EXPLORING CHANGES IN RISK PERCEPTIONS AND PUBLIC ACCEPTABILITY OF AUTONOMOUS VEHICLES BETWEEN 2017 AND 2020: A CASE STUDY IN HIROSHIMA, JAPAN

Hong NGUYEN[1], Makoto CHIKARAISHI[2], Akimasa FUJIWARA[3], Canh DO[4], Banri YASUDA[5], Diana KHAN[6]

[1]Researcher, Graduate School of Advanced Science and Engineering, Hiroshima University
(1-5-1 Kagamiyama, Higashihiroshima, Hiroshima 739-8529, Japan)
Email: hongnguyen@hiroshima-u.ac.jp
[2]Member of JSCE, Associate Professor, Graduate School of Advanced Science and Engineering, Hiroshima University
(1-5-1 Kagamiyama, Higashihiroshima, Hiroshima 739-8529, Japan)
Email: chikaraishim@hiroshima-u.ac.jp
[3]Member of JSCE, Professor, Graduate School for International Development and Cooperation, Hiroshima University
(1-5-1 Kagamiyama, Higashihiroshima, Hiroshima 739-8529, Japan)
Email: afujiw@hiroshima-u.ac.jp
[4]Researcher, Graduate School of Advanced Science and Engineering, Hiroshima University
(1-5-1 Kagamiyama, Higashihiroshima, Hiroshima 739-8529, Japan)
Email: canh.doxuan@gmail.com or canhdo@hiroshima-u.ac.jp
[5]Chuden Engineering Consultants, 2-3-30 Deshio, Minami, Hiroshima 734-8510, Japan)
Email: banri.yasuda@cecnet.co.jp
[6]PhD Student, Graduate School of Advanced Science and Engineering, Hiroshima University
(1-5-1 Kagamiyama, Higashihiroshima, Hiroshima 739-8529, Japan)
Email: d170268@hiroshima-u.ac.jp

Despite the potential benefits of autonomous vehicles (AVs), there are still limited studies related to risk perception and public acceptability of AVs. Such studies can help us to understand barriers in AV implementation from the public's perspective. This study expanded on existing work by examining changes in risk perception and AV acceptability over a four-year period and exploring factors influencing AV acceptability. By providing randomized video-based information introducing AVs into society at large and risks associated with AVs (i.e., hacking, system error, and unexpected events), web-based surveys were conducted in the first phase in 2017 and the second phase in 2020 in Hiroshima (Japan). The results showed that there is an increase in acceptable risk levels and decreases in perceived benefits, perceived risks, and risk adjustment factors after the experiments. For the two main risk characteristic factors, the dread and unfamiliarity risk of AVs in the second phase is moderately lower than in the first phase, implying that the public became more familiar with AVs after the AV experiments in 2018 and 2019. We also found that man-made AV risks (i.e., hacking and system error) have both direct and indirect impacts (through a mediator – dread risk) on AV acceptability. The impact of dread risks on AV acceptability is higher than that of unfamiliarity risk. These results suggest that both manufacturers and policy-makers should pay more attention to alleviating these man-made risks rather than aiming to increase the public's familiarity with AVs in order to increase the acceptability of AVs.

Key Words: *autonomous vehicles, public acceptability, risk perception*

1. INTRODUCTION

Over the past few years, the rapid emergence of autonomous vehicles (AVs) has significantly impacted the transportation system. Many recent studies have pointed out major potential benefits of AVs in terms of traffic safety, decrease in travel time, and travel behavior. From the traffic safety viewpoint, the number of crashes dramatically decreases by using AVs[1; 2] as most fatal traffic accidents are caused by human errors such as drunk driving, speeding, and so forth[3]. From the travel time reduction viewpoint, both private and shared AVs reduce commuters' value of travel time[2; 4]. From the travel behavior viewpoint, impacts of AVs on safety and travel time induce changes in travel behavior, such as an increase in the number of long-distance trips[1].

Despite these benefits, some major barriers, either AV cost or AV safety, still hinder the widespread adoption of AVs. Regarding the AV cost, since high AV cost could lead to fewer people being able to afford them, many studies attempted to explore the impact of automation on private vehicle ownership. In particular, AV ownership is one of the influential factors for intention to use AVs[5; 6], while other studies focused on examining whether people prefer to own or share AVs[7; 8]. Concerning AV safety, self-driving technology is seen as potentially unsafe because of the lack of human control, especially the skepticism of AV implementation at level 5 - fully driving automation. Thus, how the safety of AVs affects acceptability has been discussed in recent AVs related studies. Generally speaking, this main obstacle to AV acceptability is usually associated with both social and technological issues. While technological problems are solved by both manufacturers using innovative technologies and governments amending/introducing relevant laws and regulations, the social dilemma is quite challenging as AVs are a new technology which are still in development and which have only been introduced in the past few years[9; 10; 11]. Therefore, examining the public acceptability of this new technology is of great importance, especially before AVs appear widely on the market and are fully adopted at level 5.

Research on AVs has recently started to be interesting in issues around AV acceptability. Although many studies have focused on factors influencing people's willingness to pay for AVs or behavioral intention to use AVs considered important indicators of AV acceptance, it is essential to conduct more research to understand risk perception and public acceptance. In addition, since the provision of AV risk information significantly affects respondents' risk assessment of AVs, their acceptability of AVs may depend on the provision of this information. As AVs are a new technology and there is a low rate of public exposure to this technology, AV risk information has been provided in different ways across studies, particularly through texts[12; 13; 14; 15; 16; 17], pictures[6; 18; 19], and videos[20]. Moreover, while AV experiments involving the public have recently been implemented, how much AV risk perception and AV risk acceptance change after the AV experiment has not been widely explored. Thus, understanding factors affecting AV acceptability and how these changes over time as AVs diffuse is an essential concern for both manufacturers and policy-makers.

