Safety Science 121 (2020) 634–650

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Public perceptions of autonomous vehicle safety: An international comparison

Joanna Moody[a], Nathaniel Bailey[b], Jinhua Zhao[c,*]

[a] Department of Civil & Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Ave., 1-131, Cambridge, MA 02139, United States
[b] Department of Civil & Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Ave., 1-245, Cambridge, MA 02139, United States
[c] Edward H. and Joyce Linde Associate Professor of Transportation and City Planning, Department of Urban Studies and Planning, Massachusetts Institute of Technology, 77 Massachusetts Ave., 9-523, Cambridge, MA 02139, United States

ARTICLE INFO

Keywords:
Autonomous vehicles
Perceptions of safety
Public opinion
International comparison
Multilevel structural equation modeling
Developing countries

ABSTRACT

Autonomous vehicles (AVs) are envisioned to reduce road fatalities by switching control of safety-critical tasks from humans to machines. Realizing safety benefits on the ground depends on technological advancement as well as the scale and rate of AV adoption, which are influenced by public perceptions. Employing multilevel structural equation modeling, this paper explores differences in perceptions of AV safety across 33,958 individuals in 51 countries. At the individual level, young males report higher perceptions of current AV safety and predict fewer years until AVs are safe enough for them to use. Since young males are more likely to undertake risky driving behavior, their positivity towards AV safety could lead to more rapid manifestations of safety benefits. Urban, fully employed individuals with higher incomes and education levels also report fewer years until AVs are safe to use. The multilevel model identifies country-level effects after controlling for individual characteristics. Developed countries with greater motorization rates and lower road death rates tend to have greater awareness of AVs but are more pessimistic about their present and future safety. Individuals in developing countries that face greater road safety challenges, particularly involving 2- and 3-wheeled vehicles, predict fewer years until AVs will be safe enough for them to use. Higher AV safety perception among the most risk-taking road users and in developing countries coincide with sociodemographic groups and geographic areas facing the greatest road safety challenges and most in need of improvement, highlighting a potential opportunity to reduce the global disparity in road safety.

1. Introduction

Greater road safety is one of the key potential benefits of autonomous vehicles (AVs) because these systems assume control of safety critical tasks, the type often prone to human error (NHTSA, 2017). Several studies suggest that the potential for improved safety is a key determinant of the general public's willingness to use AVs (Casley, Jardim, & Quartulli, 2013; Howard & Dai, 2014). Therefore, perceptions of AV safety may help determine the extent to which people will accept and use AVs and the rate at which their safety benefits may be realized on the road. However, these findings largely come from data collected in a handful of developed countries[1] and therefore may fail to generalize to developing countries, where road safety is significantly worse. Thus, current literature largely fails to account for how perceptions of AV safety differ across individuals and countries and how those differences may impact the rate and scale of AV adoption.

This study examines perceptions of AV safety across a diverse sample of individuals from a wide variety of countries. Using data from an international survey, this paper explores how awareness of AV technology and perceptions and predictions of AV safety differ across 41,932 individuals in 51 countries. In particular, we investigate what sociodemographic groups (across all countries) demonstrate the most positive current perception and future predictions of AV safety. Controlling for these individual characteristics, we also isolate country-level effects independent of the individuals in those countries and use correlational analysis to understand how country-level factors such as income, car use, and road safety relate to observed variation in country effects on AV safety perceptions.

In this paper, we begin with a literature review of public perceptions of autonomous vehicle safety, with a focus on international comparisons and studies of perceptions of AV safety. Next, we present our methodological approach, providing an overview of our survey, sample,

* Corresponding author.
E-mail addresses: jcmoody@mit.edu (J. Moody), nbailey@mit.edu (N. Bailey), jinhua@mit.edu (J. Zhao).

[1] Throughout this study, we use the labels developed and developing according to the country classifications published by the United Nations (2017).

https://doi.org/10.1016/j.ssci.2019.07.022
Received 5 October 2018; Received in revised form 2 July 2019; Accepted 16 July 2019
Available online 20 July 2019
0925-7535/

key variables, and modeling framework. We then present the results of our study, including trends across individuals and across countries. Finally, we discuss how the varying perceptions of AV safety demonstrated in our survey may contribute to different rates of AV adoption across countries and, in turn, how this may interact with the existing global road safety disparity between developing and developed countries.

2. Literature review: public perceptions of autonomous vehicles

There is a wealth of research investigating what factors correspond with increased interest in AVs, more positive attitudes regarding the technology, and higher willingness to adopt, use, and buy it. Many studies have identified young adults and men as two demographics that hold more positive attitudes towards autonomous vehicle technology (Nielsen & Haustein, 2018; Anania, et al., 2018; Hulse, Xie & Galea, 2018; Lee, et al., 2017). In particular, young people and men have been shown to agree more strongly that AVs will improve safety (Nielsen & Haustein, 2018), have fewer concerns about vehicle safety (Kyriakidis, Happee & de Winter, 2015; Schoettle & Sivak, 2014), and have increased willingness to use the technology (Smith & Caiazza, 2017; Payre, Cestac, & Delhomme, 2014). These same demographics are linked to risky driving behavior (Turner & McClure, 2003) and risky pedestrian behavior (Holland & Hill, 2007; Rosenbloom, 2009) that correlate with increased collision risk and thus worse road safety outcomes. Because of this link, Hulse, Xie, and Galea (2018) make the claim that the positivity towards AVs among young males could lead to more rapid manifestations of road safety benefits should they quickly adopt AVs once the technology is introduced.

In addition to young adults and men, college educated people and people living in urban areas have also been found to have more positive attitudes towards AVs, including increased willingness to use the technology (Smith & Caiazza, 2017; Schoettle & Sivak, 2014) and increased perceptions of safety (Schoettle & Sivak, 2014; Nielsen & Haustein, 2018). A study by Sanbonmatsu et al. (2018) found that increased knowledge of AVs correlates with higher agreement that they would be unsafe both due to technological limitations and lack of operator familiarity; however, self-reported perceived knowledge of AVs had a negative association with these same beliefs.

Furthermore, several studies have identified underlying attitudinal factors that also explain these perceptions (e.g., Tussyadiah, Zach, & Wang, 2017; Nees, 2016; Choi & Ji, 2015). One particularly relevant study in Denmark identified three classes of respondents based on reported attitudes: enthusiasts, skeptics, and an indifferent group in between with higher car stress. Enthusiasts were significantly more likely than others to have university education, try new technologies earlier in the adoption curve, live in the Copenhagen region, and be male and young. Among the expected advantages of AVs, safety showed the largest gap between skeptic and enthusiast respondents; while 56.8% of enthusiasts reported a belief that self-driving cars would increase safety, only 7.4% of skeptics and 20.7% of indifferent people believed the same (Nielsen & Haustein, 2018).

2.1. International comparisons

Surveys conducted across multiple countries have indicated that public perceptions of AVs and the sociodemographics that predict them vary widely among different nations. Haboucha et al. (2017) found that gender played a significant role in predicting interest in AVs in Israel—with men more interested than women—while there was no significant gender difference in the U.S.; The authors attributed this finding to cultural differences between the two countries. Anania et al. (2018) found that Indian women reported higher willingness to ride in AVs compared to Indian men, while in the U.S. the reverse was true.

A study with respondents from Germany, China, Japan, and the U.S. found significant differences among attitudes towards automated driving in these four countries (Sommer, 2013). Autonomous driving was considered scary by 42% of respondents from Japan but by 66% from the U.S.; 43% of Japanese respondents reported belief that the technology will function reliably compared to 74% in China; and only 37% of respondents in Japan predicted that automated driving will be a part of everyday life by 2028, while 65% in China believed the same thing. A study conducted in the U.S., U.K., and Australia in 2014 also found significant differences in attitudes; respondents in the U.S. reported very positive views of AVs, but also greater concern for riding in AVs compared with respondents in other countries (Schoettle & Sivak, 2014).

While many studies, such as those above, compare average attitudes towards AVs among a small set of countries, very few examine trends among many various countries around the world. A correlational analysis across 40 countries (each with at least 25 responses) showed weak but positive relations between the country-level rates of traffic deaths (regularized by the number of vehicles and the number of individuals) and worries about the safety and reliability of AV technology (Kyriakidis, Happee & de Winter, 2015). A follow-up study involving 7188 respondents across 43 countries used principal component analysis to generate a general acceptance score indicating an individual's positivity towards AV technology, and found that country mean general acceptance score correlated negatively with country GDP per capita and motor vehicle density and correlated positively with road traffic death rate (Nordhoff et al. 2018). These studies give conflicting indications about countries where road safety is a larger issue, with one finding these countries may have more concerns about safety and the other finding that they have higher general acceptance of AV technology. Additionally, these simple correlations did not control for sample representativeness or other potential sociodemographic effects. Another survey with 5500 participants across 27 cities in 10 countries found that 58% of all respondents reported they were likely or very likely to take a ride in a fully self-driving car, but this ranged by country from 36% in Japan to 85% in India (Lang, et al., 2016). Despite noting this variation in mean responses by country, this study focuses on the relations between individual sociodemographics and perceptions of AV safety, leaving it an open question as to how much of this variation is a result of differing societal or cultural attitudes at the country level.

2.2. Perceptions of safety

While technology and road infrastructure will dictate the actual safety of AV systems, public perception of safety is significant in understanding how travel behavior may respond to the introduction of AVs on roads around the world. Knowledge of direct relations between safety perceptions and willingness to change travel behavior can shed light upon the potential safety benefits that may be realized through AVs (NHTSA, 2017).

