questions:

(1) **RQ1:** Does the perception towards AVs differ in non-motorists based on stakeholder nature (e.g. advocacy group and general public)?

(2) **RQ2:** Does prior interaction with AVs alter perception on AVs?

After the exploration of potential data sources to answer the research questions, the Research Team found that an advocacy group, BikePGH, developed a survey to understand the public perception about sharing the road with AVs as a non-motorist roadway user. The raw survey data contains responses of more than one thousand non-motorists. The current study applied Chi-Squared tests and multiple correspondence analysis (MCA) using the data collected by BikePGH in Pittsburgh, Pennsylvania, in order to describe and visually explore complex associations among the responses. Conventional survey analysis methods limit the understanding of occurrence phenomena in a complex questionnaire survey, and the interpretation and conclusions are restricted to broad generalities. This study showed that there is great value in confining the analysis to smaller clusters in order to gain knowledge about participants' response patterns, while considering whether they previously had any interaction with AVs as non-motorised users.

2. Literature review

Large-scale testing of AVs on different roadway facilities are currently being implemented in several countries. However, these technologies are not universally accepted. To successfully penetrate the marketplace, AV technologies must reduce not only technological challenges, but also social barriers. Many studies have explored consumers' opinions, public insight, and the potential adaptation of AV technologies. The literature review mainly focuses on two sections: (1) public perception of AVs, and (2) non-motorists' perception of AVs. Table 1 provides a brief overview of the studies included in the literature review.

2.1. Public perception on AVs

A majority of the public perception related studies were conducted by survey design and analysis. As AVs are costly compared to conventional vehicles, several studies focused on willingness to pay (WTP) issues. Through survey analysis, Schoettle and Sivak (2014) evaluated public sentiment on AV technology in three countries (the US, the UK, and Australia). The results indicate that females express more concern in comparison to males. It also showed that people are interested in getting AV benefits without spending much. Bansal, Kockelman, and Singh (2016) proposed a new simulation-based fleet evolution framework to predict long-term (year 2015–2045) AV adoption levels for eight different scenarios. Krueger, Rashidi, and Rose (2016) identified the characteristics of consumers who are likely to adopt AVs and evaluated their WTP. The results show that service characteristics such as travel cost, travel time, and waiting time could be critical determinants of AV use and the users' acceptance of them. This adaptation may vary among individuals in different demographic groups. Daziano, Sarrias, and Leard (2017) used data from a nationwide online panel of 1260 individuals who responded to a vehicle-purchase discrete choice experiment focusing on energy efficiency and AV features. The purpose of their study was to properly estimate individuals' WTP for AVs. The overall results suggest that the average household is willing to pay ($3500 for partial automation and $4900 for full automation).

Several other studies also considered safety issues and perception towards AVs. Bansal and Kockelman (2017) surveyed 1088 people in Texas to determine their opinions about AVs considering the respondents' demographics, travel and crash histories. The findings suggest that experienced licenced drivers and older people are more reluctant to WTP for AV technologies. The authors

Table 1. Studies on perception on AV technologies.

Studies	Method	Location	Approach
Public perception on AVs			
Schoettle and Sivak (2014)	Survey	The US, the UK, and Australia	The findings show that females express more concern compared to males. Additionally, a majority of the respondents were interested in having this technology in their vehicle; however, most were unwilling to pay additional costs.
Howard and Dai (2014)	Survey	Berkeley, California	After analyzing vehicle characteristics that were liked and disliked, positive attitudes were found to be associated with multitasking while driving, protentional safety improvements from AVs, and finding right parking spots. Nevertheless, people were concerned about the cost of vehicles, liability, and losing control. In comparison to women, men have been found to be less concerned with control and more concerned with liability.
Choi and Ji (2015)	Survey	--	The results showed that the significant determinants of intention for using self-driving cars were trust and perceived usefulness. Three constructs with positive impacts on trust were found to be technical competence, system transparency, and situation management.
Kyriakidis, Happee, and de Winter (2015)	63-question Internet-based survey	5000 responses from 109 countries	According to results from respondents, the most enjoyable mode of driving was found to be manual driving. The respondents were most concerned with legal issues, software hacking/misuse, and safety.
Bansal, Kockelman, and Singh (2016)	Simulation-based fleet evolution framework	–	The findings from this study show the long-term (year 2015–2045) adoption levels of AV technologies in the U.S. with eight scenarios.
Krueger, Rashidi, and Rose (2016)	Survey		Based on study results, AV use and the users' acceptance of AVs are dependent on service characteristics such as travel time, travel cost, and waiting time. The adaptation could vary among individuals in various demographic groups. Young people and individuals with multimodal travel patterns may be more likely to adopt AVs.
Daziano, Sarrias, and Leard (2017)	Vehicle-purchase discrete choice experiment	Nationwide online panel of 1260 individuals	Based on analyses results, the average household is willing "to pay approximately $3,500 for partial automation and $4,900 for full automation."
Menon (2017)	Survey		The findings showed that the effect of relinquishing household vehicles differs among single- and multi-vehicle households with various triggers such as current travel characteristics, socio-demographics, vehicle purchase histories, and crash severities.
Lee et al. (2017)	Survey	National sample of 1765 adults in the US	The outcome of the study identified the negative effects of age on interest in using it, perceptions of a self-driving car, and behavioral intentions to use one when it becomes available. Experiential characteristics that are associated with age, such as knowledge of, experiences with, and trust toward technology in general, have been found to have a significant effect on people's feelings towards AVs.

(*Continued*)

Table 1. Continued.

