ASIA MARKETING JOURNAL

Volume 23 | Issue 4 Article 1

January 2022

The Safety Paradox of Self-Driving Cars

Yeh Jun Lee
Virginia Tech, USA, yehjun@vt.edu

Jongwon Park
Korea University Business School, ROK, amadeus@korea.ac.kr

Recommended Citation

Lee, Yeh Jun and Park, Jongwon (2022) "The Safety Paradox of Self-Driving Cars," *Asia Marketing Journal*: Vol. 23 : Iss. 4 , Article 1.
Available at: https://doi.org/10.53728/2765-6500.1579

The Safety Paradox of Self-driving Cars☆

Yeh Jun Lee [a], Jongwon Park [b,*]

[a] Department of Marketing, Virginia Tech, USA
[b] Korea University Business School, 145 Anam-ro, Seongbuk-gu, Seoul, 02841, South Korea

Abstract

Self-driving cars are undergoing extensive road tests and should enter the market within the decade, but consumers continue to worry about the safety of autonomous vehicles—even though most traffic accidents are caused by human errors that are avoidable with automation technology. Four experiments investigated how a vehicle's automation level affects its perceived safety, why excessive safety concerns prevail, and how they can be mitigated. In all experiments, participants read descriptions of full-automation (Level 5) and high-automation (Level 4) self-driving cars: Participants consistently perceived Level 5 (vs. Level 4) vehicles as less safe. The effect persisted when objective safety information was available. A mediation analysis and a mediation-by-moderation approach suggest that the negative effect of the automation level on perceived safety is driven by the perceived lack of control over driving. Finally, the effect disappeared when participants imagined themselves as passengers rather than drivers, offering a practical implication for managers.

Keywords: Consumer judgments, Safety perception, Self-driving cars, Autonomous cars, Perceived control, High-tech innovations

1. Introduction

Although they are not yet on the market, self-driving cars are already on the road, undergoing trial operations with no drivers. Soon, these vehicles will drive us, instead of us driving them. Self-driving cars are one of the most disruptive innovations in the history of the motor industry, and their commercialization will bring many changes to our lives and society.

Self-driving cars are expected to bring many benefits to consumers and society (Clements and Kockelman 2017; Fagnant and Kockelman 2015). For example, autonomous vehicles (AVs) can improve the ease and comfort of driving, increase the efficiency of traffic flow, and increase transportation access for the disabled community. Also, AVs can provide environmental benefits through more efficient road use, greater fuel efficiency, and lower vehicle emissions (Greenblatt and Shaheen 2015; MacKenzie, Wadud, and Leiby 2014; Sun et al. 2016). Moreover, AVs can enhance traffic safety by preventing accidents caused by the errors of human drivers (Bertoncello and Wee 2015; Crew 2015; NHTSA 2021). AVs are operated by an advanced automation system with several safety-enhancing technologies: AI software and radars, 360-degree visibility cameras, ultrasonic sensors and radio antennas, and 5G cellular networks. For example, Cruise, a subordinate company of GM that focuses on AVs, boasts 42 sensors in a single vehicle (General Motors 2021).

Yet, consumers are wary of the technology. Pew Research Center (2017) reported that 56% of people in the US said they would not ride in driverless vehicles, primarily because of safety concerns. A more recent report indicates that 47% of US adults believe that AVs are less safe than cars driven by humans (Morning Consult 2021).

Contrary to these lay beliefs about safety, self-driving cars are far safer than traditional vehicles

☆ This article is in part based on the thesis research conducted by Yeh Jun Lee under the supervision of Jongwon Park. An earlier version of the article was presented at the 2021 AMA Summer Conference and received the best track paper award. The authors gratefully acknowledge members of the Korea University *B.E.S.T.* Marketing Group for their valuable suggestions pertaining to the theoretical basis for the study and the interpretation of the results. This study is partially supported by Korea University Business School Research Grant.

Received 26 November 2021; accepted 8 December 2021.
Available online 16 January 2022

* Corresponding author.
E-mail addresses: yehjun@vt.edu (Y.J. Lee), amadeus@korea.ac.kr (J. Park).

https://doi.org/10.53728/2765-6500.1579

(Blanco et al. 2016). Most fatal motor vehicle crashes are caused by *human* errors, including inattention, distractions, inadequate surveillance, tiredness, improper driver responses, and even drunk driving (Kalra and Paddock 2016). In the US, for example, 94% of the serious motor vehicle crashes in 2019 were due to human errors (NHTSA 2021). Autonomous cars, by contrast, are free from these hazardous human habits and thus are better able to protect drivers, passengers, and other people on the road—so much so that self-driving cars are expected to reduce vehicle fatalities by 90% (Bertoncello and Wee 2015; Crew 2015).