Several studies have identified that the same sociodemographic factors correlated with increased perceptions of AV safety are also associated with increased intention to adopt AV technology (Smith & Caiazza, 2017; Payre, Cestac & Delhomme, 2014; Hulse, Xie & Galea, 2018). Furthermore, research has suggested that perceptions of safety are associated with interest in and intended use of AVs, meaning an understanding of perceptions of safety is useful in understanding the potential future adoption of the technology. In one survey conducted in the U.S. in 2013, 59.5% of respondents indicated that the safety of AVs had a positive influence on their desire to purchase the technology and 82% of respondents indicated that safety was the most influential appeal of AVs, ahead of cost (Casley, Jardim & Quartulli, 2013). However, other studies have found much smaller proportions of people who rate safety as a primary motivation for interest in AV technology, such as 17% among American adults (Smith & Caiazza, 2017) or 31% across an international sample (Lang, et al., 2016). Just as there is evidence that positive perceptions of AV safety might motivate its use, concerns about safety may also be a major driver of lack of interest in AVs across countries. Among respondents in an international sample who indicated they were unlikely to take a ride in a fully self-driving vehicle, 50% did not feel safe if the car was driving itself, 45% expressed desire to be in control of the vehicle at all times, and 23% would be concerned the car could be hacked (Lang, et al., 2016). Kyriakidis, Happee, and de Winter (2015) found that 64.5% of respondents agreed that automated driving worries them because of safety and reliability concerns. Thus, the literature suggests that safety perceptions are a major barrier to AV adoption, but may also be a motivator for adoption among certain groups.

A growing body of literature indicates that safety perceptions (of AVs as well as conventional modes) lead travelers to shift mode choice and other travel behavior. A stated preference study in Israel found that perceived risk of road crashes is directly related to intention to shift travel towards public transit (Elias & Shiftan, 2012), indicating that travelers are willing to change travel behavior to reduce immediate personal safety risk. Several studies have corroborated this effect in the AV-specific context. For individuals who rode in an AV under controlled conditions, experiential feelings of safety during the ride were found to significantly predict increased behavioral intention to use, buy, and recommend AVs, as well as willingness to take further rides in AVs (Xu et al., 2018). Several other studies have found that attitudes towards AV safety prior to actual use significantly influence intention to adopt and use AVs. One study found that an attitudinal factor of contextual acceptability of AVs, including attitudes towards safety, correlated positively with intention to use AVs, intention to buy the technology, and willingness to pay for the technology (Payre, Cestac & Delhomme, 2014). A recent study found that perceived safety risk was a significant contributor to feelings of trust towards AV technology, and that this trust was the strongest contributor towards intention to use and purchase AVs in the future (Zhang et al., 2019). These studies suggest that individual perceptions of safety may play a large role in shaping the adoption and use of AVs in the future, and are therefore important in understanding the technology's resulting safety impacts.

2.3. Our contribution

While significant research has explored what factors contribute to an individual's perception of AVs, much of these findings are limited to homogeneous samples in a single region or (developed) country. Existing international comparisons have been limited to descriptive statistics and bivariate correlations that often fail to account for multivariate relations among individual sociodemographics, public perceptions, and travel behavior (Lang, et al., 2016; Kyriakidis, Happee & de Winter, 2015; Sommer, 2013). Furthermore, existing international comparisons often fail to control for individual-level factors that make up the samples of each country. This severely limits the ability to draw conclusions about differences between countries due to factors other than differences in the sociodemographics of the people that live in them. This study builds on existing literature by providing an international comparison of perceptions of AV safety across a sample of unprecedented size and country coverage. This wealth of data allows us to employ a rigorous multilevel structural equation modeling technique that carefully apportions sample variance to individuals and countries. We can thereby explore how much of observed differences in levels of AV awareness as well as current perceptions and future predictions of AV safety are attributable to individuals vs. to country contexts.

This study has two main research aims. At the individual level, we are interested in what types of people (across all countries) are the most aware of AVs and are the most positive in terms of their current perception of AV safety as well as their predictions for when AVs will be safe enough for them to use in the future. This individual level analysis leverages our sample's greater global coverage and our model's multivariate approach to corroborate and extend existing literature on public perception of AV safety. At the country level, we demonstrate for the first time in published literature that small, but significant country-to-country variance in perceptions of AV safety exist even after controlling for the characteristics of the individuals in those countries. Having isolated these country effects (no longer confounded by individual characteristics), we examine how national indicators of wealth, income inequality, motorization, and road safety conditions are associated with country-level perceptions and predictions of AV safety. With these results, we discuss how more optimistic perceptions of AV safety across countries may lower attitudinal barriers to rapid AV adoption in those countries that might benefit most from the road safety improvements promised by AV technology.

3. Methods

3.1. Survey design and respondent recruitment

A 20-question survey was administered by Dalia Research via mobile phones to participants in 51 countries during the two-month period from December 2016 through January 2017.[2] Mobile phone based data collection provides unprecedented global coverage. Worldwide, more people now have access to the internet through mobile devices than through desktop computers, particularly in low- and middle-income countries (Statistica.com, n.d.). Therefore, we are able to collect an international sample that includes respondents from a much broader range of countries, (with a much less developed country bias, than previous studies).

Sample respondents were recruited through a variety of ad-exchanges, demand-side platforms (DSPs), apps and mobile websites. While browsing content on their mobile device, individuals would be prompted to take a short survey. Respondents who completed the survey were rewarded in the form of virtual currencies, prepaid credits, access to premium content, and other rewards depending on the specific recruitment channel.

Since respondents are recruited within apps, attention spans may be short and this may raise concerns over data quality. Dalia Research prescreens respondents and assigns each a trustworthiness score based on criteria such as answer consistency, consistency with passive device data, checks against location data, attentiveness check, and speeding. Each individual is rated based on average performance across all criteria and this score is dynamically updated as users complete additional surveys. Only high-quality, verified users were asked to voluntarily complete our survey.

3.2. Sample

The initial sample consisted of 41,932 voluntary survey participants from 51 countries. Quota sampling was used to ensure reasonable sample representativeness for age and gender for each of the 51 countries based on population statistics, adjusted to match the internet-connected population (Moody, 2019). Therefore, any inference on our sample can only extend to internet-connected, mobile-phone users in each of the countries surveyed. For this study, 7,947 respondents who did not report either their monthly household income or education level (two key covariates in our model) were removed from analysis. This left a final sample size of 33,958 respondents from 51 countries, with within-country sample sizes varying from 170 to 928.[3]

[2] The study reported in this paper was approved by the Committee on the Use of Humans as Experimental Subjects at the Massachusetts Institute of Technology prior to any recruitment or data collection – protocol #1610719971. Electronic informed consent was obtained from all participants.

[3] Removing these observations could result in a loss of sample representativeness at the country-level if the missingness of key covariates is systematic across certain types of individuals. However all results presented in this study were also calculated for the full sample of 41,932 individuals (including observations with missing values for monthly household income or education level) and there were no substantial changes to any of the conclusions we present here.

Due to the hierarchical nature of the data—with individuals nested within countries—we must consider sample representativeness not only of individuals, but also of countries (Lucas, 2014). In this study, data was collected primarily for inference at the individual-level. As a consequence, the 51 countries are a simple convenience sample and are not intended to be representative of all countries in the world. In particular, our sample contains none of the 34 countries designated as "low income" by the World Bank (2018). Therefore, any inference across countries applies only to the specific high- and middle-income countries included in our sample, and we caution against any generalization to a wider population of countries.

3.3. Data

For each individual, the survey collected sociodemographic information, including age, gender, employment status, educational attainment, monthly household income, the population of the city or town in which they reside, and whether or not they own a car. In addition, each individual was asked three questions related to autonomous vehicles (nominally defined as Level 5 automation or "fully self-driving cars").

First, individuals were asked to report their familiarity with autonomous vehicles, answering the question "Have you seen, heard, or read anything about self-driving cars?" with one of three ordered choices—"No", "Yes, a bit", and "Yes, a lot." Individuals were then asked their perceptions of current AV safety: "How safe do you think self-driving cars are, as of now?" Responses were recorded on a 1–4 scale from "not safe at all" to "very safe." Finally, for those who indicated that they do not yet think AVs are "very safe," a follow-up question asked "how soon, if at all, do you think self-driving cars will be safe enough for you to consider using one?" Respondents were provided with ranges of years, which were coded into a quasi-continuous variable by the midpoint of each range.[4] Respondents that reported AVs as "very safe" in the previous question were coded as 0 years, which assumes that they already feel self-driving cars are safe enough to use. Note that this question does not ask about the time until AV technology reaches an objective safety threshold, but rather about the time until it satisfies an individual's personal requirements of safety such that they would use it for their own transportation. Survey respondents' personal requirements of safety may naturally depend on the current road safety environment in which they live as well as their own risk-taking behavior.