Studies	Method	Location	Approach
Bansal and Kockelman (2017)	Survey	1088 people in Texas	The findings suggest that more experienced licensed drivers and older people are less WTP for all new vehicle technologies. These findings are able to predict the long-term adoption of AVs technologies and help transportation planners understand the characteristics of regions with high or low future-year CAV adoption levels.
Bansal and Kockelman (2018)	Survey	Internet-based survey asking 347 Austin, TX residents	The results concluded that respondents considered equipment failure as their top concern of self-driving cars and fewer crashes as the primary benefit.
Hulse, Xie, and Galea (2018)	Survey	1000 individuals	The findings showed that there was little opposition to AV use on public roads as they are perceived as a "somewhat low risk" form of transportation. Additionally, these vehicles were also perceived as more risky than existing autonomous trains. Age, gender, and risk-taking features were found to have various relationships with the general attitudes towards these cars and the perceived risk of different vehicle types. For example, younger adults and men expressed greater acceptance.
Canis (2018)	Survey	US	Results indicate that more than half of the drivers in the United States "feel less safe at the prospect of sharing the road with a self-driving vehicle."
Das et al. (2019a)	Text mining on relevant YouTube video comments	–	Compared to the past, the public is engaging more with AVs technologies. They also found that as the automation level increases, the possible perception of safety increases as well. Finally, they concluded that positive sentiments towards AVs are more common than uncertain, negative, or litigious sentiments.
Non-motorists' perception on AVs			
Deb et al. (2017)	Pedestrian receptivity questionnaire	482 participants from the US	People who show positive behavior believed that the overall traffic safety would improve with the addition of FAVs. Those who show higher lapse, violation, and aggression scores were found to feel more confident about crossing the road in front of a FAV. This questionnaire used in this study has the potential for designing and improving FAVs for road-users outside the vehicles.
Penmetsa et al. (2019)		Survey data collected by BikePGH	Findings from the study revealed that respondents with direct experience of interaction with AVs reported significantly higher expectations of their safety advantages in comparison to respondents with no experience in AV interaction.

mentioned that these findings can predict the long-term adoption of AVs and contribute to transportation planners to understand the features of regions with high or low future-year AV adoption levels. In a follow-up study, Bansal and Kockelman (2018) conducted an online survey asking 347 Austinites about their insights on AV technologies. The results conclude that respondents considered fewer crashes to be the primary benefit of AVs, and they considered equipment failure to be their top concern. Canis (2018) found that 30 per cent of survey participants expressed reluctance in buying an AV. The study also reported that more than half of US drivers feel less safe in the circumstances of sharing road with AVs. Menon (2017) examined the potential market segments of AV consumers and revealed influential factors in adopting AVs. Hulse, Xie, and Galea (2018) surveyed nearly one thousand individuals on their perceptions towards AVs. The findings showed that participants consider AVs as 'somewhat low risk' and there do not oppose AV implementation on public roads. Gender, age, and risk-taking features were found to have various relationships with the perceived risk of different vehicle types and general attitudes towards these cars. For example, men and younger adults expressed greater acceptance.

Familiarity of AV technology or prior interaction with AVs can also shape public perception towards AVs. A case study by Howard and Dai (2014) assessed public attitudes regarding AVs by utilising the responses of 107 adopters in Berkeley, California. An evaluation of the vehicle characteristics that people liked and disliked was conducted, and the participants also expressed how they envisioned the inclusion of the technology. The positive attitudes are associated with potential safety improvements from AVs, finding parking spots, and multitasking while driving. On the other hand, people were also concerned with liability, high price, and less control. Men have been found to be more concerned with liability as well as less concerned with control than women. Choi and Ji (2015) analysed the user's adoption perspective of the AVs. The findings show that perceived usefulness and trust are significant determinants of intention for using AVs. Moreover, it is found that three constructs – system transparency, technical competence, and situation management – have positive impacts on trust. In addition, Kyriakidis, Happee, and de Winter (2015) investigated user acceptance, attitudes, and WTP for different automation levels. They used a 63-question Internet-based survey which led to 5000 responses from 109 countries. On average, the results indicated that respondents found manual driving the most enjoyable mode of driving. Additionally, respondents were mostly concerned with safety, security, and legal issues. Lee et al. (2017) investigated the responses from a national sample of 1765 adults in the US to identify the main influences of the acceptance of AVs. The findings indicate negative effects of age on perceptions of AV, interest in using it, and behavioural intents to use one when it becomes available. Moreover, trust and familiarity toward technology were found to have a significant impact on AV preference. By using two natural language processing (NLP) tools, Das et al. (2019a) evaluated people's attitudes toward AVs and the existing polarities regarding content and automation level to perform knowledge discovery from a bag of approximately seven million words from a large number of YouTube videos. They found that the public is engaging more with AVs technologies than in the past, and they also found that as the automation level increases, as does the possible perception of safety. Finally, they concluded that positive sentiments towards AVs are more common than negative, uncertain, or litigious sentiments.

2.2. Non-motorists' perception on AVs

While a majority of the studies focused on public perception towards AVs, very few studies focused on non-motorists' perception towards AVs. Using a pedestrian receptivity questionnaire from 482 participants in the US, Deb et al. (2017) showed that participants with higher violation, lapse, and aggression scores were found to feel more confident about crossing the road in front of a fully autonomous vehicle (FAV). Penmetsa et al. (2019) examined BikePGH survey data and the findings show that respondents with direct interaction experience with AVs have higher expectations of AV safety advantages than respondents with no prior AV interaction experience.

The current state-of-the-art literature review has several limitations. First, the indications of attitudes are not dependent on the future safe adoption of AVs. Second, the interaction between participants and AVs is unknown in most of the studies. Third, only a few studies investigated non-motorists' view on AVs. Fourth, conventional survey analysis methods are limited in interpreting the co-occurrences of the responses. The current study presents a suitable data analysis tool that can identify patterns and associations from a complex survey to understand the perception of roadway users towards the adoption of AVs (Table 1).

3. Data description

3.1. Survey design and participants

According to the first edition of the Highway Safety Manual (HSM), approximately 94 per cent of crashes occur due to human errors (AASHTO 2010). The AV companies anticipate that the AV technologies could greatly reduce or eliminate these crashes by removing the human error component in the driving tasks. Irrespective of the automation modes (full, semi, or partial), AVs promise many potential benefits such as reducing roadway crashes and fatalities, easing traffic congestion, and increasing mobility (AASHTO 2010; GAO 2017). However, AVs can also pose safety and infrastructure challenges for state DOT authorities. DOTs must decide if the current approach to vehicle testing and standards can adequately ensure a safe driving environment. Additionally, there is a need to address how AVs interact with other road users. AVs could require potential infrastructure changes, and regulatory agencies will need to decide what changes to pursue, while also providing for conventional vehicles which will likely remain on the roads for decades. However, many agencies do not have readily available comprehensive plans that will set clear goals on the deployment of AVs on the roadways (Keeney 2017).

Since September 2016, AV companies have tested AVs in cities, including Pittsburgh. Pittsburgh is one of the ten AV proving groups designated by the United States Department of Transportation (USDOT) in 2017. BikePGH is a charitable non-profit with a mission to transform '… our streets and communities into vibrant, healthy places by making them safe and accessible for everyone to bike and walk' In early 2017, BikePGH designed a survey to see how both BikePGH members and non-member residents feel about sharing the road with AVs as a bicyclist and/or as a pedestrian (Bike PGH 2019).