Based on the discussion above, this study explores changes in AV acceptability from the first phase (in 2017) and the second phase (in 2020). Surveys were conducted before and after the virtual reality and actual choice experiments (in 2018 and 2019, respectively) on a connected autonomous bus and light rail transit in Hiroshima (Japan). As the actual experiment was the world's first on connected autonomous buses and light rail transit[21], news about this experiment spread in the media. It is assumed that AV acceptability would increase after the experiments, as people living in Hiroshima gained more knowledge and experience of AVs. Although a previous study examined AV acceptability using data from the first phase[20], the current study extends the previous work through two aspects: (*i*) examining changes in risk perception and AV acceptability between the two phases, and (*ii*) exploring factors influencing AV technology in general instead of focusing on each AV technology. By providing randomized video-based information showing AV risk information directly to the participants, a mixed Tobit model is developed to examine how much safer respondents believe AVs should be if their current risk level is unacceptable. In addition to socio-demographic factors, four AV technologies, i.e., AV-Bus (level 3), AV-Car (level 3), AV-Bus (level 4), and AV-Car (level 4), are also addressed in the model, in order to explore how AV acceptance across the four AVs technologies changed over the years (before and after the experiments). Furthermore, since different participants may evaluate risk differently, the assumption that women are sensitive to risk factors is verified through the model results.

This paper is organized as follows. The following section summarizes the literature related to risk perception, focusing on AVs. This is followed by a discussion on survey design and data. Then the main results and discussions are given. Finally, the conclusions, limitations, and potential expansions for future research are presented.

2. LITERATURE REVIEW

Risk perception is subjective risk judgment and is typically investigated via the psychometric paradigm associated with cognitive risk maps, based on psychophysical scale and factors analysis[22; 23]. The cognitive risk map typically shows the relationship between two factors across different hazardous activities and technologies: the factor "dread risk" (i.e., fear related to lack of control, catastrophic, and fatal consequences) and the factor "unfamiliarity risk" (i.e., knowledge about risk, immediacy, and novelty). The research indicates that people are less likely to accept an activity or technology characterized by dread risk or unfamiliarity risk[22; 23]. Since AVs are new and involve less control than traditional driving, it is necessary to address these factors to understand AV acceptability.

Recent studies related to AV acceptability examined dread risk through different forms. As lack of trust leads to drivers being sensitive to dread risk, the acceptance of self-driving vehicles was examined through the dimension of trust, determined by ratings and open-ended comments on how much drivers would trust self-driving technology[24]. The adoption of driverless cars is significantly influenced by some key factors such as privacy (under surveillance, being tracked locations, personal autonomy in making choices) and security from hacking[15]. Another study has shown that the risk-acceptance rate of self-driving had a negative relationship with the traffic-risk frequency of self-driving vehicles[18]. One of the significant predictors of affective connected and autonomous vehicle evaluations is privacy consequence which involves personal data being abused, less secure, and monitored by the third parties[19]. Many other works also proved that factors associated with a desire to have control and privacy concerns about the security of personal data affected the intention to use autonomous electric buses[17; 25; 26; 27; 28].

As the public is mostly unfamiliar with AV technology, potential misconceptions regarding the technology could affect intention to use. Thus many AV studies determined the connection between familiarity and AV acceptability. One study mentioned that the public discourse is not unified about "autonomous driving"[29]. In general, those familiar with technology, especially those who are more informed about AVs, are more likely to accept AVs[6; 14; 17; 28; 30; 31; 32; 33; 34]. In particular, a study of 1355 Chinese respondents showed that those who have heard about AVs technology had a higher willingness to pay for AVs[6]. Using rates of familiarity with different systems of AVs corresponding to the five levels of autonomy, a study of 336 Australians showed that user acceptance and experience with AVs were influenced by familiarity with these systems[28]. Specifically, the highest user acceptance and experience were observed among different autonomy levels for people familiar with cars. Participants having pre-experience with AVs tended to accept more AV functions than inexperienced people. Another study of 834 US participants demonstrated that those familiar with AVs had a statistically positive attitude towards owning and sharing AVs[14].

Different socio-demographic clusters seem to have differing knowledge about AVs, so socio-demographic factors are often considered in studies related to AV acceptability. The elderly are less likely to accept AV use due to physical and cognitive limitations associated with new technology. While the youth are usually more interested in AV technology[35] and more willing to pay for AVs[33; 36; 37], older people are less willing to pay for adding AV technology for the next car[6]. In addition, gender differences in risk perception have been noted through various research. In general, women are found to have high perceived risk and less positive attitudes towards new technology than men. Women have higher anxiety, lower perceived benefits, and thus lower willingness to use AVs than men[34] and lower willingness to pay for adding AV technology in their next car than men [33]. Besides, other demographic factors such as income and education affect willingness to pay for AVs[6]. This study contributes to this literature by examining the interaction between women and dread risk factors towards AV acceptability.

This study builds on previous work analyzing the risk acceptability of AVs in Hiroshima in 2017[20]. Dread risk is determined by various risk characteristics (i.e., control over risk, chronic to catastrophic, common to dread, severity of consequences, voluntariness of risk, and immediacy of effect). In contrast, familiarity risk is presented by other risk characteristics (i.e., knowledge about risk for an exposed and professional person and newness)[20]. In addition, since different socio-demographic clusters seem to have various knowledge about AVs, socio-demographic factors (age, gender, car users, and bus users) also are taken into account for understanding the acceptability of AVs over the years.

Table 1 Randomized video-based information about AV-related risk elements

Type	Sample size		Combination of risk-based elements
	1st phase (2017)	2nd phase (2020)	
1	206	148	System error + hacking + unexpected events
2	206	148	System error + hacking
3	206	148	System error
4	206	148	Hacking + unexpected events
5	206	148	Hacking
6	206	148	Unexpected events
7	206	147	System error + unexpected events

3. SURVEY AND DATA

The web-based surveys were conducted for the first phase with 1442 respondents in March 2017 and for the second phase with 1035 respondents in March 2020 in Hiroshima (Japan). Respondents watched AV-related videos that first introduced AVs technology and then randomly showed one of seven types of AV-related risk elements associated with hacking, error systems, and unexpected events (**Table 1**).