To complement the individual level survey data, country-level covariates were gathered from various sources. As a proxy for national wealth, gross domestic product (GDP) per capita adjusted for purchasing power parity was collected (World Bank, Inernational Comparison Program Database, n.d.). We also obtained the Gini index[5] for each country as a proxy for income inequality (World Bank Development Research Group, n.d.). We additionally controlled for the motorization rate (total vehicles in use per 1000 people) by country from the International Organization of Motor Vehicle Manufacturers (OICA, 2015). Finally, we explored whether current national road safety conditions influence average country perceptions of AV safety. We used the World Health Organization's road safety statistics, including the road traffic death rate (per 100,000 population) and the percentage of road deaths by type of road user (driver or passenger of 4-wheeled motor vehicle, driver or passenger of 2-wheeled motor vehicle, or pedestrian) (WHO, n.d.).

3.4. Analytic plan

Given the hierarchical nature of the data—with 33,958 individuals nested within 51 countries—we adopt a multilevel modeling approach that enables the study of complex relations among variables while allowing individuals within countries to share common cultural and social characteristics modeled as correlated regression error terms (Muthén & Asparouhov, 2009; Muthén, 1994). We estimate a multilevel structural equation model (MSEM) to explore what characteristics of individuals predict awareness of AV technology (ordinal), current perceptions, of AV safety (ordinal) and future predictions of AV safety (quasi-continuous) (Fig. 1). We assume that individual characteristics precede awareness of AV technology as well as perceptions and predictions of the safety of fully autonomous vehicles (which are a relatively new phenomenon). We allow for the three outcomes to be correlated due to our expectation that awareness of AV technology may be related to current perceptions and future predictions of AV safety (Fig. 1).

At the individual level, all sociodemographics are country-mean centered to remove any country level variance from the estimation of the individual-level path coefficients (Enders & Tofighi, 2007; Asparouhov & Muthén, 2007). We estimate fixed slopes for these individual sociodemographic characteristics across all 51 countries. Therefore, our model does not capture differences across countries in the association of any given sociodemographic and perceptions of AV safety; instead it measures the average association of individual sociodemographics and perceptions of AV safety across all countries. This simplification is made for model tractability, but still allows us to identify global trends in individual-level perceptions of AV safety that remain significant above potential country-to-country variation.

A post-hoc power analysis using Monte Carlo simulation suggests that our sample size of 51 countries is too limited to support a multivariate exploration of the factors that contribute to country-level variation. Therefore, we estimate a completely saturated model, with only the random intercepts for the three outcomes and their covariances, at the country-level. These country-level intercepts estimate the effect of being from a specific country on individual perceptions of AVs, after controlling for individual sociodemographics. Although our model cannot explain the cause of these country-level effects, it allows us to isolate them from individual-level effects.

The model is estimated using Bayesian estimation in Mplus version 8.1 using a seed value of 200 and no preset starting values (Muthén and Muthén, 1998–2019). We implemented diffuse (non-informative) priors for all model parameters, relying on the default settings of the software (Muthén and Muthén, 1998–2019). For the ordinal outcomes, the default probit link function is used. Four Markov chains were implemented for each parameter and distinct starting values were provided for each of the chains. To assess chain convergence, the Gelman and Rubin (1992a, 1992b) convergence diagnostic was implemented as described in the Mplus user manual with a stricter convergence criterion of 0.01 rather than the default setting of 0.05. An initial burn-in phase of 100,000 iterations was specified, with a fixed a fixed number of postburn-in iterations of 100,000. The Gelman and Rubin diagnostic indicated that convergence was obtained with these fixed iterations for each of the four chains. The trace plots for each model parameter were also visually inspected. For each of the model parameters, all chains appeared to converge, being visually stacked with a constant mean and variance in the postburn-in portion of the chain. To ensure that convergence was obtained and that local convergence was not an issue, we estimated the model again but with the number of burn-in and postburn-in iterations doubled (400,000 iterations in total). Again the Gelman and Rubin convergence diagnostic indicated convergence was obtained and the visual inspection of trace plots was consistent with that finding. Percent of relative deviation was calculated to examine

[4] Responses coded in number of years: " < 2 years" = 1, "2–5 years" = 3.5, "5–10 years" = 7.5, "10–20 years" = 15 years, "greater than 20 years" = 25, "never" = 50. For those who already thought that AVs are safe, responses were coded as 0 years.

[5] Given significant sparseness in the Gini index for any given year, this variable was derived by taking the most recent estimate available within 2010–2015 for each country.

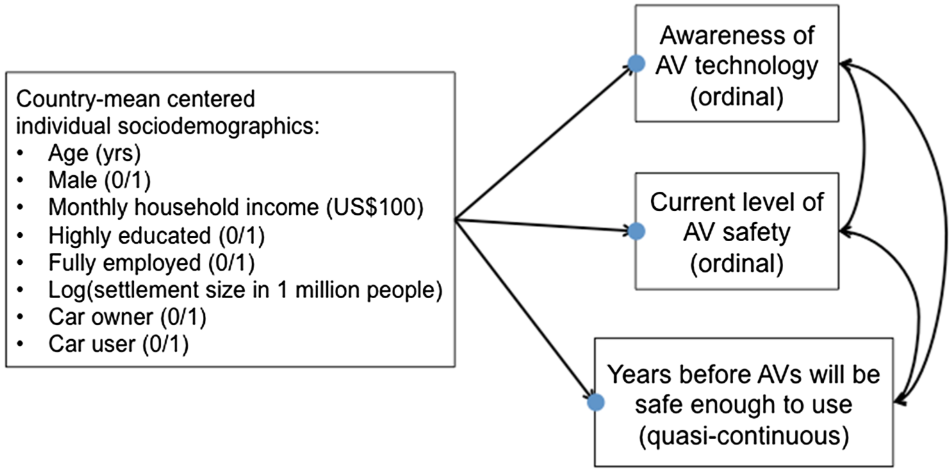

Fig. 1. Analytic Path Diagram for the Individual-level of the MSEM. *Figure Note:* Blue circle indicates random intercept estimated at the country-level. Variances and covariances of all exogenous (independent) variables and disturbance terms for all endogenous (dependent) variables are estimated, but not pictured.

how similar (or different) parameter estimates are across these two analyses using the formula: [(estimate from initial model) – (estimate from expanded model)/(estimate from initial model)] × 100. We found that results were almost identical with relative deviation levels no more than |1|% for all parameters. Note that all applicable points on the WAMBS-checklist (Depaoli and van de Schoot, 2017) were addressed and the results from this checklist can be downloaded as supplementary material from https://github.com/jcmoody6/intl-av-safety along with the Mplus output code from the analysis.

4. Results

4.1. Descriptive statistics

Looking at the raw data across the 33,958 respondents in our 51 countries, we see significant variance in reported levels of AV awareness, current perceptions of AV safety, and predictions of when AVs will be safe enough to use (see Fig. 2). The majority of respondents across all countries (55.9%) reported that they were “a bit” aware of AVs (Fig. 2a), which somewhat parallels findings from other international surveys which found that 49.9–52.2% of respondents had heard of the Google Driverless Car before (de Winter, et al., 2015; Kyriakidis, Happee, & de Winter, 2015).

Across the entire international sample, we find that most current perceptions of AV safety are moderate, with 34% of respondents across all countries reporting that AVs are “somewhat safe” (Fig. 2b). Only 10.4% of respondents across all countries think AVs are “very safe” and only 6.8% think AVs are “not at all safe.” In the reported number of years until AVs will be safe enough to use (Fig. 2c), the mean response across all individuals in the sample is 9.8 years (2026–2027). These numbers are in line with or slightly more optimistic than the results of other international studies in which the majority of respondents believed that fully automated vehicles would be able to drive on public roads by 2030 (Kyriakidis, Happee, & de Winter, 2015; de Winter, et al., 2015; Underwood, 2014; Sommer, 2013).

The variations in awareness of AV technology, current perceptions of AV safety, and reported number of years until AVs are safe enough to use that we see in our international sample (Fig. 2) can result from differences in both individual perceptions and country effects. In the next section, we use multilevel structural equation modeling (MSEM) to apportion the observed sample variance across these two sources.

4.2. Structural equation model

We estimate the multilevel structural equation model (MSEM) shown in Fig. 1, using individual sociodemographics to predict awareness of AV technology, current perceptions of AV safety, and the reported number of years until AVs are safe enough to use. The MSEM framework allows us to assess the overall “goodness of fit” of our model. Using Bayesian Posterior Predictive Checking using chi-square, we find that there is no statistically significant difference between the observed and replicated chi-square values with a 95% confidence interval = [−16.579, 39.188], $p = .217$. This suggests that our model adequately reproduces the covariance matrix implied by the sample data.

4.2.1. Intraclass correlation coefficients

Adopting the multilevel modeling structure allows us to determine what percentage of observed variance in each of our outcome variables is attributable to individuals or to countries (the intraclass correlation coefficient or ICC). Overall, we find that most of the variance in awareness of AV technology, current perceptions of AV safety, and future predictions of AV safety is attributed to differences across individuals rather than countries. Our model suggests that 11.8% of observed variance in AV awareness is attributable to country context, compared to 4.9% and 2.9% for current perceptions and future predictions of AV safety, respectively. These ICCs suggest that, while country context does play a role in levels of AV awareness and perceptions and predictions of AV safety, these perceptions are largely dictated by individual-level factors. This finding should serve as a caution to researchers who simply compare mean sample responses across countries without accounting for the vast majority of variance explained by the fact that individuals are different across these countries.