This survey asked participants about their opinions on sharing roadways with AVs. To help policymakers comprehend the complexity of possible future implementation of AVs, the survey was conducted to show that AV technology can bring different marketplace models to the cities and town centres. BikePGH conducted the survey in two parts. First, the survey was limited exclusively to the donor-members, yielding 321 responses (out of 2900 members) via email. In the second stage, BikePGH allowed the residents to participate by promoting it on the BikePGH website, social media channels, and a few other media outlets. The second stage yielded 798 responses. The survey questions are listed below:

- **InteractBicycle**: Prior interaction with an AV while riding bicycle on the streets of Pittsburgh.
- **InteractPedestrian**: Prior interaction with an AV while using sidewalks and crosswalks in Pittsburgh.
- **BikePghPosition**: Opinion on BikePGH's position on AVs.
- **CircumstancesCoded**: Circumstances coded in six categories: AV Safer, Cautious about AV, Negative about AV, No Difference, No Experience, and Others.
- **SafetyHuman**: Opinion on feeling safe using Pittsburgh's streets with human-driven cars.
- **SafetyAV**: Opinion on feeling safe using Pittsburgh's streets with AVs.
- **AVSafetyPotential**: Do AVs have the potential to reduce injuries and fatalities?
- **RegulationTesting**: Opinion on regulatory authority's role with regulations regarding how AVs are tested.

- **RegulationSpeed**: Opinion on regulatory authority's capping the speed limit in AV operated roadways.
- **RegulationSchoolZone**: Opinion on regulatory authority's preventing AVs from operating in an active school zone.
- **RegulationShareData**: Opining on data sharing of the AV operators with regulatory and related authorities.
- **FeelingsProvingGround**: Opinion on using Pittsburgh's public streets as a proving ground for AVs.
- **AdvocacyIssues**: Is this an advocacy issue that BikePGH should dedicate resources to?
- **PayingAttentionAV**: To what extent have you been paying attention to the subject of AVs in the news?
- **FamiliarityTechnoology**: How familiar are you with the technology behind AV?

4. Methodology

4.1. Perception difference between stakeholders

The research team used the final survey dataset with 321 responses from the BikePGH members (BPG) and 793 responses from the general public (Public) for a total of 1114 respondents. Due to the missing values, five Public responses were discarded. Pettigrew and Cronin (2019) showed that perceived knowledge towards AVs differ among different stakeholders such as government, research, private, and advocacy representatives. This hypothesis has not been examined for non-motorists' perception towards AVs based on their stakeholder role. This study performed a chi-square test to investigate RQ1.

Table 2 lists the chi-square test values (a convenient test to identify the difference between the dataset attributes) and descriptive statistics of the key variables. The low *p*-values from the chi-square tests indicate that some of the variables are significantly different for two types of participants (BPG and Public).

Among the survey respondents, any interaction with an AV as a pedestrian was higher than BPG participants. Among the respondents, 10 per cent were unsure if they had interactions with AVs as pedestrians. For Public participants, 47 per cent reported interaction with AVs while riding a bicycle, whereas 43 per cent of BPG participants have such experiences. For the public participants, 7 per cent believe that BikePGH should actively oppose AVs. Only 3 per cent of BPG participants are opposed to AVs regarding the BikePGH position.

The circumstances are coded into six categories: AV Safer, Cautious about AV, Negative about AV, No Difference, No Experience, and Others. Around 50 per cent of both participant groups do not have prior experience of AV circumstances. For Public participants, 24 per cent think that Pittsburgh's streets are safe with human-driven cars. This percentage is 15 per cent for the BPG participants. On the other hand, 11 per cent of BPG members consider Pittsburgh's streets to be unsafe or very unsafe with AVs. This percentage is 17 per cent for the Public respondents. Public participants see fewer safety potentials from AVs than the BPG participants (62 compared to 72 per cent).

The majority of both participant groups are in favour of testing and speed regulations for the AVs. Public participants are more in favour of school zone regulation of the AVs than the BPG participants. Around 50 per cent of the survey respondents approved Pittsburgh's role as a proving ground for AVs. Slightly more BPG participants are paying more attention to AVs and are getting familiar with the AV technologies compared to the public participants.

Figure 1 shows the bar chart distribution of those questions with yes/no/not sure potential responses. These questions included regulatory, safety potential, and interaction related questions. Figure 1 shows the results for both groups with the top portion showing the results for the BPG participants and the bottom portion showing the results for the public participants. Public attitudes are higher for school zone and speed-related regulations for AVs compared to BPG participants. For other

Table 2. Chi squared tests and descriptive statistics for key variables by BPG and public participants.

Questions	BPG (*N* = 321)	Public (*N* = 793)	*p*-val	Questions	BPG (*N* = 321)	Public (*N* = 793)	*p*-val
InteractPedestrian			0.047*	RegulationTesting			0.199
1: Yes	41%	35%		1: Yes	72.90%	69.90%	
2: No	48%	56%		2: No	9.03%	12.90%	
3: Not Sure	11%	9%		3: Not Sure	18.10%	17.30%	
InteractBicycle			0.279	**RegulationSpeed**			0.038*
1: Yes	42.70%	46.70%		1: Yes	46.40%	53.00%	
2: No	48.00%	42.70%		2: No	30.50%	30.10%	
3: Not Sure	9.35%	10.60%		3: Not Sure	23.10%	16.90%	
BikePghPosition			0.008*	**RegulationSchoolZone**			0.01*
Actively Oppose	2.80%	7.19%		1: Yes	18.70%	27.10%	
Actively Support	49.80%	42.60%		2: No	49.50%	46.30%	
Neither Support nor Oppose	38.90%	38.80%		3: Not Sure	31.80%	26.60%	
No Opinion	8.41%	11.30%		**RegulationShareData**			0.451
CircumstancesCoded			0.074*	1: Yes	74.10%	70.60%	
AV Safer	2.49%	2.90%		2: No	11.80%	12.60%	
Cautious about AV	6.23%	6.18%		3: Not Sure	14.00%	16.80%	
Negative about AV	1.25%	4.04%		**FeelingsProvingGround**			0.019*
No Difference	40.50%	34.00%		1: Not at All	3.74%	9.33%	
No Experience	47.70%	49.60%		2: Little	8.41%	8.95%	
Others	1.87%	3.28%		3: Some	12.10%	13.50%	
SafetyHuman			0.01*	4: Moderate	22.70%	19.30%	
1: Very Unsafe	4.98%	5.42%		5: A Lot	53.00%	48.90%	
2: Unsafe	32.70%	26.70%		AdvocacyIssues			0.126
3: Not Sure (Neutral)	45.50%	38.60%		1: Not at All	2.49%	5.42%	
4: Safe	14.60%	24.20%		2: Little	13.70%	15.00%	
5: Very Safe	1.56%	4.29%		3: Some	41.10%	40.10%	
No experience	0.62%	0.76%		4: Moderate	38.00%	33.20%	
SafetyAV			0.094*	5: A Lot	4.67%	6.31%	
1: Very Unsafe	2.80%	6.18%		PayingAttentionAV			0.724
2: Unsafe	8.10%	10.10%		1: Not at all	0.93%	1.51%	
3: Not Sure (Neutral)	26.20%	22.20%		2: Little	7.48%	9.84%	
4: Safe	35.80%	31.80%		3: Some	30.20%	30.00%	
5: Very Safe	16.80%	19.30%		4: Moderate	34.30%	32.80%	
No experience	10.30%	10.50%		5: A Lot	27.10%	25.90%	
AVSafetyPotential			0.001*	FamiliarityTechnoology			0.489
1: Yes	72.30%	61.80%		1: Not at All	5.30%	6.81%	
2: No	3.43%	7.82%		2: Little	22.10%	20.70%	
3: Not Sure	24.30%	30.40%		3: Some	44.90%	41.90%	
				4: Moderate	17.40%	21.30%	
				5: A Lot	10.30%	9.33%	