The surveys were designed with a focus on risk perception based on studies by Fischhoff *et al.*[22] and Slovic[23] to capture perceived benefits, perceived risk, and risk adjustment factors across 20 activities and technologies: nuclear power, motor vehicles, handguns, smoking, alcoholic beverages, general/private aviation, large construction, mountain climbing, bicycling, energy drinks, electric power (nonnuclear), skiing, railways, amusement attractions, drones, prescription antibiotics, AV-bus (level 3), AV-bus (level 4), AV-car (level 3), and AV-car (level 4). It is noted that the definition of AV levels (level 3 - under human control, level 4 - under automatic control) was mentioned in the video. For the perceived benefits and risk, the respondents were asked to rate the least beneficial/risky activity/technology as ten and rate the benefit/risk of remaining activities and technologies using this activity/technology as a reference. For example, a rating of 12 indicated the activity/technology is 1.2 times as beneficial/risky as the least beneficial/risky activity/technology (i.e., 20% more beneficial or riskier). Based on respondents' judgment on each activity/technology, the risk adjustment factor was defined as 1/X for those who judged the activity/technology could be riskier (i.e., it would be acceptable if it was X times riskier), 1 for those who judged the activity/technology could be accepted as it is (i.e., it is presently acceptable), Y for those who assessed the activity/technology needs to be safer (i.e., it would be acceptable if it was Y times safer). Although some respondents judged the activity/technology could be riskier or needs to be safer, it would be illogical for them to report that X or Y is equal to 1. These respondents might not have understood the question's instructions or had a low willingness to answer. Therefore, these respondents are excluded in this study to reduce noise/bias, and as a result, 1195 samples in the first phase (in 2017) and 1035 samples in the second phase (in 2020) are used to do further analysis.

Nine risk characteristics of each activity/technology were also collected by using a seven-point Likert scale as follows:

i. Voluntariness of risk: To what extent do people get into the risky situation voluntarily (1 = involuntary, 7 = voluntary)
ii. Immediacy of the effect: To what extent is the risk of death immediate (1 = immediate, 7 = delayed)
iii. Knowledge about the risk for exposed people: To what extent is the risk known precisely by the exposed persons (1 = not known, 7 = known precisely)
iv. Knowledge about the risk for professionals: To what extent is the risk known to science (1 = not known, 7 = known precisely)
v. Control over risk: To what extent can people avoid death when engaging in the activity/technology (1 = uncontrollable, 7 = controllable)
vi. Newness: To what extent is the risk new and novel (1 = new, 7 = old)
vii. Chronic - catastrophic: To what extent does the risk kill people at a time (chronic risk) or lots of people at once (catastrophic risk) (1 = catastrophic, 7 = chronic)
viii. Common - dread: To what extent have people learned to live with the risk (1 = dread, 7 = common)
ix. Severity of the consequences: To what extent will the consequence of risk be fatal (1 = certain to be fatal, 7 = certain not to be fatal).

Table 2 Description of respondents' characteristics

Socio-demographic factors	**1st phase**		**2nd phase**		***p*-value**	**Standardized Mean Difference (SMD)**
	Mean	SD	Mean	SD		
Age	45.17	-13.03	45.98	-13.53	0.15	0.06
Age (24 years or younger) [D]	0.05	-0.21	0.05	-0.21	0.96	0.00
Age (25–34 years) [D]	0.19	-0.40	0.17	-0.38	0.18	0.06
Age (45–44 years) [D]	0.25	-0.43	0.25	-0.43	0.81	0.01
Age (45–54 years) [D]	0.26	-0.44	0.26	-0.44	0.87	0.01
Age (55–64 years) [D]	0.16	-0.37	0.16	-0.37	0.88	0.01
Age (65 years or older) [D]	0.09	-0.29	0.11	-0.31	0.16	0.06
Female [D]	0.45	-0.50	0.46	-0.50	0.83	0.01
Car User [D]	0.60	-0.49	0.55	-0.50	0.01	0.11
Bus User [D]	0.08	-0.28	0.06	-0.24	0.05	0.09
Sample size	1195		1035			

Note: [D]: Dummy variable

Table 3 Perceived risk, perceived benefit, and acceptable risk level for 20 activities and technologies

No.	Activities/technologies	Perceived benefit *(Geometric mean)*		Perceived risk *(Geometric mean)*		Risk adjustment factor *(Geometric mean)*		Acceptable risk level	
		1st phase	2nd phase	1st phase	2nd phase	1st phase	2nd phase	1st phase	2nd phase
1	Nuclear power	18.16	17.20	28.34	24.96	4.61	4.05	6.15	6.17
2	Motor vehicles	27.11	25.01	23.81	22.51	1.20	1.27	19.85	17.69
3	Handguns	12.35	12.31	29.05	26.76	10.60	9.01	2.74	2.97
4	Smoking	12.78	12.71	24.80	23.57	5.66	5.32	4.39	4.43
5	Alcoholic beverages	17.38	16.42	20.29	19.48	1.66	1.55	12.25	12.53
6	General (private) aviation	23.40	21.16	18.12	18.21	1.39	1.34	13.06	13.59
7	Large construction	21.80	20.40	18.72	18.34	1.44	1.45	13.01	12.65
8	Mountain climbing	16.68	16.65	18.19	17.26	1.62	1.43	11.24	12.08
9	Bicycles	22.24	20.57	17.19	16.30	1.14	1.07	15.14	15.19
10	Energy drink	15.28	15.16	13.64	13.79	1.41	1.40	9.67	9.86
11	Electric power (nonnuclear)	27.92	25.36	16.34	15.90	1.14	1.04	14.35	15.35
12	Skiing	15.63	15.36	16.19	15.47	1.37	1.34	11.85	11.53
13	Railways	26.04	23.73	16.26	16.07	1.03	1.03	15.85	15.62
14	Amusement attraction	18.73	17.68	15.02	15.01	1.31	1.25	11.46	12.04
15	Drones	20.01	19.18	14.72	14.41	1.60	1.31	9.22	10.97
16	Prescription antibiotics	24.55	22.56	16.22	15.76	1.38	1.29	11.74	12.20
17	**AV-bus (level 3)**	**23.19**	**21.95**	**19.72**	**18.42**	**2.44**	**1.99**	**8.08**	**9.24**
18	**AV-bus (level 4)**	**23.32**	**22.35**	**20.12**	**18.92**	**2.82**	**2.35**	**7.13**	**8.05**
19	**AV-car (level 3)**	**23.52**	**22.34**	**20.35**	**19.13**	**2.54**	**2.10**	**8.02**	**9.11**
20	**AV-car (level 4)**	**23.77**	**22.77**	**20.51**	**19.37**	**2.88**	**2.52**	**7.11**	**7.67**

The balance of covariates between the first and the second phases is examined through standardized mean difference (SMD). The results show that the SMD in all socio-demographic factors is greater than 0.1 (Note the car user variable with SMD less than 0.2). The threshold is recommended for declaring balance[38; 39] (**Table 2**). Meanwhile, respondents' characteristics in both phases are balanced.