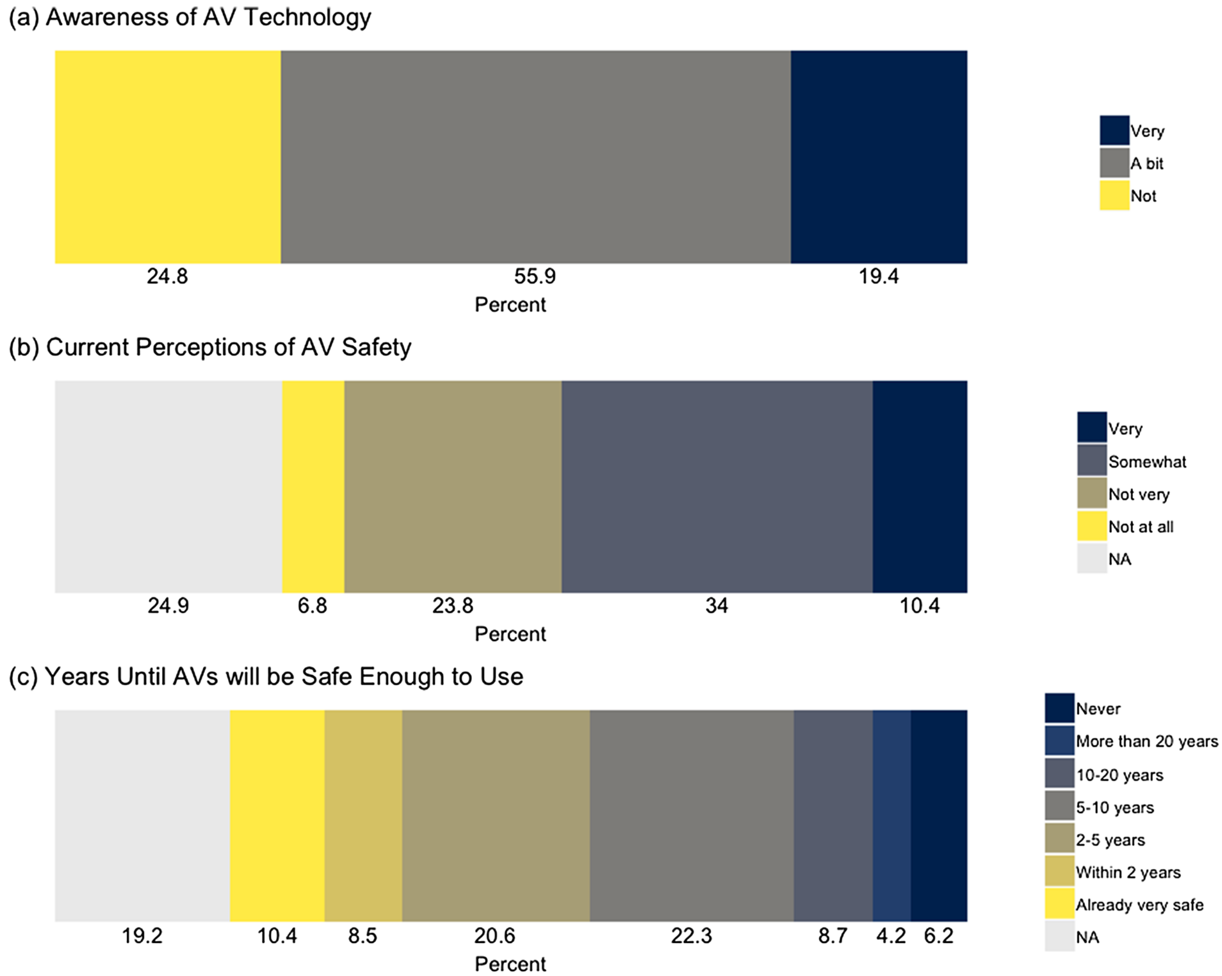

Fig. 2. Raw Percentages of Individual Responses by Category for the Three Study Questions. *Figure Note:* "NA" = "not sure" or not answered.

4.2.2. Relations among AV awareness and perceptions/predictions of AV safety

Looking at the correlations among the outcome variables across individuals, we find that awareness of AV technology is moderately correlated with current perceptions of AV safety (0.387) and predicted number of years until AV safety (−0.258). This means that individuals who are more aware of AV technology have higher current perceptions of AV safety and more optimistic predictions of the number of years until AVs will be safe enough to use. This finding is in line with previous research that suggests familiarity with, enthusiasm for, and perceived knowledge about AV technology are all positively correlated with perceptions of safety and willingness to adopt the technology sooner (Nielsen & Haustein, 2018; Kyriakidis, Happee, & de Winter, 2015; Sanbonmatsu, et al., 2018). These results might suggest that increasing levels of awareness and familiarity with AV technology could help mitigate concerns for AV safety, reducing this potential attitudinal barrier to their rapid adoption.

We also find a substantial negative correlation between current perceptions of AV safety and predicted number of years until AV safety (−0.545). These results are intuitive, suggesting that individuals who have higher perceptions of current AV safety report a fewer number of years until AVs are safe enough for them to use.

4.2.3. Trends across individuals

At the individual level, we predict levels of AV awareness and current perceptions and future predictions of AV awareness with sociodemographic factors to identify what types of people (across all countries in our sample) are most optimistic of AVs. We find that those who are younger, male, highly educated, fully employed, and who have higher than average household incomes report higher awareness of AV technology, more favorable current perceptions of AV safety, and a lower number of years until AVs will be safe enough to use (see Table 1). Our results corroborate and extend previous research that finds young people, men, and those with higher educational status are more optimistic about AV safety (Nielsen & Haustein, 2018; Schoettle & Sivak, 2014; Payre, Cestac, & Delhomme, 2014). Furthermore, we find that individuals living in areas with greater population size report greater awareness of AV technology and fewer years until AVs will be safe enough for them to use, but this variable is not significantly predictive of current perceptions of AV safety. This finding partially corroborates previous research findings that respondents in more urban areas have increased perceptions of safety (Schoettle & Sivak, 2014; Smith & Caiazza, 2017; Nielsen & Haustein, 2018).

In addition, we find that individuals who currently own or lease a car (car owners) as well as individuals who drive a car as their typical

Table 1
Individual- (within-) level parameter estimates for the MSEM specified in Fig. 1.

Dependent Variable	Predictor	Unstandardized coefficient	95% Credibility Interval		Standardized coefficient
			Lower	Upper	
Awareness of AV technology (1–3; ordinal)	Age (yrs)	−0.005	−0.006	−0.004	−0.053
	Male (0/1)	0.287	0.262	0.311	0.138
	Full time employed (0/1)	* 0.014	−0.012	0.040	0.007
	Log(settlement size)	0.014	0.010	0.018	0.039
	Household income ($100)	0.003	0.003	0.003	0.093
	Highly educated (0/1)	0.205	0.179	0.232	0.096
	Car owner (0/1)	0.166	0.133	0.199	0.076
	Car user (0/1)	0.088	0.055	0.120	0.040
Perception of AV safety (1–4; ordinal)	Age (yrs)	−0.004	−0.005	−0.003	−0.042
	Male (0/1)	0.182	0.156	0.208	0.089
	Full time employed (0/1)	0.055	0.027	0.082	0.027
	Log(settlement size)	* −0.001	−0.005	0.004	−0.003
	Household income ($100)	0.002	0.002	0.002	0.060
	Highly educated (0/1)	0.104	0.076	0.132	0.050
	Car owner (0/1)	0.060	0.026	0.095	0.028
	Car user (0/1)	0.027	−0.007	0.060	0.012
Years until AVs are safe enough to use	Age (yrs)	0.058	0.044	0.072	0.052
	Male (0/1)	−1.173	−1.478	−0.868	−0.045
	Full time employed (0/1)	−1.223	−1.541	−0.906	−0.047
	Log(settlement size)	−0.140	−0.193	−0.086	−0.032
	Household income ($100)	−0.017	−0.022	−0.012	−0.042
	Highly educated (0/1)	−1.446	−1.771	−1.120	−0.055
	Car owner (0/1)	−1.216	−1.618	−0.813	−0.045
	Car user (0/1)	−0.697	−1.085	−0.308	−0.026

Note: * = 95% credibility interval (CI) crosses zero.
Variance explained: awareness (pseudo-R^2 = 0.064, 95% CI = [0.058, 0.069]), perception of AV safety (pseudo-R^2 = 0.021, 95% CI = [0.017, 0.025]), and years until AVs are safe enough to use (R^2 = 0.022, 95% CI = [0.018, 0.025]).

weekday mode (car users) have greater awareness of AV technology and more optimistic perceptions of current and future AV safety.

Taken together, these individual-level results suggest that the early adopters of AVs (across a diverse array of countries) might be younger, male, higher income, more educated, and potentially more urban. They are also likely to be current car owners and frequent users. These findings generally corroborate findings from existing research, but extend them to individuals in a much more diverse set of countries. Therefore, our international comparison provides stronger evidence that these individual-level results hold as a global trend across many different types of countries. However, these results should be caveated by the fact that the variance in awareness of AV technology as well as current perceptions and future predictions of AV safety explained by our model are low (see note for Table 1). This suggests that other individual-level factors not captured in the survey—such as attitudes—may contribute to an individual's awareness of AV technology, current perceptions of AV safety, and predictions of the number of years until AVs will be safe enough to use.