Note: p-values with * indicate statistically significant at 90% confidence level. The variable names are bold with *p*-values with *.

regulations, the differences of opinions are not significantly wide. More BPG participants believe AVs have the potential to improve safety than the Public participants. Based on the chi-square test and Figure 1, the general understanding is that perception towards AVs vary based on the stakeholder role, which is line with other studies (Pettigrew and Cronin 2019; Penmetsa et al. 2019)

4.2. Patterns of responses

4.2.1. Multiple correspondence analysis (MCA)

Different frameworks of MCA have been developed while keeping goals similar (Greenacre and Blasius 2006; Hoffman and De Leeuw 1992). In recent years, several studies applied correspondence analysis (CA) and its variants in transportation studies (Fontaine 1995; Das and Sun 2015; Das and Sun 2016; Das et al. 2018; Jalayer, Pour-Rouholamin, and Zhou 2018; Das et al. 2019b; Raghunandan, Zhou, and Jalayer 2019; Ali et al. 2018; Degraeve, Granie, and Pravossoudovitch 2015; Das et al. 2019c; Das and Dutta 2020). MCA, a data mining approach, does not require defining a response variable. This framework requires the construction of a matrix based on pairwise cross-tabulation of each variable.

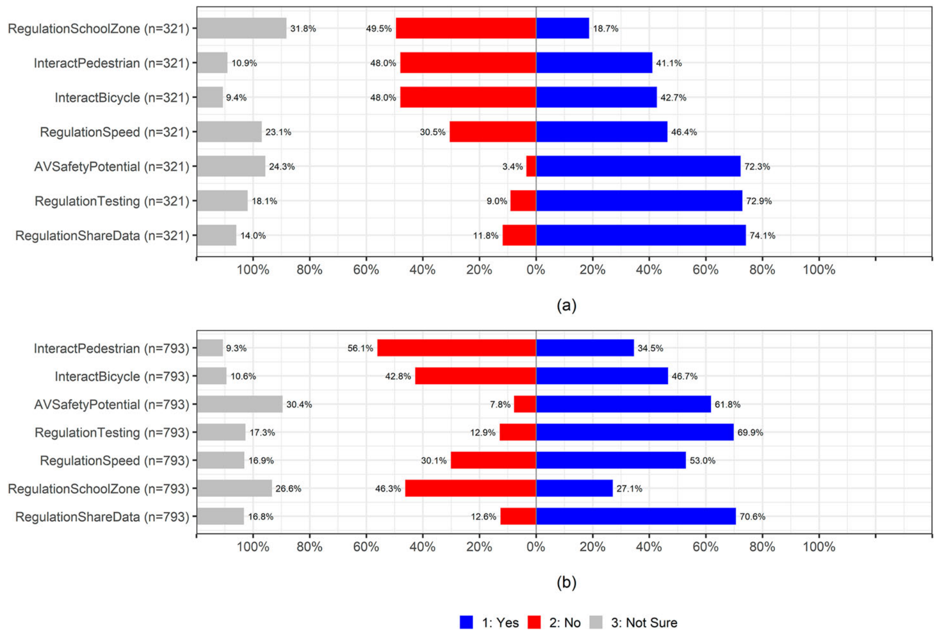

Figure 1. Distribution of regulation and interaction questions (a. BPG, II. Public).

As an example, the final dataset of this study has matrix in the form of 1114 × 10 (total survey respondents = 1114, and questions analysed in this survey = 10). For the matrix with dimension 1114 × 10, one can explain MCA by taking an individual record (in row), *i* [*i* = 1–1114], where 10 categorical or nominal variables (represented by 10 columns) have different sizes of attributes. Based on these 10 variables, MCA can generate the spatial distribution of the points by a set of defined or required dimensions.

Consider P as the number of survey questions (shown in columns), and I as the number of responses from the survey participants (shown in rows). This consideration can develop a matrix of *I multiplied by P*. By considering L_{p_p}as the number of attributes for variable *p*, the total number of attributes for all variables is, $L = \sum_{p=1} L_p$. It generates another matrix *I multiplied by L*. In this generated matrix form, each of the categorical variables contain several columns to show all of their possible attributes (for example, yes and no response of a question will generate two columns). The cloud of categorical attributes can be considered as a weighted combination of J points. Category *j* can be represented by a point denoted by $C^j$with the weight of n_j. For each of the variables, the sum of the weights of category points is *n*. In this way, for the whole set *J*, the sum is calculated as *nP*. The relative weight w_j for point C^j can be represented by $w_j = n_j/(nP) = f_j/P$. The sum of the relative weights of category points is 1/P, which makes the sum of the whole set as 1 *(23)*.

$$w_j = \frac{n_j}{nP} = \frac{f_j}{P} \text{ with } \sum_{j \in J_q} w_j = \frac{1}{P} \text{ and } \sum_{j \in J} w_j = 1$$