4. RESULTS

(1) Perceived risk, perceived benefit, and acceptable risk level

Table 3 shows perceived risk, perceived benefit, and acceptable risk level for twenty activities and technologies. Notably, the geometric mean was used to avoid the overly large influence of extreme values. In general, the acceptable risk level in the second phase is higher than that in the first phase, while the opposite trend is seen in perceived risk, perceived benefit, and risk adjustment factors. For perceived benefit, electric power (nonnuclear) (#11) was rated highest, followed by motor vehicle (#2) and railway (#13) in both phases. For the perceived risk, in both phases, the highest risk belongs to handguns (#3), followed by nuclear power (#1), smoking (#4), and motor vehicle (#2), in descending order. These results are consistent with findings in the study by Fischhoff *et al.*[22]. In terms of travel modes (i.e., motor vehicles, railways, bicycles, and AVs), although AVs (#17 to #20) are more beneficial than bicycles (#9), AVs (#17 to #20) are riskier than railways (#13) and bicycles (#9), and safer than motor vehicles (#2). This finding can be interpreted as unfamiliarity with AVs or feelings of dread risk of AVs, which is later confirmed by our analysis. Among the four AV technologies in both phases, the AV-car (#19, #20) is seen as having higher benefit and risk than AV-bus (#17, #18), while AVs at level 4 (#18, #20) were rated as having slightly higher perceived benefit and risk than AVs at level 3 (#17, #19). This result suggests that level 4 AV is associated with more dread risks such as lack of control or fatal consequences.

The acceptable risk level is calculated as perceived risk divided by the risk adjustment factor. The least acceptable risk level is the handgun, followed by smoking and AVs in both phases. Based on Welch's t-test results, despite no significant differences in perceived risk among the four AVs, there are significant differences in acceptable risk level between level 3 and 4: AV-bus (level 3) and AV-bus (level 4), with t = 1.85 for the first phase and t = 1.86 for the second phase, and between AV-car (level 3) and AV-car (level 4), with t = 1.72 for the first phase and t = 2.17 for the second phase.

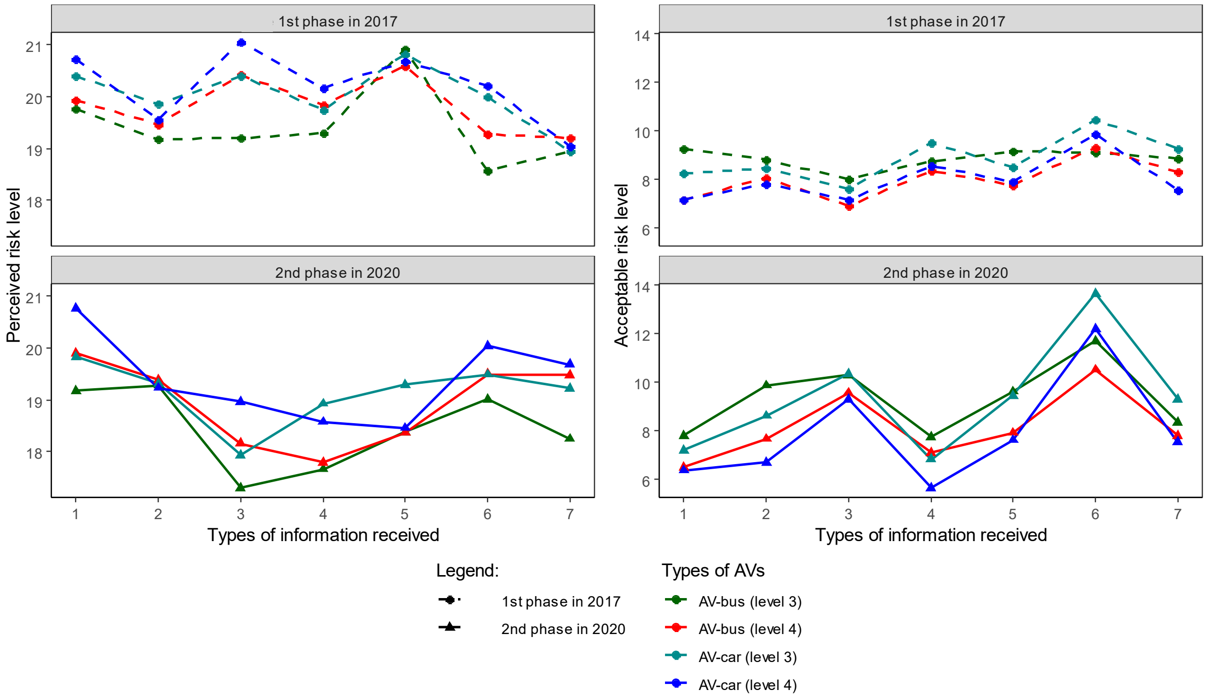

Fig. 1 Perceived risk and acceptable risk level across types of information received

Table 4 Factors generated from risk characteristics

Risk characteristics	1st phase		2nd phase	
	Dread risk	**Unfamiliarity risk**	**Dread risk**	**Unfamiliarity risk**
1. Voluntariness of risk	**-0.82**	-0.36	**-0.81**	-0.41
2. Immediacy of effect	**-0.73**	0.10	**-0.66**	0.17
3. Knowledge about risk (for exposed people)	0.05	**-0.99**	0.11	**-0.99**
4. Knowledge about risk (for professionals)	-0.02	**-0.98**	0.07	**-0.93**
5. Control over risk	**-0.97**	-0.16	**-0.99**	-0.15
6. Newness	-0.01	**-0.92**	-0.03	**-0.89**
7. Chronic-catastrophic	**-0.91**	-0.09	**-0.83**	-0.04
8. Common-dread	**-0.84**	0.14	**-0.81**	0.20
9. Severity of consequences	**-0.93**	0.32	**-0.90**	0.41
Proportion Variance	*0.50*	*0.34*	*0.47*	*0.34*