4.2.4. Trends across countries

While we find that the majority of variance in AV awareness as well as current and future predictions of AV safety is attributable to individual characteristics, small but statistically significant differences do exist across countries after controlling for individual-level relations. Fig. 3 maps the random country-level intercepts for each outcome in the MSEM. These country-level intercepts represent the effect of country context on an individual's awareness and perceptions of AVs (after accounting for individual-level factors). Table A1 in the Appendix gives the full list of each outcome variable by country, and each country's rank in each outcome variable.

From these results, we identify a few specific trends in country-level effects. A group of Western European countries (Germany, Sweden, Austria, the UK, and the Netherlands) as well as Canada report moderately above-average awareness of AVs, low perceptions of AVs' current safety, and the greatest number of years until AVs are safe enough to use. Meanwhile, developing countries in Asia (including much of Southeast Asia, China, and India), along with Brazil, Portugal, and the UAE, report high awareness of AVs and have high perceptions of current and future AV safety. The seven Latin American countries in our sample besides Brazil all rank in the bottom nine of awareness of AVs and have high perceptions of current safety and predict low-to-moderate number of years until AVs are safe enough to use. Russia, Ukraine, and Turkey have very low perceptions of current AV safety, though in our other outcomes of interest they do not exhibit significant differences from many other countries (moderately below-average awareness and moderately above-average years until AVs are safe). The US and Singapore, where the bulk of current autonomous vehicle development and testing is being conducted, report high awareness of AVs, yet ranked with many other countries around average in both current and future perceptions of AV safety.

Next, we explore what national characteristics might help to explain the variation we see in our country intercepts. While the multilevel modeling approach that we have adopted could allow for specification of multiple regression relations at the country-level similar to how we treated the individual-level above, our small sample of 51 countries lacks sufficient statistical power to support such a multivariate approach. Therefore, we limit our investigation of trends across countries to bivariate correlations between our country intercepts and indicators of national wealth, income inequality, vehicle ownership and use, and road safety for the 51 countries in our sample (see Table 2).

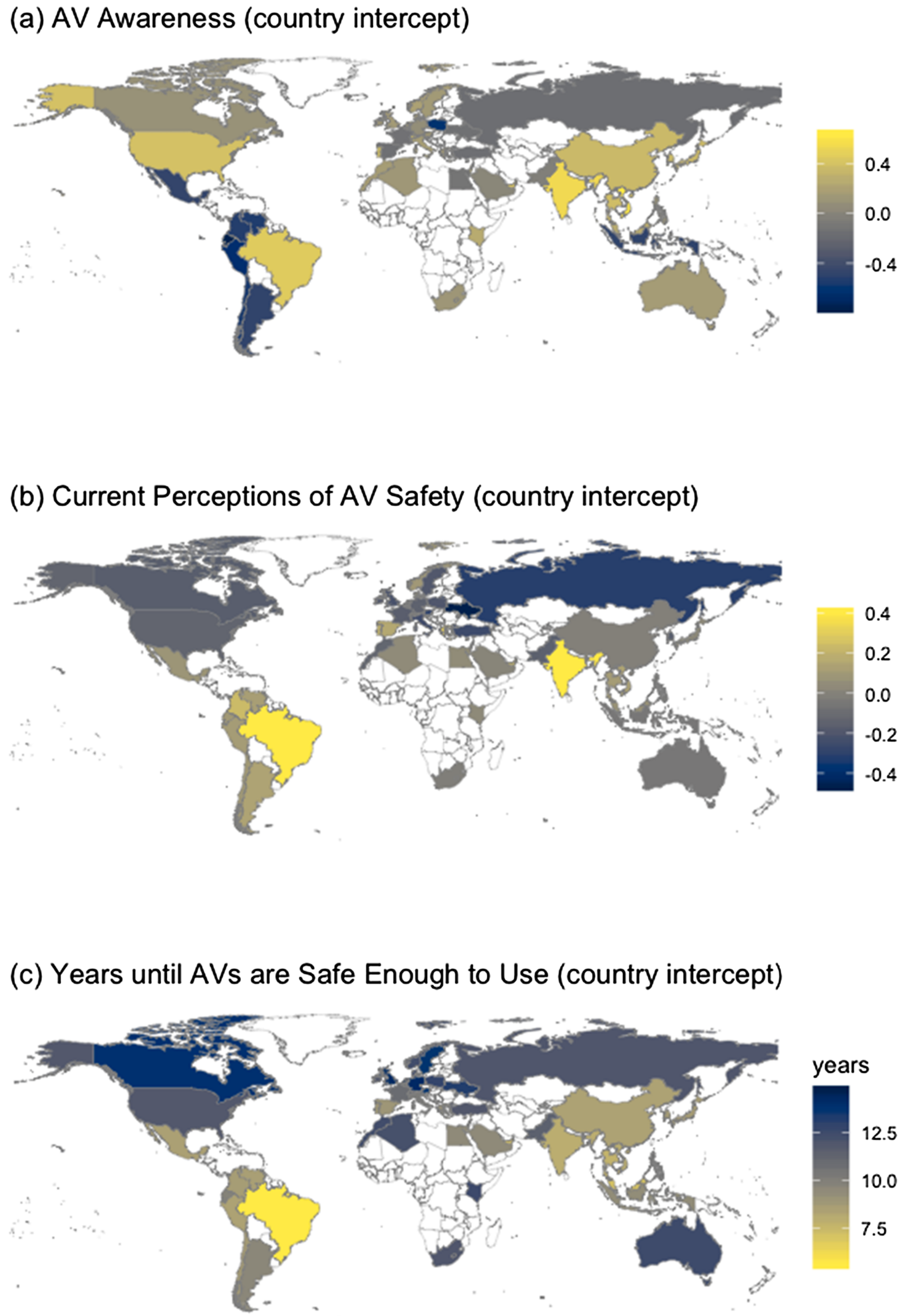

Fig. 3. Variation in country-intercepts for (a) AV awareness, (b) current perceptions of AV safety, and (c) future predictions of years until AVs will be safe enough to use.

We find that country-level awareness of autonomous vehicles is positively correlated with GDP per capita and negatively correlated with Gini index. This suggests that more economically developed countries report higher awareness than others. Countries with higher motorization rate (high car ownership) express somewhat greater awareness of autonomous vehicles, but have significantly more pessimistic views on current and future AV safety. Our results show that car usage (measured by passenger road km per capita) has the same directionality of effect on our outcomes as car ownership, but the magnitude of these relations is much smaller.

Our correlation coefficients also indicate that national road safety conditions may be strongly tied to country-level perceptions of current and future AV safety. We find that having a greater road death rate correlates with higher perceptions of current AV safety and predictions of fewer years until they will be safe enough to use at the country-level. A greater percentage of road deaths made up of drivers and passengers of 4-wheeled vehicles correlates with greater awareness of AVs, worse perceptions of current AV safety, and less optimistic predictions of when AVs will be safe enough to use. While the percentage of road deaths made up of drivers and passengers 2- and 3-wheeled vehicles

Table 2
Pearson correlation coefficients between country intercepts and country covariates.

	Awareness of AV	Current perception of AV safety	Years until AVs will be safe enough to use
GDP per capita, PPP	0.299	−0.240	0.276
Gini index	−0.292	0.403	−0.497
Passenger road km per capita	0.115	−0.048	0.064
Motorization rate	0.175	−0.290	0.382
Road death rate	0.010	0.353	−0.413
Percent of road deaths, 4-wheelers	0.188	−0.299	0.466
Percent of road deaths, 2/3-wheelers	0.294	0.202	−0.332
Percent of road deaths, pedestrians	−0.232	−0.085	−0.089

also correlates with greater AV awareness, it has the opposite relation with perceptions of safety. Countries with more road deaths from 2- and 3-wheeled vehicles have more positive perceptions of current AV safety and predict fewer years until they will be safe enough to use. The percentage of road deaths made up of pedestrians correlates negatively with country-level awareness of AVs and has only minor negative relations with perceptions of current AV safety and number of years until AVs will be safe enough to use. Taken together, these results suggest that individuals living in countries that face greater road safety challenges (particularly from 2- and 3-wheeled motor vehicles) are more optimistic of AV safety than similar individuals living in countries with better road safety conditions.

5. Discussion

This study represents an unprecedented international comparison of perceptions of AV safety across 33,958 individuals in 51 countries. Employing multilevel structural equation modeling that simultaneously accounts for characteristics of both individuals and countries, we are able to break out differences in awareness of AV technology, current perceptions of AV safety, and future predictions of years until AVs will be safe enough to use into individual-level and country-level effects. We can then explore what types of individuals, across a diverse set of countries, are more aware of AVs and more optimistic of their safety now and in the future. We can also identify country-level variation in public perceptions of AVs after accounting for differences in individuals within these countries. We find that, while country-level differences do exist in awareness of AV technology as well as current perceptions and future predictions of AV safety, most of the variation is explained by differences in individual-level characteristics.

At the individual level, we investigate what sociodemographic groups (across all countries) have the most positive perceptions of AV safety currently and the earliest predictions of when AVs will be safe enough for them to use in the future. Our model corroborates and extends previous findings that young males are more optimistic towards AV safety; we find that young males (across all countries) are a key global demographic that report higher current perceptions of AV safety and fewer years until AVs are safe enough to use. Given that young males are also the demographic most linked to risky driving and pedestrian behavior (Turner & McClure, 2003; Holland & Hill, 2007; Rosenbloom, 2009), their positivity towards AV safety and early adoption of AVs once the technology is introduced could lead to more rapid manifestations of road safety benefits (Hulse, Xie, & Galea, 2018). Our model also corroborates and extends previous literature that finds urban and college-educated individuals have greater perceptions of AV safety. Our findings indicate that individuals who are fully employed, high income, and highly educated, who may have the means to be early adopters of AV technology when it becomes available, also have positive perceptions of AV safety that are linked to increased intention to purchase and use AVs in the future (Payre, Cestac, & Delhomme, 2014; Zhang et al., 2019).