In this case, the notation $n_{jj'}$ characterises the count of individual records which have both *k* and *k'* categories. The squared distance between two categories C^j and $C^{j'}$ can be shown using Equation (1) *(23):*

$$(C^j C^{j'})^2 = \frac{n_j + n_{j'} - 2n_{jj'}}{n_j n_{j'}/n} \tag{1}$$

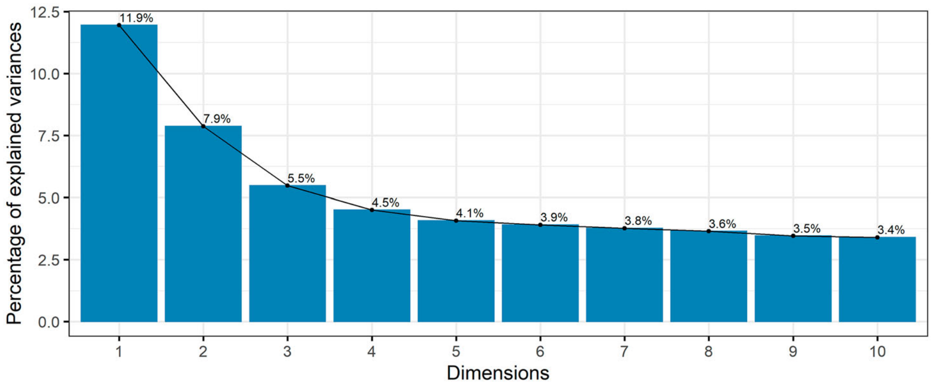

Figure 2. Inertia explained by 10 dimensions.

The numerator of Equation (1) is the count of individual records relating with either j or j' but not both. For two different variables, p, and p', the denominator is the count for the cell (j, j') of the two-way matrix $J_p \times J_{p'}$.

The variables with high p-values (greater than 0.10, see Table 2) indicate that both groups of participants are not significantly different in attitude towards AVs for the associated attributes. The p-values from Table 2 indicate that the responses associated with the nine questions show a significant difference in responses for two types of participants (*InteractPedestrian, BikePghPosition, CircumstancesCoded, SafetyHuman, SafetyAV, AVSafetyPotential, RegulationSpeed, RegulationSchoolZone, and FeelingsProvingGround*). The group of the participants is considered as the 10th variable. To conduct the MCA analysis, 10 variables are considered for analysis. Figure 2 illustrates the percentages of inertia (i.e. variance) explained by each MCA dimension. The first two dimensions explained nearly 20 per cent of total inertia.

MCA plots or biplots are sometimes difficult to interpret due to the large number of attributes on a two-dimensional plot. The parameter squared cosine ($\cos^2$) indicates the degree of association between variable attributes and an axis. If a variable attribute is well represented by two dimensions, the sum of the $\cos^2$ will be approximately one. Sometimes, three-dimensional display is needed if two dimensions do not sufficiently cover inertia or variance. Figure 3 displays the $\cos^2$ values of the row categories (on all dimensions) in an ascending order bar plot. The closer the locations of the attributes in the MCA plot, the closer the associations. The research team developed six different clusters based on the coordinate values of the attributes.

It is also important to show which attribute is dominant in each axis. The top 5 attributes of dimension 1 (i.e. Axis 1) are *FeelProving_1: Not at All, RegulationSchoolZone_1: Yes, BpgPos_Actively Oppose, AVSafetyPotential_2: No,* and *SafetyAV_1: Very Unsafe*. The top 5 attributes of dimension 2 (i.e. Axis 2) are SafetyAV_1: Very Unsafe, FeelProving_1: Not at All, BpgPos_Actively Oppose, AVSafetyPotential_2: No, and RegulationSchoolZone_3: Not Sure. The attributes with top 5 high $\cos^2$ values for two dimensions are *FeelProving_1: Not at All, BpgPos_Actively Oppose, FeelProving_5: A Lot, SafetyAV_1: Very Unsafe,* and *AVSafetyPotential_1: Yes*. The majority of these attributes are in Cluster 6.

5. Results and discussions

Figure 4 shows the MCA plot generated for the variable attributes. Five different clusters are shown in Figure 4. As the MCA plot is limited (−1,1), Cluster 6 is not shown in the MCA plot (the values are listed in Table 3). General inspection of the MCA plot shows that participants of similar mindset are clustered in groups. For example, participants with negative views are clustered in the first quadrant, participants with positive attitudes are clustered in the second quadrant, and those with neutral

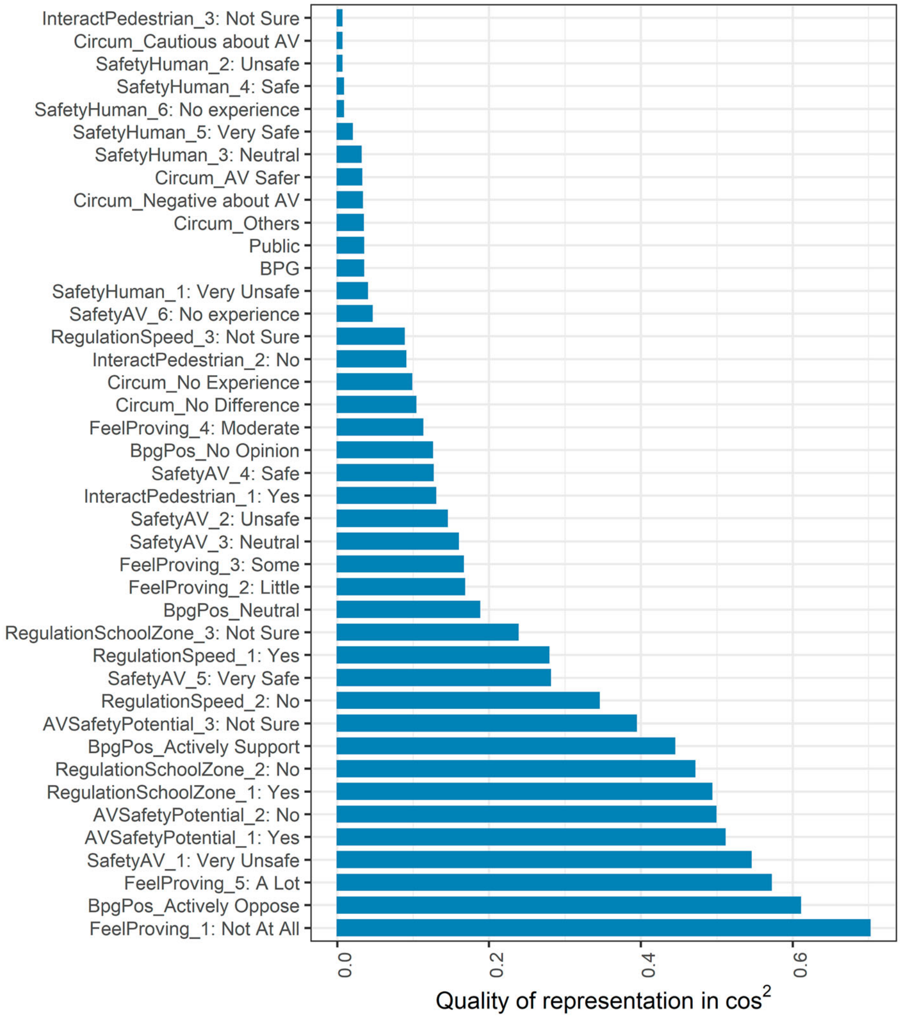

Figure 3. Quality of representation by the attributes.