Why is the public excessively, and even paradoxically, concerned about the safety of self-driving cars? The present research intends to provide insight into this safety paradox. One intuitive possibility for excessive safety concerns is the lack of information about safety, that is, people simply are not sufficiently informed about the safety of self-driving cars (relative to the safety of traditional or less-autonomous vehicles). In contrast, building research on the role of perceived control (König and Neumayr 2017) and anxiety (Mineka and Kelley 1989; Watson 1967) in human judgments and behaviors, we posit that excessive concerns about the safety of self-driving cars are due to the perceived lack of control over driving and the resultant anxiety, not due to a lack of information about the actual safety of the vehicles. This "control-based" account leads to two hypotheses: (1) people perceive full-automation vehicles as *less* safe (not safer) than high-automation vehicles, and (2) the difference holds regardless of whether people receive objective information about the safety of the vehicles. Four experimental studies confirm these predictions, find support for the control-based mechanism, and cast doubt on the information-based mechanism. Moreover, our finding of the greater safety concern about the full-automation vehicles (vs. less-automated vehicles), contrary to the actual superiority of the full-automation ones, extends prior research showing that perceived lack of control is negatively correlated with the adoption of self-driving cars. Finally, the final study tests an intervention that can eliminate the difference in the perceived safety of full-automation and high-automation vehicles.

2. Theoretical considerations

Self-driving cars are automobiles that can operate without human intervention or with minimal human intervention. They are also called driverless cars or autonomous vehicles (AVs).

According to the Society of Automotive Engineers (SAE 2018), cars are categorized by the level of automation, from fully manual to fully automated. Specifically, Level 0 has no automation; Level 1–2 cars have driver assistance features such as cruise control and other long-standing partial automation features, such that a human driver has to perform most driving activities; Level 3 cars have automated "environmental detection" capabilities and make informed decisions but require some driver input most of the time; Level 4 (L4) relinquishes human control to an automated system for most driving tasks, with limited exceptions that require human override; and Level 5 (L5) does not require a human driver *at all* and has no steering wheel or pedals. Although L5 vehicles are still in the testing phase, they are expected to be commercialized by 2030 at the latest (Litman 2017). The present study compares the perceived safety of L4 ("high automation") and L5 ("full automation").

2.1. Consumer perceptions of autonomous vehicles, and the safety paradox

Consumers remain wary of self-driving cars in the face of a steady stream of research and articles on the myriad benefits of AVs (Morning Consult 2021; Pew Research Center 2017). Prior research has identified several factors for this wariness: the insufficient reliability of the technology (Bansal and Kockelman 2018; Howard and Dai 2014; Schoettle and Sivak 2014), safety concerns (e.g., Howard and Dai 2014), insufficient security (e.g., "system hacking," Douma and Palodichuk 2012), moral and ethical issues (Lin 2015), and insufficient laws, regulations, and AV-related infrastructure (KPMG 2019). Safety seems to be the most serious concern (Choe et al. 2015; Howard and Dai 2014; Hwang and Cho 2016; Piao et al. 2016; Schoettle and Sivak 2014), and in the minds of many consumers, these concerns apparently outweigh the benefits of self-driving cars (Kohl et al. 2017; Lee 2017; Lee, Chang, and Park 2018).

Obviously, car manufacturers should strive to enhance the safety of AVs with ongoing technological improvements. However, the perceived dangers of AVs are not borne out in the evidence. As noted earlier, AVs can prevent accidents caused by human errors (Bertoncello and Wee 2015; Crew 2015; NHTSA 2021), and AVs are objectively safer than traditional vehicles (Beiker 2012; Blanco et al. 2016; Douma and Palodichuk 2012). Nevertheless, people misperceive that AVs are less safe than cars driven by humans (Morning Consult 2021). It is important to understand why consumers hold excessive safety concerns so that those concerns can be mitigated.

2.2. Present research

One intuitive explanation for excessive safety concerns is that people simply are not sufficiently informed about the safety of self-driving cars (relative to the safety of traditional or less-autonomous vehicles). People may feel uncertain about new technologies in general (Carleton et al. 2012; McEvoy and Mahoney 2012) or may perceive themselves as not ready for new technologies (Han and Park 2016; Oh, Yoon, and Yuen 2010). Consumers may also worry about a possible automation system failure of cars (Rupp and King 2010). If a lack of information explains the excessive concerns, then providing people with objective information about AV safety should mitigate the concerns. However, we consider a different, and less intuitive, possibility: excessive safety concerns are due to the perceived lack of control over driving.