Additionally, our multilevel structural equation model isolates country-to-country variation in public perceptions of AV safety from the variation attributable to the individuals who make up our country subsamples. These isolated country-level effects are a novel contribution to the literature, as previous studies have confounded country variation with individual characteristics. As a result, they potentially conflate differences arising from country populations with those attributable to social and cultural contexts.

Mapping these country-level effects, we identify trends in perceptions of AV safety across countries. We corroborate these trends with correlational analysis with country covariates, including indicators of national wealth, income inequality, car ownership and use, and current road safety conditions. We find that countries with higher motorization rates and lower road death rates tend to report worse perceptions of current and future AV safety. This indicates that developed countries, particularly Western Europe and Canada, are less optimistic of AV safety than developing countries, especially those in Latin America and Asia. We additionally identify differences among developing regions. Developing Asia and Brazil report extremely high awareness of AVs and extremely optimistic predictions of AV safety, while the rest of Latin America report extremely low awareness and slightly pessimistic predictions of AV safety.

We also observe relationships between several road safety indicators and country-level effect on perceptions of AV safety. We find that individuals living in countries that face greater road safety challenges are more optimistic of AV safety than similar individuals living in countries with better road safety conditions. Higher road death rate, more road deaths attributable to drivers and passengers of 2- and 3-wheeled vehicles, and fewer road deaths attributable to drivers and passengers of 4-wheeled vehicles—collectively characteristic of many developing countries—all correlate with more positive perceptions of AV.

One hypothesis to explain these relationships is that AV safety is perceived relative to the existing safety context in each country. Individuals in developed countries with low road death rates may feel that an AV would need to meet a high threshold of safety in order to be acceptable given current road safety conditions. Individuals in developing countries face a much different road safety context, with a larger share of 2- and 3-wheeled vehicles that more frequently violate traffic laws and a much higher rate of road fatalities. In these situations, an AV may be safe enough to use even if it does not meet the same safety standard that an individual in a developed country would require of it. A recent study provides support for a slightly different hypothesis, finding that most individuals in the U.S. believe AVs should only be allowed on the road once their driving is safer than that individual's own perceived driving ability (Nees, 2019). If this result holds in international contexts, it is possible that individuals in countries with worse road safety conditions have lower opinions of their own driving safety, likewise leading to beliefs that AVs may be safe enough to use at a lower level of safety. Future research could test these different explanations for our findings.

The finding that countries facing the greatest road safety challenges are also the most optimistic of AV safety may be an important insight for policymakers grappling with a growing global disparity in road safety. While deaths due to traffic accidents are a critical issue for national governments across the globe (UN General Assembly, 2015), road users in low and middle-income countries are particularly vulnerable. Road fatality rates in these developing countries are more than twice that observed in high-income countries (WHO, 2015). Moreover, while road fatality rates in high-income countries have been decreasing for decades, fatality rates in low and middle-income countries remain on the rise (WHO, 2015). With the Sustainable Development Goals including a global target to reduce road traffic deaths and injuries 50% by 2020 *(*UN General Assembly, 2015*)*, researchers and practitioners need to develop an understanding of how new technologies, such as autonomous vehicles (AVs), could be leveraged to meet these global goals and to address the existing disparity in road safety across countries.

In summary, these results suggest that optimistic public perceptions and predictions of AV safety may drive early adoption of AV technology among risk-taking young males, particularly in developing countries. If legal, economic, and political barriers to AV implementation are resolved quickly and if AV technology is safer than the human drivers they replace on the roads, AVs could improve road safety conditions in those countries that currently face the greatest road safety challenges. Thus, this survey indicates that public perception may drive faster adoption of AVs among the most risk-taking drivers in developing countries, which could in turn help to alleviate the existing global road safety disparity.

5.1. Limitations and future work

This paper furthers understanding of what types of individuals have greater awareness of AV technology and more optimistic views of AV safety. This understanding may be used to better target informational campaigns and marketing interventions to the groups and regions of the world that may benefit most from the adoption of safer AV technologies. However, future research is needed to address a number of limitations of this initial study.

First, additional research may more clearly demonstrate whether stated perceptions of AV safety on surveys will materialize in actual adoption or use of these vehicles when they enter the market. Although stated preferences and survey responses do not necessarily match travel behavior, surveys remain a powerful and low-cost means to obtain initial observations. Understanding public perception can be particularly valuable when considering, as in the case of fully autonomous vehicles, the development of future technologies when human subject experiments in real-world conditions are not yet feasible.

Second, while there is significant theoretical basis for assuming that individual characteristics precede perceptions of fully autonomous vehicle technology, the directed relations presented in this paper are estimated from cross-sectional data. Future research using longitudinal data or instrumental variables could extend this understanding from correlational to causal and could further investigate the formation and dynamics of perceptions of AV safety over time.

Third, future research could identify other individual and country factors that contribute to an individual's awareness of AV technology and perceptions of AV safety. The low pseudo-R^2 values of our model at the individual-level suggest that much of the variation in public perceptions of AVs is not explained by simple sociodemographics (like age, gender, income, education, employment), and current travel behavior (like car ownership and use). Therefore, our study suggests there is significant value in continued exploration of how other aspects of travel behavior or individual's attitudes may contribute to perceptions of AV safety and intended use of these vehicles.

Finally, while our model results indicate that the vast majority of variation in awareness and perceptions of AVs is attributable to individual characteristics, we do find contextual effects across countries. While this study demonstrates clear trends in awareness of AVs as well as current perceptions and future predictions of AV safety across countries, we are limited to a bivariate exploration of the national factors contributing to these trends. In theory, the MSEM framework adopted here does allow for the specification of multivariate relations among variables at the country (as well as individual) level. However, in practice, our international sample includes only 51 countries, which post-hoc power analysis suggests is an insufficient sample size to detect statistically meaningful relations at the country level. While we are unable to use the MSEM framework to its fullest potential, research equipped with data from more countries (or cities) can build on the modeling framework that we present here to not only demonstrate, but also explain country-level trends in perceptions of AV safety.

Acknowledgements

The authors would like to thank Ashley Nunes and colleagues at the JTL Urban Mobility Lab for their theoretical and methodological critiques throughout the development of this paper. This work was supported through the MIT Energy Initiative's Mobility of the Future study. Dalia Research provided participant recruitment, survey implementation, and data.

Appendix A

See Table A1.

Table A1
Estimated country intercepts and country rank for AV awareness, current perceptions of AV safety and future predictions of years until AVs will be safe enough to use.

	Awareness		Current Perceptions of AV Safety		Years Until AVs will be Safe Enough to Use	
Country	Intercept	Rank	Intercept	Rank	Intercept	Rank
Vietnam	0.638	1	0.142	8	7.959	46
India	0.541	2	0.406	2	7.947	47
Brazil	0.459	3	0.406	2	5.565	51
United Arab Emirates	0.44	4	0.163	6	7.246	49
USA	0.403	5	−0.135	37	11.822	19
Portugal	0.389	6	0.213	5	8.649	39
Thailand	0.377	7	0.111	12	7.69	48

(*continued on next page*)

Table A1 (*continued*)

	Awareness		Current Perceptions of AV Safety		Years Until AVs will be Safe Enough to Use	
Country	Intercept	Rank	Intercept	Rank	Intercept	Rank
Switzerland	0.372	8	−0.04	28	10.903	22
Singapore	0.364	9	−0.099	35	10.197	28
South Korea	0.357	10	−0.166	42	8.726	38
Japan	0.354	11	0.031	21	8.603	41
China	0.351	12	−0.009	25	8.406	44
Israel	0.291	13	−0.02	27	9.808	29
Malaysia	0.271	14	0.075	17	7.068	50
Kenya	0.263	15	0.034	20	12.557	9
Netherlands	0.241	16	−0.076	32	14.728	1
Norway	0.2	17	0.093	15	12.385	12
Belgium	0.181	18	−0.002	24	10.702	25
Italy	0.178	19	−0.248	47	10.226	27
Morocco	0.172	20	−0.125	36	12.385	12
Australia	0.165	21	−0.05	30	12.485	10
UK	0.16	22	−0.223	46	14.264	2
Sweden	0.146	23	−0.192	44	13.656	6
Algeria	0.134	24	0.039	19	12.252	14
South Africa	0.124	25	−0.019	26	11.909	16
Austria	0.11	26	−0.292	49	13.69	5
Greece	0.108	28	0.259	3	9.194	35
Ireland	0.108	28	−0.175	43	11.828	18
Denmark	0.098	29	0.007	23	12.388	11
Canada	0.094	30	−0.165	41	13.842	4
Hong Kong	0.084	31	−0.076	32	11.253	21
Germany	0.065	32	−0.149	38	14.237	3
Philippines	0.063	33	−0.043	29	10.413	26
Bahrain	0.043	34	−0.083	34	10.869	24
Saudi Arabia	0.018	35	0.012	22	9.444	32
Pakistan	−0.041	36	−0.154	39	11.474	20
Egypt	−0.11	37	0.042	18	9.438	33
France	−0.138	38	−0.162	40	10.902	23
Ukraine	−0.143	39	−0.467	51	13.203	7
Spain	−0.146	40	0.158	7	8.909	36
Turkey	−0.153	41	−0.256	48	11.83	17
Russia	−0.161	42	−0.315	50	11.932	15
Mexico	−0.465	43	0.081	16	8.469	43
Argentina	−0.48	44	0.14	9	9.594	31
Indonesia	−0.486	45	−0.051	31	9.326	34
Colombia	−0.525	46	0.231	4	8.625	40
Venezuela	−0.541	47	0.119	10	8.539	42
Chile	−0.566	48	0.1	13	8.744	37
Poland	−0.616	49	−0.195	45	12.785	8
Peru	−0.659	50	0.112	11	8.392	45
Ecuador	−0.764	51	0.099	14	9.795	30

Appendix B. International survey

This Appendix includes the full international survey as administered. This survey represents a collaboration among multiple researchers as part of the MIT Energy Initiative Mobility of the Future study and only a subset of the questions are analyzed for the purpose of this thesis. In addition to the sociodemographic information collected in the survey, the Dalia research system profiles of each respondent also include age, gender, education level (as low, medium, or high), urban vs. rural, and location information—country code, city name, latitude and longitude.