responses are clustered in the third or fourth quadrant. One unique feature of MCA is its ability to identify the cooccurrences of the responses. The number of clusters was not developed based on any algorithm. The clusters are based on the co-ordinate adjacency of the response attributes. Discussions on these clusters are given below:

Cluster 1 (BpgPos_Actively Support, Circum_AV Safer, FeelProving_5: A Lot, RegulationSchoolZone_2: No, and SafetyAV_5: Very Safe)

This cluster is associated with participants who have positive views on AVs. These participants think that BikePGH should actively support AVs. They consider Pittsburgh's streets safe with human-driven cars, their experiences of AV circumstances are positive, and they are in favour of Pittsburgh as the proving ground of AVs. The participants of this group think that there should not be any regulation for AVs in the school zone. The $\cos^2$ and contribution values of three attributes of this cluster are in the top 10 $\cos^2$ and contributions values. The higher values indicate that this cluster is well represented among the survey participants. The percentage values of Table 4 indicate that these attributes are well explained in Axis 1. Hulse, Xie, and Galea (2018) also showed that participants considered AVs as low risk and they not concerned about usage of AVs on public roads.

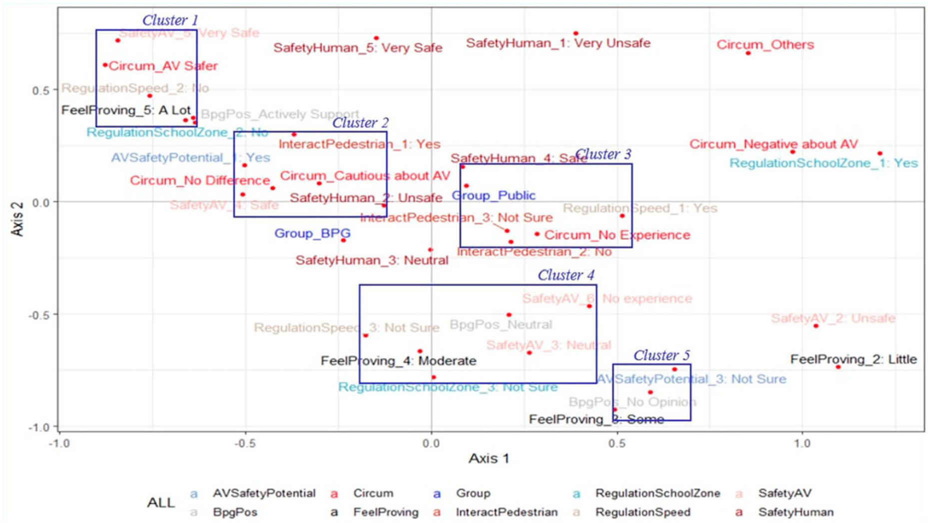

Figure 4. MCA plot of the attributes.

Cluster 2 (AVSafetyPotential_1: Yes, Circum_Cautious about AV, Circum_No Difference, InteractPedestrian_1: Yes, RegulationSpeed_2: No, SafetyAV_4: Safe, and SafetyHuman_2: Unsafe)

This cluster is associated with participants who have had prior interaction with AVs as pedestrians. These participants consider AVs to be safer than human drivers. One possible reason for this is that AVs are typically deployed on roadways with lower posted speed limit. AVs with a low and constant speed might be considered safer than human drivers with different operating speeds. These participants either feel no difference or feel somewhat cautious while interacting with AVs in the real world. They also understand that there are safety potentials for AVs. They do not think that there should be any speed regulation on AVs. Two of the attributes of this cluster are in the top 10 $\cos^2$ and contribution values. This cluster is moderately represented among the survey participants. The percentage values of Table 4 indicate that these attributes are thoroughly explained in Axis 1. Other studies also show that familiarity with AVs and any prior experience has a significant impact on the public perception of AVs (Lee et al. 2017; Penmetsa et al. 2019). These trends in this cluster partially answer **RQ2**.

Cluster 3 (Circum_No Experience, Group_Public, InteractPedestrian_2: No, InteractPedestrian_3: Not Sure, RegulationSpeed_1: Yes, and SafetyHuman_4: Safe)

This cluster is associated with Public participants, especially those with no prior interaction with AVs as pedestrians or bicyclists. These participants consider Pittsburgh's streets to be safe with human-driven cars. They are also in favour of the regulation of speed for AVs. None of the attributes of this cluster are in the top 10 $\cos^2$ and contribution values. The findings of this cluster are in line with other studies (Grush and Niles 2018; Henaghan 2018).

Cluster 4 (BpgPos_Neutral, FeelProving_4: Moderate, RegulationSchoolZone_3: Not Sure, RegulationSpeed_3: Not Sure, SafetyAV_3: Neutral, SafetyAV_6: No experience)

This cluster is associated with participants who have neutral views (i.e. responses with not sure) on AVs. The participants in this cluster either have no experience or show neutral views as to whether the Pittsburgh's streets are safe with AVs. The participants also have a neutral view about whether the BikePGH should oppose or support AVs. These participants are not sure about the regulation of AVs for school zone and speed control. Three attributes of this cluster are in the top 10 contributors of dimension 2. This cluster is moderately represented among the survey participants. The percentage values of Table 4 indicate that these attributes are well explained in Axis 2.

Cluster 5 (AVSafetyPotential_3: Not Sure, BpgPos_No Opinion, FeelProving_3: Some)

Table 3. MCA outputs for the attributes.