(2) Impacts of AV risk information on perceived benefit and acceptable risk level of AVs

Fig. 1 shows the perceived benefit and acceptable risk level of the four AV technologies for different types of information received. Generally speaking, while perceived risk associated with video-based information related to single risk information, either hacking or system error, differs between the two phases, significant differences in acceptable risk level are observed in respondents receiving the video showing only system error or only unexpected events. Based on the one-way ANOVA test results, there is no statistically significant impact of video-based risk information on the perceived risk and acceptable risk level, except for acceptable risk level in AV-car in the second phase ($F(6,1028) = 2.62$, $p = 0.02$ for AV-car (level 3), and $F(6,1028) = 2.84$, $p = 0.01$ for AV-car (level 4)). The results indicate that it is likely that the types of information received do have a significant effect on the acceptable risk level of AV-car in the second phase.

(3) Cognitive map of risk perception

Table 4 shows the result of a factor analysis using the Bartlett factor score. Particularly, the two factors (dread risk and unfamiliarity risk) were generated from the nine risk characteristics. More than 80% of the observed variance in the nine characteristics was explained by these two factors in both phases, which proves that these characteristics fit with the theory proposed by Slovic[23)] and Fischhoff *et al.*[22)]. Specifically, the dread risk is determined by six characteristics (i.e., control over risk, chronic to catastrophic, common dread, severity of consequences, voluntariness of risk, and immediacy of effect). In comparison, familiarity risk is presented by three risk characteristics (i.e., knowledge about risk for an exposed and professional person, and newness).

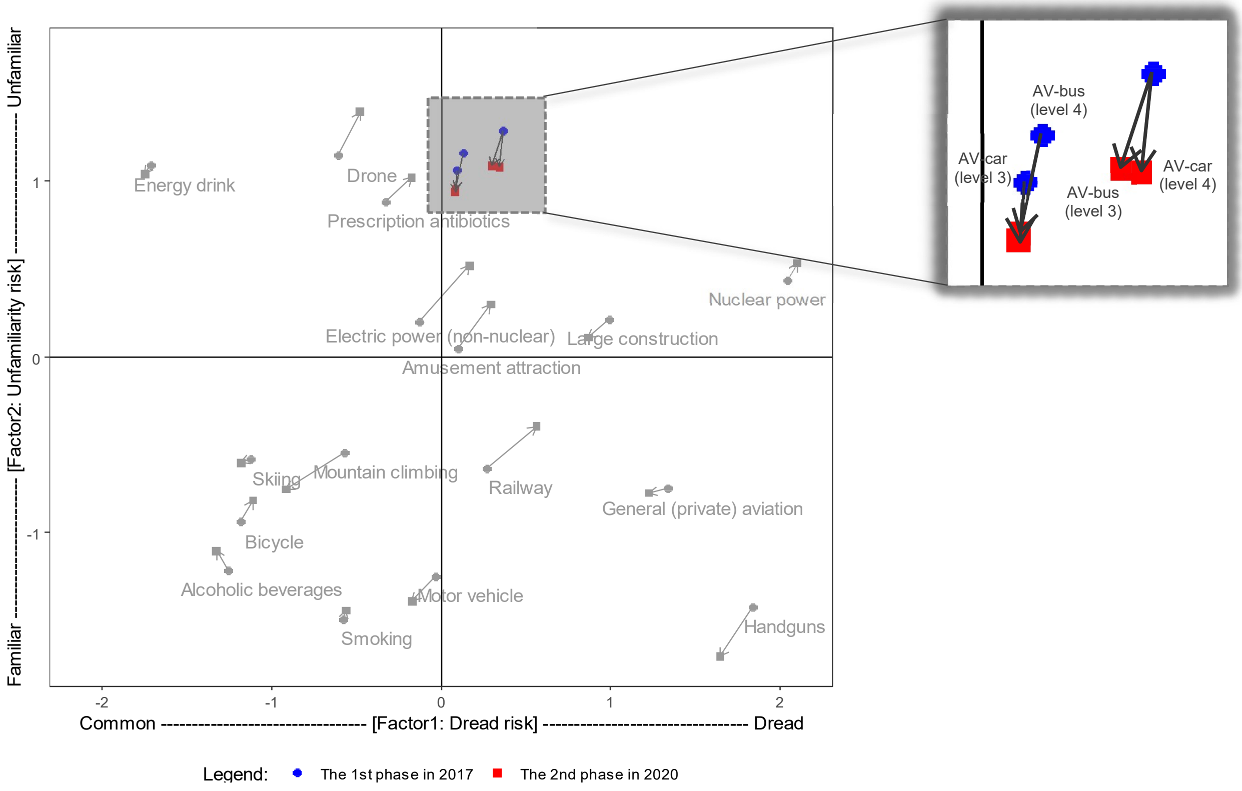

Fig. 2 Cognitive risk map of 20 activities and technologies

The cognitive risk map of 20 activities and technologies is created based on factor scores of the two factors (dread risk and unfamiliarity risk) (see **Fig. 2**). Smoking and alcoholic beverages belong to a quarter of familiar and common risks, whereas nuclear power and handguns are judged as having high dread but low familiarity. Unlike other travel modes (e.g., bicycle, motor vehicle, railway) be highly familiar to the public, as expected, the four AVs technologies (i.e., AV-Bus (level 3), AV-Car (level 3), AV-Bus (level 4), and AV-Car (level 4)) have high unfamiliarity and less dread, indicating that newness and inexperience influence the risk perception of AVs. Regarding automation levels, the dread and unfamiliarity risks of level 4 AVs are always more significant than that of level 3 AVs, which might be interpreted as people feeling a greater sense of lack of control and unfamiliarity with the fully automated level. Regarding the acceptable risk level of AVs in the two phases, the dread and unfamiliarity of AVs in the second phase were moderately lower than that in the first phase, implying that AVs after the experiments become more common and familiar to the public compared to before the experiments. As a result, AV acceptability may be higher than in the past, proven by later analysis.