For ease of legibility of this appendix, the questions have been broken up into sections, but these headings were not displayed to respondents. Furthermore, the order of questions as they appear here may not directly match that experienced by respondents. Do to the mobile- phone based platform, all questions were presented in multiple choice format. Questions with circular radio buttons allow only one response category to be selected. Questions with square radio buttons allow multiple responses to be selected. Shaded blocks are used here to indicate questions that are displayed only for some respondents (based on their answers to previous questions). Simple instructions, registration on the Dalia platform (for new respondents), and a consent question preceded all the questions outline here.

Sociodemographics

Which best describes the place where you live?

- Countryside
- Town with fewer than 1,000 people
- Town with 1,000 - 50,000 people
- City with 50,000 - 250,000 people
- City with 250,000 - 1 million people
- City with 1 million - 5 million people
- City with 5 million - 10 million people
- City with more than 10 million people

What is your household's monthly income after taxes?
[Ranges were specified in U.S. dollars, but were automatically converted into local currency for respondents based on current market exchange rates and rounded to the nearest whole number.]

- Under 250
- 250 - 500
- 500 - 1,000
- 1,000 - 2,000
- 2,000 - 3,000
- 3,000 - 4,000
- 4,000 - 6,000
- 6,000 - 8,000
- 8,000 - 10,000
- 10,000 - 12,000
- 12,000 - 15,000
- More than 15,000
- Prefer not to say

Which of the following categories best describes your employment status?

- In school, university or practical training
- Employed, working 1 to 29 hours per week
- Employed, working 30 or more hours per week
- Self-employed / Freelancer # Entrepreneur / Employer
- Not employed, currently looking for work
- Not employed, currently NOT looking for work
- Disabled / not able to work
- Retired
- None of the above

While in school, university or practical training, are you...?

- ...not employed, currently NOT looking for work
- ...not employed, currently looking for work
- ...employed

Mobility Patterns

Do you own a car? ('Own' includes cars that are on long-term lease / financing plans)

- ○ No, I don't
- ○ No, but I have regular access to one
- ○ Yes, I do

Which of the following do you take to get to work / school / other regular journey on a weekday?

- ☐ Car: driver
- ☐ Car: passenger
- ☐ Bicycle
- ☐ Electric bicycle
- ☐ Motorbike/scooter
- ☐ Boat / ferry
- ☐ Walking
- ☐ Bus or minibus
- ☐ Tram
- ☐ Train
- ☐ Underground / metro / subway
- ☐ Other public transport
- ☐ Taxi or other hired vehicle
- ☐ Rickshaw
- ☐ Other private vehicle

How many hours do you spend on transportation / commuting / trips per week - day?

- ○ Less than 30 minutes
- ○ 30 minutes - 1 hour
- ○ 1-2hours
- ○ 2-3hours
- ○ 3-4hours
- ○ More than 4 hours

What would roughly be the value (purchase price) of the next car you buy / lease? [Ranges were again specified in U.S. dollars, but were automatically converted into local currency.]

- ○ Under 5,000
- ○ 5,000 - 10,000
- ○ 10,000 - 20,000
- ○ 20,000 - 30,000
- ○ 30,000 - 40,000
- ○ 40,000 - 50,000
- ○ 50,000 - 60,000
- ○ 60,000 - 70,000
- ○ 70,000 - 80,000
- ○ More than 80,000
- ○ No idea

Among your peers, what proportion of them do you think drive regularly?

- ○ All / Almost all
- ○ Most of them
- ○ Some of them
- ○ Few of them
- ○ None / Almost none
- ○

If the respondent owns or has regular access to a car:

On days when you drive, how many miles do you drive typically?

- ○ None / not applicable
- ○ Up to 10mi (16km)
- ○ More than 10mi (16km) and up to 50mi (80km)
- ○ More than 50 mi (80km) and up to 100mi (160km)
- ○ More than 100 mi (160 km)

Where are your car(s) usually parked overnight?

- ○ In a private garage
- ○ In a public garage
- ○ In a driveway
- ○ Other off-street parking
- ○ On the street / some other public location

For which of the following reasons do you use a car instead of other transport options? Please select all that apply.

- ☐ I don't have access to public transportation
- ☐ The public transportation isn't good enough
- ☐ I prefer to be independent
- ☐ I like owning something valuable
- ☐ It is more comfortable / relaxing
- ☐ I need it for long-distance travel
- ☐ I need it for transporting equipment and heavy objects
- ☐ I need it to drive my kids
- ☐ I prefer the privacy
- ☐ I can control my own schedule
- ☐ It is faster
- ☐ It is safer
- ☐ It is cheaper
- ☐ None of the above

Policy Support

If the government decides to improve overall transportation conditions in your location, which of the following policies would you support? Please select up to three.

- ☐ Build additional roads
- ☐ Discourage the use of private automobiles in the city center
- ☐ Expand bike lanes
- ☐ Expand public transportation services (bus/train)
- ☐ Improve pedestrian facilities (sidewalks, street crossings etc.)
- ☐ Introduce car-free pedestrian zones in the city center
- ☐ Lower public transportation fares
- ☐ Prioritize public bus lanes and/or bus rapid transit
- ☐ Provide clean energy-based public transportation options
- ☐ Provide more parking spaces
- ☐ Subsidize clean energy vehicles

Car Pride and Car Dependence

Which of these statements reflect your feelings about driving / using a car (now or in the future)? Select all that apply

- ☐ Driving meets my self esteem or personal image.
- ☐ I would be ashamed if future financial circumstances prevented me from driving.
- ☐ If more people saw me in / with my car, I would drive more.
- ☐ I gain respect from my peers because I drive a car.
- ☐ I would feel better about myself if I drove less.
- ☐ A car is a sign of social status.
- ☐ My lifestyle is dependent on having a car.
- ☐ I don’t have time to think about how I travel; I just get in my car and go.
- ☐ I would like to reduce my car use, but there are no practical alternatives.
- ☐ I am actively trying to use my car less.
- ☐ I am not interested in reducing my car use.
- ☐ I need a car for my job/work.
- ☐ None of the above

Which of these statements reflect your feelings about owning a car (now or in the future)? Select all that apply

- ☐ Having a car is connected with my social image.
- ☐ Others would see me as more successful if I owned a better car or more cars.
- ☐ I have achieved in life and therefore I deserve to own a good car.
- ☐ I feel proud of owning a car.
- ☐ I have a sense of accomplishment after buying a car.
- ☐ If I could, I would prefer not to own a car now or in the future.
- ☐ None of the above

Electric Vehicles

Which of the following is true of your experience with electric vehicles? Select all that apply.

- ○ I know someone who has one
- ○ I have seen one in person
- ○ I have seen an image of one
- ○ I have been in one
- ○ I own one
- ○ None of these

Next time you buy / lease a car, how likely are you to buy an all-electric car?

- ○ Very likely
- ○ Somewhat likely
- ○ Not very likely
- ○ Not at all likely

If you were to buy an electric vehicle, what would be the minimum acceptable range for you on a full charge?

- 10 mi (16 km)
- 50 mi (80 km)
- 100 mi (160 km)
- 200 mi (320 km)
- 300 mi (480 km)
- More than 300 mi (480 km)
- Don't know

Autonomous Vehicles

Have you seen, heard or read anything about self-driving cars?

- Yes, a lot
- Yes, a bit
- No

How safe do you think self-driving cars are, as of now?

- Very safe
- Somewhat safe
- Not very safe
- Not safe at all
- Not sure

If the respondent does not select "very safe" above:

How soon, if at all, do you think self-driving cars will be safe enough for you to consider using one?

- Within the next 2 years
- Within the next 5 years
- Within the next 10 years
- Within the next 20 years
- More than 20 years
- Never (50)
- Don't know

Appendix C. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2019.07.022.

References

Anania, E.C., Rice, S., Walters, N.W., Pierce, M., Winter, S.R., Milner, M.N., 2018. The effects of positive and negative information on consumers' willingness to ride in a driverless vehicle. Transp. Policy. https://doi.org/10.1016/j.tranpol.2018.04.002.