Attributes	Coordinates		Contribution		cos^2				
	Ax 1	Ax 2	Ax 1	Ax 2	Ax 1	Ax 2	Tot	Quad	Clus
SafetyAV_5: Very Safe	−0.843	0.721	3.565	**3.962**	0.162	0.119	0.281	2	1
RegulationSchoolZone_2: No	−0.635	0.352	**5.136**	2.401	0.360	0.111	**0.471**	2	1
FeelProving_5: A Lot	−0.661	0.365	**5.904**	2.739	0.438	0.134	**0.572**	2	1
Circum_AV Safer	−0.877	0.610	0.578	0.424	0.022	0.011	0.033	2	1
BpgPos_Actively Support	−0.640	0.375	**4.942**	2.582	0.331	0.114	**0.445**	2	1
SafetyHuman_2: Unsafe	−0.127	−0.015	0.125	0.003	0.006	0.000	0.007	3	2
SafetyAV_4: Safe	−0.506	0.032	2.279	0.014	0.126	0.001	0.126	2	2
RegulationSpeed_2: No	−0.758	0.472	**4.688**	2.756	0.249	0.096	0.345	2	2
InteractPedestrian_1: Yes	−0.370	0.300	1.346	1.343	0.078	0.052	0.130	2	2
Circum_No Difference	−0.426	0.061	1.764	0.054	0.102	0.002	0.104	2	2
Circum_Cautious about AV	−0.300	0.083	0.151	0.017	0.006	0.000	0.006	2	2
AVSafetyPotential_1: Yes	−0.501	0.163	**4.393**	0.702	0.462	0.049	**0.511**	2	2
SafetyHuman_4: Safe	0.085	0.155	0.042	0.210	0.002	0.007	0.009	1	3
RegulationSpeed_1: Yes	0.513	−0.062	3.634	0.080	0.275	0.004	0.279	4	3
InteractPedestrian_3: Not Sure	0.205	−0.129	0.111	0.066	0.005	0.002	0.006	4	3
InteractPedestrian_2: No	0.213	−0.180	0.661	0.713	0.053	0.038	0.091	4	3
Group_Public	0.096	0.070	0.177	0.144	0.023	0.012	0.035	1	3
Circum_No Experience	0.286	−0.143	1.084	0.411	0.079	0.020	0.098	4	3
SafetyAV_6: No experience	0.425	−0.465	0.507	0.922	0.021	0.025	0.046	4	4
SafetyAV_3: Neutral	0.265	−0.673	0.444	**4.338**	0.021	0.138	0.160	4	4
RegulationSpeed_3: Not Sure	−0.177	−0.595	0.158	2.709	0.007	0.081	0.088	3	4
RegulationSchoolZone_3: Not Sure	0.005	−0.781	0.000	**7.020**	0.000	0.238	0.238	4	4
FeelProving_4: Moderate	−0.030	−0.665	0.005	3.681	0.000	0.113	0.113	3	4
BpgPos_Neutral	0.209	−0.502	0.457	**4.009**	0.028	0.160	0.188	4	4
FeelProving_3: Some	0.493	−0.927	0.859	**4.614**	0.037	0.130	0.166	4	5
BpgPos_No Opinion	0.590	−0.850	0.986	3.109	0.041	0.085	0.126	4	5
AVSafetyPotential_3: Not Sure	0.654	−0.745	3.308	**6.512**	0.172	0.223	**0.394**	4	5
SafetyAV_1: Very Unsafe	2.277	2.178	**7.293**	**10.118**	0.285	0.260	**0.545**	1	6
FeelProving_1: Not at All	2.279	1.788	**10.832**	**10.115**	0.435	0.268	**0.702**	1	6
BpgPos_Actively Oppose	2.414	1.965	**9.325**	**9.378**	0.367	0.243	**0.610**	1	6
AVSafetyPotential_2: No	2.097	1.648	**7.783**	**7.289**	0.308	0.190	**0.499**	1	6
SafetyHuman_6: No experience	0.524	−0.955	0.053	0.268	0.002	0.007	0.009	4	–
SafetyHuman_5: Very Safe	−0.149	0.729	0.021	0.763	0.001	0.019	0.020	2	–
SafetyHuman_3: Neutral	−0.003	−0.215	0.000	0.772	0.000	0.032	0.032	3	–
SafetyHuman_1: Very Unsafe	0.390	0.752	0.217	1.228	0.008	0.032	0.040	1	–
SafetyAV_2: Unsafe	1.037	−0.552	2.761	1.187	0.113	0.032	0.145	4	–
RegulationSchoolZone_1: Yes	1.208	0.215	**9.734**	0.467	0.479	0.015	**0.494**	1	–
Group_BPG	−0.237	−0.173	0.437	0.354	0.023	0.012	0.035	3	–
FeelProving_2: Little	1.096	−0.734	2.854	1.942	0.116	0.052	0.168	4	–
Circum_Others	0.853	0.664	0.565	0.519	0.022	0.013	0.035	1	–
Circum_Negative about AV	0.972	0.222	0.824	0.066	0.032	0.002	0.033	1	–

Note: Ax = Axis; Bold number indicates top 10 values.

This cluster is also associated with participants who have somewhat neutral views on AVs. They do not have any opinion towards BikePGH's position on AVs. They are unsure about the safety

potential of AVs. They are somewhat in support for the proving ground of AVs. The cos^2 and contribution values of two attributes of this cluster are in the top 10 cos^2 and contributions values. The higher values indicate that this cluster is somewhat represented among the survey participants.

Table 4. Overall contributions of the clusters.

Cluster	Contribution		cos^2	
	Axis 1	Axis 2	Axis 1	Axis 2
1	24%	13%	29%	17%
2	18%	5%	23%	7%
3	7%	2%	10%	3%
4	2%	25%	2%	26%
5	6%	15%	6%	15%
6	43%	40%	31%	33%

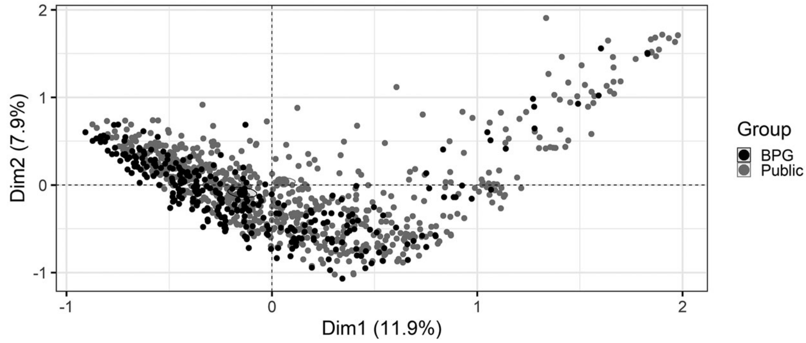

Figure 5. Biplot of individual respondents.