(4) Impact of risk information received on dread and unfamiliarity risks factors

The seven types of AV risk information were classified into three groups: hacking-related information, system error-related information, and unexpected event-related information as the above analysis show that the perceived benefit and acceptable risk level for AVs are different across the seven types of AV risk information received, especially the single risk information of AVs (i.e., hacking, system error, unexpected events). To assess the impact of AVs risk information received on the two factors of dread risk and unfamiliarity risk, an ANOVA analysis was implemented to test the significant differences in dread and unfamiliarity risks among the three groups of AVs risk information. Based on the above factor analysis result, dread risk is simply calculated as the mean value of the six risk characteristics (i.e., control over risk, chronic catastrophic, common dread, severity of consequences, voluntariness of risk, and immediacy of effect), and familiarity risk is simply calculated as the mean value of the three remaining risk characteristics (i.e., knowledge about risk for exposed and professional people and newness). Since the four AV technologies (i.e., AV-Bus (level 3), AV-Car (level 3), AV-Bus (level 4), and AV-Car (level 4)) are integrated into a single variable to give an overview of AV technology, the type III ANOVA for a linear mixed model is employed to control individual heterogeneity in this analysis.

Table 5 Type III ANOVA analysis in dread risk and unfamiliarity risk across AV risk information received

	AVs technology			
	1st phase		2nd phase	
	F-value $F(1, 1191)$	*p*-value	*F*-value $F(1, 1031)$	*p*-value
Dread risk				
Hacking-related AVs risk information	1.99	0.16	**9.64**	**1.95e-3**
System error-related AVs risk information	**7.26**	**0.01**	**2.90**	**0.09**
Unexpected event-related AVs risk information	0.22	0.64	0.04	0.84
Unfamiliarity risk				
Hacking-related AVs risk information	0.06	0.81	0.82	0.36
System error-related AVs risk information	1.30	0.25	1.03	0.31
Unexpected event-related AVs risk information	0.97	0.32	1.86	0.17

Table 5 shows the ANOVA results in dread and unfamiliarity risks based on the three groups of AV risk information. Regarding the dread risk, while there was a statistically significant difference for participants who received AV risk information related to system errors for both phases ($F(1,1191) = 7.26$ with $p = 0.01$ in the first phase, $F(1,1031) = 2.90$ with $p = 0.09$ in the second phase), there is only a statistically significant difference for those who received AV risk information about hacking ($F(1,1031) = 9.64$ with $p = 1.95e\text{-}3$) in the second phase. This phenomenon may be because the number of hacking systems has increased in recent years in Japan, especially before the Olympics 2020, leading to an increase in the public's fear about hacking. In terms of the unfamiliarity risk, there is no statistically significant difference across the three groups of AV risk information, which may be explained by the above reason. This result shows that AV risk information does not significantly affect perceived risk and acceptable risk level.

(5) Factors influencing AVs acceptance

The mixed Tobit model is developed to examine whether the respondents accept the current risk level and how much safer respondents believe AVs should be if their current risk level is unacceptable. In principle, there are two steps in estimating the model: (*i*) identify whether the respondents accept the current risk or not, and (*ii*) select those who do not accept the current risk to estimate how much safer AVs should be to be accepted. Note that in this study, as the four types of AV technologies were integrated into a single AV technology category to facilitate the analysis of AV acceptability, a mixed Tobit model is developed to capture fixed and random effects coupled with heterogeneity among individuals. The dependent variable is defined as the difference between perceived risk and acceptance risk level.

As shown in **Table 6**, regarding the socio-demographic variables, the youth tend to accept AVs risk compared to those aged from 65 years and above (a reference group). Specifically, the younger they are, the more acceptable AV technology becomes, consistent with the previous findings[18; 33; 36; 37; 40)] as the youth are usually more interested in AV technology[35)]. Interestingly, those aged 35 to 44 are statistically insignificant in the first phase but are statistically significant in the second phase. For the interaction between gender and dread risk, the results show that females are likely to be sensitive to increases in dread risk, which influences their AV acceptability compared with males. Notably, the female respondents in the first phase are more sensitive to increases in dread risk than men, and those in the second phase are less sensitive to increases in dread risk than men. A reasonable explanation of the result in the second phase could be that women have higher anxiety and lower perceived benefits about AV technology due to recent accidents associated with AV technology, which lessen their AV acceptability, consistent with existing findings [33; 41)]. Regarding the main travel mode, car and bus users in both phases tend to accept AV technology more than other transportation users.

Concerning AV risk information received, AV risk information (except for system error in the second phase) is statistically significant and has a negative impact on AVs acceptability, whereas hacking-related AV risk information in the first phase positively affects AV acceptability statistically. To explain the change from negative to positive, it may be the case that in the first phase, people view hacking associated with AVs as being low risk. This result is consistent with the risk homeostasis theory, which indicates that safety is unlikely to improve unless the amount of risk they are willing to take is reduced [42)]. In conjunction with the above results, AV risk information has both direct and indirect impacts (through dread risk factor) on AV acceptability.

Table 6 Estimation result of the Mixed Tobit model

Variables	AVs technology			
	1st phase		2nd phase	
	Parameter	*t*-value	Parameter	*t*-value
Intercept	4.68	32.26***	4.45	24.21***
Age (24 years or younger) [D]	-1.81	-12.53***	-2.40	-11.75***
Age (25–34 years) [D]	-1.05	-10.78***	-0.79	-6.43***
Age (35–44 years) [D]	-0.04	-0.46	-0.66	-5.86***
Age (45–54 years) [D]	-0.59	-6.56***	-0.73	-6.55***
Age (55–64 years) [D]	-0.60	-6.38***	-0.76	-5.82***
Female* Dread risk	0.19	11.90***	-0.21	-10.18***
Car user [D]	-0.30	-5.73***	-0.19	-2.74**
Bus user [D]	-0.75	-7.85***	-0.43	-3.28**
Hacking-related AV risk information [D]	-0.48	-9.57***	0.86	12.34***
System error-related AV risk information [D]	0.17	3.28**	0.02	0.24
Unexpected event-related AV risk information [D]	0.25	4.92***	0.17	2.59***
Factor 1: Dread risk	**0.59**	**23.71*****	**1.01**	**30.61*****
Factor 2: Unfamiliarity risk	**0.42**	**19.01*****	**0.34**	**11.34*****
AV-Bus (Level 3) [D]	**-0.35**	**-5.88*****	**-0.48**	**-6.58*****
AV-Bus (Level 4) [D]	-0.05	-0.65	**-0.24**	**-2.50***
AV-Car (Level 3) [D]	**-0.18**	**-2.46***	**-0.32**	**-3.42*****
log (SigmaMu)	0.77	53.20***	0.87	46.53***
log (SigmaNu)	0.09	10.39***	0.21	17.93***
Log-likelihood at constant	*-5705.27*		*-4639.05*	
Final log-likelihood	*-5421.80*		*-4420.22*	
Sample size: Total	*4780*		*4140*	
Sample size: Risk is acceptable (left-censored)	*2518*		*2411*	
Sample size: Risk is not acceptable	*2262*		*1729*	