Asparouhov, T., Muthén B., 2007. Constructing Covariates in Multilevel Regression. Mplus Web Notes: No. 11. https://www.statmodel.com/download/webnotes/webnote11.pdf.

Casley, S.V., Jardim, A.S., Quartulli, A.M.A., 2013. A Study of Public Acceptance of Autonomous Cars. Worcester Polytechnic Institute, Worcester, MA.

Choi, J.K., Ji, Y.G., 2015. Investigating the importance of trust on adopting an autonomous vehicle. Int. J. Hum.-Comput. Int. 31 (10), 692–702.

de Winter, J.C.F., Kyriakidis, M., Dodou, D., Happee, R., 2015. Using CrowdFlower to study the relationship between self-reported violations and traffic accidents. Presented at the 6th International Conference on Applied Human Factors and Ergonomics (AHFE), Las Vegas.

Depaoli, S., van de Schoot, R., 2017. Improving transparency and replication in bayesian statistics: the WAMBS-checklist. Psychol. Methods 22 (2), 240–261. https://doi.org/10.1037/met0000065.

Elias, W., Shiftan, Y., 2012. The influence of individual's risk perception and attitudes on travel behavior. Transport. Res. Part A: Pol. Pract. 46 (8), 1241–1251. https://doi.org/10.1016/j.tra.2012.05.013.

Enders, C.K., Tofighi, D., 2007. Centering predictor variables in cross-sectional multilevel models: a new look at an old issue. Psychol. Methods 12 (2), 121–138. https://doi.org/10.1037/1082-989X.12.2.121.

Gelman, A., Rubin, D.B., 1992a. Inference from iterative simulation using multiple sequences. Stat. Sci. 7, 457–511.

Gelman, A., Rubin, D.B., 1992b. A single series from the Gibbs sampler provides a false sense of security. In: Bernardo, J.M., Berger, J.O., Dawid, A.P., Smith, A.F.M. (Eds.), Bayesian Statistics 4. Oxford University Press, Oxford, UK, pp. 625–631.

Haboucha, C.J., Ishaq, R., Shiftan, Y., 2017. User preferences regarding autonomous vehicles. Transport. Res. Part C: Emerg. Technol. 78, 37–49. https://doi.org/10.1016/j.trc.2017.01.010.

Holland, C., Hill, R., 2007. The effect of age, gender and driver status on pedestrians' intentions to cross the road in risky situations. Accid. Anal. Prev. 39 (2), 224–237. https://doi.org/10.1016/j.aap.2006.07.003.

Howard, D., Dai, D., 2014. Public perceptions of self-driving cars: The case of Berkeley, California. In: Transportation Research Board 93rd Annual Meeting, vol. 14(4502), pp. 1–16.

Hulse, L.M., Xie, H., Galea, E.R., 2018. Perceptions of autonomous vehicles: relationships with road users, risk, gender and age. Saf. Sci. 102, 1–13.

International Organization of Motor Vehicle Manufacturers [OICA], 2015. World Vehicles in use: All vehicles (including motorization rate). http://www.oica.net/category/vehicles-in-use/ (accessed May 2018).

Kyriakidis, M., Happee, R., de Winter, J.C.F., 2015. Public opinion on automated driving: results of an international questionnaire among 5000 respondents. Transport. Res. Part F: Traffic Psychol. Behav. 32, 137–140. https://doi.org/10.1016/j.trf.2015.04.014.

Lang, N., Rüßmann, M., Mei-Pochtler, A., Dauner, T., Komiya, S., Mosquet, X., Doubara, X., 2016. Self-Driving Vehicles, Robo-Taxis, and the Urban Mobility Revolution. The Boston Consulting Group and World Economic Forum. http://www.auto-mat.ch/wAssets/docs/BCG-Self-Driving-Vehicles-Robo-Taxis-and-the-Urban-Mobility-Revolution.pdf.

Lee, C., Ward, C., Raue, M., D'Ambrosio, L., Coughlin, J.F., 2017. Age differences in acceptance of self-driving cars: a survey of perceptions and attitudes. In: International Conference on Human Aspects of IT for the Aged Population. Springer, Cham, pp. 3–13.

Lucas, S.R., 2014. An inconvenient dataset: bias and inappropriate inference with the multilevel model. Qual. Quant. 48 (3), 1619–1649. https://doi.org/10.1007/s11135-

013-9865-x.
Moody, J. 2019. Measuring Car Pride and its Implications for Car Ownership and Use across Individuals, Cities, and Countries. [Doctoral dissertation]. Cambridge, MA: Massachusetts Institute of Technology.
Muthén, B., Asparouhov, T., 2009. Beyond multilevel regression modeling: multilevel analysis in a general latent variable framework. In: Hox, J., Roberts, J.K. (Eds.), The Handbook of Advanced Multilevel Analysis. Taylor and Francis.
Muthén, B., 1994. Multilevel covariance structure analysis. Sociol. Methods Res. 22, 376–398.
National Highway Traffic Safety Administration [NHTSA]. 2017. Automated Driving Systems 2.0: A Vision for Safety. U.S. Department of Transportation, Washington, D. C. https://www.nhtsa.gov/manufacturers/automated-driving-systems.
Nees, M.A., 2016. September. Acceptance of self-driving cars: an examination of idealized versus realistic portrayals with a self-driving car acceptance scale. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Vol. 60, No. 1. Sage CA: Los Angeles, CA: SAGE Publications. pp. 1449–1453.
Muthén, B., Muthén, L., 1998–2019. Mplus User's Guide, Version 8. Muthén & Muthén, Los Angeles, CA.
Nees, M.A., 2019. Safer than the average human driver (who is less safe than me)? Examining a popular safety benchmark for self-driving cars. J. Saf. Res. 69, 61–68.
Nielsen, T.A.S., Haustein, S., 2018. On sceptics and enthusiasts: what are the expectations towards self-driving cars? Transp. Policy 66, 49–55. https://doi.org/10.1016/j.tranpol.2018.03.004.
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. J. Adv. Transport. 2018.
Payre, W., Cestac, J., Delhomme, P., 2014. Intention to use a fully automated car: attitudes and a priori acceptability. Transp. Res. Part F: Traffic Psychol. Behav. 27, 252–263. https://doi.org/10.1016/j.trf.2014.04.009.
Rosenbloom, T., 2009. Crossing at a red light: behavior of individuals and groups. Transport. Res. Part F: Traffic Psychol. Behav. 12 (5), 389–394. https://doi.org/10.1016/j.trf.2009.05.002.
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. Transport. Res. Part F: Traffic Psychol. Behav. 55, 114–122. https://doi.org/10.1016/j.trf.2018.02.029.
Schoettle, B., Sivak, M. 2014. A survey of public opinion about autonomous and self-driving vehicles in the U.S., U.K., and Australia. Report No. UMTRI-2014-21. University of Michigan Transport Research Institute. https://deepblue.lib.umich.edu/handle/2027.42/108384.
Smith, A., Caiazza, T., 2017. Automation in Everyday Life. Pew Research Center, Washington, D.C.
Sommer, K., 2013. Mobility Study 2013. Continental AG, Hanover, Germany.
Statistica.com. Percentage of all global web pages served to mobile phones from 2009 to 2018. https://www.statista.com/statistics/241462/global-mobile-phone-website-traffic-share/.
Turner, C., McClure, R., 2003. Age and gender differences in risk-taking behaviour as an explanation for high incidence of motor vehicle crashes as a driver in young males. Injury Control Safety Promot. 10 (3), 123–130. https://doi.org/10.1076/icsp.10.3.123.14560.
Tussyadiah, I.P., Zach, F.J., Wang, J., 2017. Attitudes toward autonomous on demand mobility system: the case of self-driving taxi. In: Information and Communication Technologies in Tourism 2017. Springer, Cham, pp. 755–766.
United Nations, 2017. Statistical annex: country classification. World Economic Situation and Prospects.
United Nations General Assembly. 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. http://www.refworld.org/docid/57b6e3e44.html.
Underwood, S.E., 2014. Automated vehicles forecast vehicle symposium opinion survey. In: Presented at the Automated Vehicles Symposium, San Francisco, CA.
World Bank, Development Research Group, n.d. GINI index (World Bank estimate). World Bank Open Data. https://data.worldbank.org/indicator/SI.POV.GINI (accessed May 2018).
World Bank, International Comparison Program database, n.d. GDP per capita, PPP (constant 2011 international $). World Bank Open Data. https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD (accessed May 2018).
World Health Organization [WHO], 2015. Global Status Report on Road Safety 2015. World Health Organization Press, Geneva.
World Health Organization [WHO], n.d. Road traffic deaths. Data by country. Global Health Observatory data repository. Last updated May 16, 2018. http://apps.who.int/gho/data/node.main.A997?lang=en.
World Health Organization [WHO], n.d. Reported distribution of road traffic deaths by type of road user. Data by country. Global Health Observatory data repository. Last updated February 25, 2016. http://apps.who.int/gho/data/node.main.A998?lang=en.
Xu, Z., Zhang, K., Min, H., Wang, Z., Zhao, X., Liu, P., 2018. What drives people to accept automated vehicles? Findings from a field experiment. Transport. Res. Part C: Emerg. Technol. 95, 320–334.
Zhang, T., Tao, D., Qu, X., Zhang, X., Lin, R., Zhang, W., 2019. The roles of initial trust and perceived risk in public's acceptance of automated vehicles. Transport. Res. Part C: Emerg. Technol. 98, 207–220.