Cluster 6 (AVSafetyPotential_2: No, BpgPos_Actively Oppose, FeelProving_1: Not at All, and SafetyAV_1: Very Unsafe)

The participants of these clusters have strong opposing views on AVs. They feel that Pittsburgh's streets will be totally unsafe with AVs. They oppose using Pittsburgh as the proving ground for AVs. They believe that BikePGH should actively oppose AVs. They do not see any safety potential from AVs. The cos2 and contribution values of all attributes of this cluster are in the top 10 cos2 and contributions values. The higher values indicate that this cluster is very well represented among the survey participants. The percentage values of Table 3 indicate that these attributes are thoroughly explained in both axes. Although the frequency of these attributes was fairly low, these attributes dominate the map by showing the strong cooccurrences of these attributes in the responses. Canis (2018) also shows that half of US drivers feel less safe in the presence of AVs on the roadways.

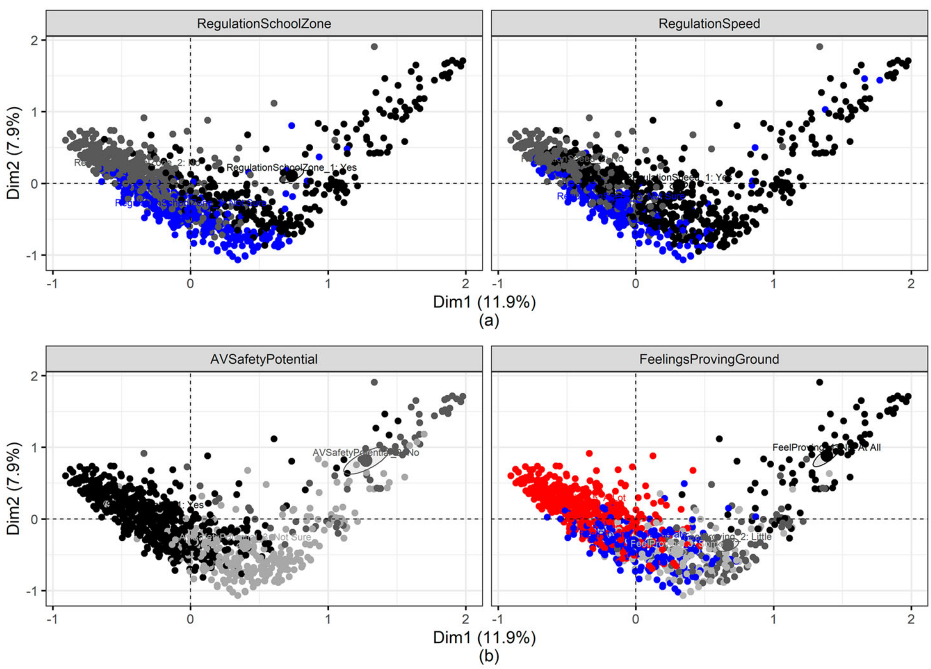

Figure 6. (a) Factor map of RegulationSchoolZone, and RegulationSpeed, (b) Factor map of AVSafetyPotential, and FeelingsProvingGround.

Trust and safety issues have been explored in several other studies too (Bansal and Kockelman 2017; Bansal and Kockelman 2018; Hulse, Xie, and Galea 2018).

Figure 5 shows a global pattern of the individual respondents. The BPG participants are shown in black colour, and public participants are shown in grey. This visualisation also proves that responses of the participant vary based on stakeholder nature. Figure 6(a) illustrates the individual respondents grouped by two variables: RegulationSchoolZone and RegulationSpeed. The distribution of the attributes shows that these two regulations have similar patterns. Participants asking for school zone regulation for AVs are also asking for speed regulation for AVs. Figure 6(b) illustrates the individual respondents grouped by two variables: AVSafetyPotential, and FeelingsProvingGround. The distribution of the attributes shows that these two variables have similar patterns. Participants who think of no safety potentials for AVs are also against the proving ground of AVs in Pittsburgh. These findings are in line with other studies (Grush and Niles 2018; Henaghan 2018).

6. Conclusions

Gaining the feedback from the end-users and understanding acceptability thresholds will be critical to the extensive deployment of AVs. Additionally, comprehending public perception of emerging technologies like AVs is crucial for policymaking. AV companies predict that AVs will be sufficiently reliable and affordable, and that they will replace most human driving by 2030, providing independent mobility to roadway users. As AV technologies are rapidly growing, there is a need to regulate these technologies and their adoptions in the real-world roadway condition.

Non-motorised travel modes, such as walking and biking, have become popular due to health benefits and environment protection. Unfortunately, non-motorised crashes have been sharply rising, perhaps due to this increase in non-motorised activity in urban locations. As both AVs and non-motorised travels are gaining traction in recent years, it is important to understand the perception of the public towards the interaction between non-motorised roadway users and AVs.

This study conducted a less explored AV related study by investigating two research questions: (1) Does the perception towards AVs differ in non-motorists based on stakeholder nature? and (2) Does prior interaction with AVs alter perception on AVs? The findings showed that perception towards AVs differs among the participants based on their stakeholder role. To assist policy development for AV adoption, this study evaluated attitudes of participants towards AV with sensitivity to their experiences with AVs technology. The current study shows that pedestrians with earlier interactions with AVs consider them to be safer than human drivers and they recognise the safety potential for AVs. For those without earlier interactions, the survey shows that they are associated with believing Pittsburgh streets are safer with human-driven cars and that the speed in which AVs are allowed to operate should have a cap. The results of the study provide an assertion that AV human interaction and participant's knowledge on AV technologies are associated with positive attitudes and perceptions. This finding supports the value of having demonstration projects that provide the opportunity for pedestrians and bicyclists to interact with AVs.

The current study does have limitations. First, the survey is limited to a certain region. Second, comprehensive details of circumstances (interaction between AVs and vulnerable users) are not publicly available. Text mining on these narratives can help in understanding the missing link between the perception of AV acceptance among the non-motorists. Third, the survey was conducted before the occurrence of a reported AV crash with non-motorists. It is anticipated that the non-motorists' perception on AVs may have changed. There is a need for a new survey that may reflect the impact of AV-non-motorist crash on non-motorists.

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No potential conflict of interest was reported by the author(s).

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