Note: *p < 0.05; **p < 0.01; ***p < 0.001;
[D]: Dummy
SigmaMu: Variance of individual-specific effects
SigmaNu: Variance of remaining unexplained effects

Among the four types of AVs technology, the AV-Car (level 4) (as a reference group) would be the most challenging technology to be accepted in public. In addition, the level 3 AV technology tends to be easier to be accepted in public than the level 4 AV technology. These statements are concretely confirmed in the second phase.

For the two risk factors (dread risk and unfamiliarity), generally speaking, the increases in these risks lead to the decreases in AVs acceptability, as expected. The impact of dread risk on AV acceptability is always higher than unfamiliarity risk in both phases. These findings are consistent with the existing study[20)].

5. CONCLUSION

Implementation of AVs has brought potential benefits to transportation systems, such as reducing some traffic accidents and decreasing travel time. However, there are still limited studies related to risk perception and public acceptability of AVs, especially how much safer the public believes AVs should be if the current risk level is unacceptable. This study contributes to the growing literature on AVs acceptance using surveys in which participants were directly provided with randomized video-based information showing AVs risk information to collect their attitudes about AVs. The online surveys of 1442 respondents in the first phase (in 2017) and 1035 respondents in the second phase (in 2020) were conducted before and after the implementation of virtual reality and actual choice experiments (in 2018 and 2020, respectively) of a connected public transport between an autonomous bus and a light rail transit in Hiroshima (Japan).

The results show an increase in acceptable risk level and decrease in perceived benefits, perceived risks, and risk adjustment factors after the implementation of the experiments, which was primarily as the residents of Hiroshima gained more knowledge and experience about AVs. Significantly, as expected, the dread and unfamiliarity risk of AVs in the second phase was moderately lower than in the first phase, implying that AVs after the experiments became more common and familiar with the public than before the experiments. The study also suggests AVs are more likely to be accepted by youth, males, car users, and bus users, and thus targeting these people could lead to greater AV adoption by the public. In addition, AV risk information provided to participants about hacking, system error, and unexpected events has both direct and indirect impacts (through a mediator – dread risk) on AV acceptability. Significantly, the public pays more attention to the effects of man-made AV risks (i.e., hacking and system error) on dread risk in the second phase due to increases in recent AV accidents (e.g., the death of Elaine Herzberg killed by an Uber AV in the US). Additionally, the impact of dread risk on AV acceptability is higher than that of unfamiliarity risk. These results indicate that both manufacturers and policy-makers should focus more on mitigating these man-made risks rather than aiming to increase the public's familiarity with AVs in order to increase the acceptability of AVs. In other words, gaining trust is a key factor in promoting the acceptability of AV among the public.

Some limitations of this study and future research directions should be noted. First, instead of providing randomized video-based information related to AV risk to participants, showing AV risk using the virtual reality technology would significantly affect respondents' attitudes about AVs as they can deeply perceive the risks associated with AVs. Second, as risk perception is associated with emotional rather than analytical factors, risk perception may be socially constructed. Although the current study examined risk perception at the individual level, focusing on the social amplification of AV risk should be addressed in further work.

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REFERENCES

1) Dannemiller, K. A., Mondal, A., Asmussen, K. E., & Bhat, C. R. (2021). Investigating autonomous vehicle impacts on individual activity-travel behavior. *Transportation Research Part A: Policy and Practice,* 148, 402-422.
2) Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice,* 77, 167-181.
3) Shinar, D. (2019). Crash causes, countermeasures, and safety policy implications. *Accident Analysis & Prevention,* 125, 224-231.
4) Zhong, H., Li, W., Burris, M. W., Talebpour, A., & Sinha, K. C. (2020). Will autonomous vehicles change auto commuters' value of travel time? *Transportation Research Part D: Transport and Environment,* 83, 102303.
5) Lee, J., Lee, D., Park, Y., Lee, S., & Ha, T. (2019). Autonomous vehicles can be shared, but a feeling of ownership is important: Examination of the influential factors for intention to use autonomous vehicles. *Transportation Research Part C: Emerging Technologies,* 107, 411-422.
6) Liu, P., Guo, Q., Ren, F., Wang, L., & Xu, Z. (2019). Willingness to pay for self-driving vehicles: Influences of demographic and psychological factors. *Transportation Research Part C: Emerging Technologies,* 100, 306-317.
7) Lavieri, P. S., Garikapati, V. M., Bhat, C. R., Pendyala, R. M., Astroza, S., & Dias, F. F. (2017). Modeling individual preferences for ownership and sharing of autonomous vehicle technologies. *Transportation Research Record,* 2665(1), 1-10.
8) Mohammadzadeh, M. (2021). Sharing or owning autonomous vehicles? Comprehending the role of ideology in the adoption of autonomous vehicles in the society of automobility. *Transportation Research Interdisciplinary Perspectives,* 9, 100294.
9) Bonnefon, J.-F., Shariff, A., & Rahwan, I. (2016). The social dilemma of autonomous vehicles. *Science,* 352(6293), 1573.
10) Martin, R., Kusev, I., Cooke, A. J., Baranova, V., Van Schaik, P., & Kusev, P. (2017). Commentary: The Social Dilemma of Autonomous Vehicles. *Frontiers in psychology,* 8, 808-808.
11) Awad, E., Dsouza, S., Kim, R., Schulz, J., Henrich, J., Shariff, A., et alRahwan, I. (2018). The Moral Machine experiment. *Nature,* 563(7729), 59-64.
12) Casley, S. V., Quartulli, A. M., & Jardim, A. S. (2013) *A Study of Public Acceptance of Autonomous Cars*, Worcester,
13) Lee, J. D., & Kolodge, K. (2020). Exploring trust in self-driving vehicles through text analysis. *Human factors,* 62(2), 260-277.
14) Wang, S., Jiang, Z., Noland, R. B., & Mondschein, A. S. (2020). Attitudes towards privately-owned and shared autonomous vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour,* 72, 297-306.
15) Kaur, K., & Rampersad, G. (2018). Trust in driverless cars: Investigating key factors influencing the adoption of driverless cars. *Journal of Engineering and Technology Management,* 48, 87-96.
16) Rezaei, A., & Caulfield, B. (2020). Examining public acceptance of autonomous mobility. *Travel Behaviour and Society,* 21, 235-246.
17) Kyriakidis, M., Happee, R., & de Winter, J. C. (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transportation Research Part F: Traffic Psychology and Behaviour,* 32, 127-140.

18) Liu, P., Yang, R., & Xu, Z. (2019). How safe is safe enough for self‐driving vehicles? *Risk analysis,* 39(2), 315-325.
19) Kacperski, C., Kutzner, F., & Vogel, T. (2021). Consequences of autonomous vehicles: Ambivalent expectations and their impact on acceptance. *Transportation Research Part F: Traffic Psychology and Behaviour,* 81, 282-294.
20) Chikaraishi, M., Khan, D., Yasuda, B., & Fujiwara, A. (2020). Risk perception and social acceptability of autonomous vehicles: A case study in Hiroshima, Japan. *Transport Policy,* 98, 105-115.
21) Fujiwara, A., Chikaraishi, M., Khan, D., Ogawa, A., Suda, Y., Yamasaki, T., et alNamba, S. (2021). Autonomous Bus Pilot Project Testing and Demonstration Using Light Rail Transit Track. *International Journal of Intelligent Transportation Systems Research*, (in Print).
22) Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., & Combs, B. (1978). How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. *Policy sciences,* 9(2), 127-152.
23) Slovic, P. (1987). Perception of risk. *Science,* 236(4799), 280-285.
24) Lee, J. D. (2019). Trust and the teleology of technology. *Ergonomics,* 62(4), 500-501.
25) Herrenkind, B., Brendel, A. B., Nastjuk, I., Greve, M., & Kolbe, L. M. (2019). Investigating end-user acceptance of autonomous electric buses to accelerate diffusion. *Transportation Research Part D: Transport and Environment,* 74, 255-276.
26) Zmud, J. P., & Sener, I. N. (2017). Towards an understanding of the travel behavior impact of autonomous vehicles. *Transportation research procedia,* 25, 2500-2519.
27) Planing, P. (2014). *Innovation acceptance: the case of advanced driver-assistance systems*, Springer Science & Business Media.
28) Rödel, C., Stadler, S., Meschtscherjakov, A., & Tscheligi, M. (2014). *Towards autonomous cars: The effect of autonomy levels on acceptance and user experience.* Paper presented at the Proceedings of the 6th international conference on automotive user interfaces and interactive vehicular applications.
29) Fraedrich, E., & Lenz, B. (2016). Societal and individual acceptance of autonomous driving *Autonomous driving* (pp. 621-640), Springer.
30) Sweet, M. N., & Laidlaw, K. (2019). No longer in the driver’s seat: How do affective motivations impact consumer interest in automated vehicles? *Transportation*, 1-34.
31) Nordhoff, S., De Winter, J., Kyriakidis, M., Van Arem, B., & Happee, R. (2018). Acceptance of driverless vehicles: Results from a large cross-national questionnaire study. *Journal of Advanced Transportation,* 2018.
32) Sanbonmatsu, D. M., Strayer, D. L., Yu, Z., Biondi, F., & Cooper, J. M. (2018). Cognitive underpinnings of beliefs and confidence in beliefs about fully automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour,* 55, 114-122.
33) Bansal, P., Kockelman, K. M., & Singh, A. (2016). Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transportation Research Part C: Emerging Technologies,* 67, 1-14.
34) Daziano, R. A., Sarrias, M., & Leard, B. (2017). Are consumers willing to pay to let cars drive for them? Analyzing response to autonomous vehicles. *Transportation Research Part C: Emerging Technologies,* 78, 150-164.
35) Owens, J. M., Antin, J. F., Doerzaph, Z., & Willis, S. (2015). Cross-generational acceptance of and interest in advanced vehicle technologies: A nationwide survey. *Transportation Research Part F: Traffic Psychology and Behaviour,* 35, 139-151.
36) Bansal, P., & Kockelman, K. M. (2018). Are we ready to embrace connected and self-driving vehicles? A case study of Texans. *Transportation,* 45(2), 641-675.
37) Abraham, H., Lee, C., Brady, S., Fitzgerald, C., Mehler, B., Reimer, B., & Coughlin, J. F. (2017). *Autonomous vehicles and alternatives to driving: trust, preferences, and effects of age.* Paper presented at the Proceedings of the transportation research board 96th annual meeting (TRB'17).
38) Abdia, Y., Kulasekera, K., Datta, S., Boakye, M., & Kong, M. (2017). Propensity scores based methods for estimating average treatment effect and average treatment effect among treated: A comparative study. *Biometrical Journal,* 59(5), 967-985.
39) Stuart, E. A., Lee, B. K., & Leacy, F. P. (2013). Prognostic score–based balance measures can be a useful diagnostic for propensity score methods in comparative effectiveness research. *Journal of clinical epidemiology,* 66(8), S84-S90. e81.
40) Hulse, L. M., Xie, H., & Galea, E. R. (2018). Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age. *Safety science,* 102, 1-13.
41) Hohenberger, C., Spörrle, M., & Welpe, I. M. (2016). How and why do men and women differ in their willingness to use automated cars? The influence of emotions across different age groups. *Transportation Research Part A: Policy and Practice,* 94, 374-385.
42) Wilde, G. J. (1998). Risk homeostasis theory: an overview. *Injury prevention,* 4(2), 89-91.

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