Our theory is informed by the research on perceptions of control and the anxiety that accompanies a perceived lack of control. *Perceived control* is the extent to which people believe they personally influence or manage the cause of an event or risk (McAuley, Duncan, and Russell 1992). Extant research suggests that the perception of control is an essential part of life; it is important for self-esteem (Friedland, Keinan, and Regev 1992), increases the motivation to work hard (Chapman and Turner 1986), and provides a pleasant feeling (Rothbaum, Weize, and Snyder 1982). Meanwhile, a lack of control leads to poor motivation and “learned helplessness” in education contexts (Koller and Kaplan 1978); it increases anxiety (Mineka and Kelly 1989; Watson 1967) and fear (Whalen 1998; Whitson and Galinsky 2008), which, in turn, significantly affect the perceived risk associated with the object under consideration (Klein and Kunda 1994; Nordfjærn, Jørgensen, and Rundmo 2012; Nordgren, Van der Pligt, and Van Harreveld 2007; Weinstein 1984).

The self-driving capability of AVs comes at the expense of the human driver's control over driving (König and Neumayr 2017)—an activity that generally instills a feeling of control (Burger and Cooper 1979; Dixon et al. 2020; Taylor and Deane 2000). Research has confirmed that autonomous driving is highly correlated with a perceived lack of control and expectations for a lack of safety (Heinrichs and Cyganski 2015; Sommer 2013), and a person's desire for control is negatively correlated with the person's attitude toward AVs (Syahrivar et al. 2021). Further, the perceived lack of control induces personal discomfort with using AVs (Hartwich, Beggiato, and Krems 2018) and evokes anxiety (Nordfjærn, Jorgensen, and Rundmo 2012), which decreases usage intentions (Hohenberger, Sporrle, and Welpe 2017; Zmud, Sener, and Wagner 2016).

The above findings suggest that the automation system of AVs deprives the human driver of control, which induces anxiety, which decreases the perceived safety of AVs. We reason that as the automation level increases (e.g., from L4 to L5) and the human driver's control decreases, the perceived lack of control and anxiety should increase, and the perceived safety of the AV should decrease. Note that the predicted trend in perceived safety is contrary to the actual improvement in safety when switching from L4 (high automation) to L5 (full automation).

In sum, self-driving cars are effective at preventing traffic accidents that are caused by human errors—which account for most serious accidents—yet consumers perceive AVs as less safe than traditional vehicles. We posit that the excessive safety concerns are rooted in the perceived lack of control over driving. Thus, we predict that consumers perceive L5 AVs as *less* safe than L4 AVs, and the difference is mediated by the perceived lack of control. We expect the negative effect of the automation level on perceived safety to hold even when consumers receive objective information about the safety of L4 and L5 AVs. Finally, the effect should attenuate when the importance of having control over driving is less salient.

We confirmed these predictions in four experimental studies. In studies 1a and 1b, we gave participants basic descriptions of L4 and L5 AVs, and participants judged the L5 version as less safe than the L4 version, as predicted. Study 2 replicated the effect with a different measure of perceived safety and with participants who received objective safety information about L4 and L5 AVs. Study 2 also measured anxiety, perceived lack of control over driving, and several exploratory mediators; the only significant pathway occurred through perceived lack of control and anxiety. Study 3 provided further evidence against the information-based account and in support of our control-based account; in a mediation-by-moderation approach, the negative effect of the automation level on perceived safety did not occur when the importance of having control was made less salient.

3. Experiments

3.1. Studies 1a and 1b

Studies 1a and 1b were designed to provide initial evidence of the hypothesis that consumers perceive full-automation AVs (L5) as less safe than high-automation AVs (L4), contradicting the actual safety profiles of the cars. We provided participants with descriptions of L4 and L5 AVs and asked them to judge the safety of each automobile. The studies were identical except for the dependent measure (a free-response procedure in study 1a and a rating scale in study 1b), which we varied to check the robustness of the findings.

3.1.1. Study 1a

Method: Participants were 94 adults (52.13% female, $M_{age} = 38.22$) recruited from Amazon MTurk. We excluded eight participants who failed to follow the instructions. All participants received general instructions for the study, followed by descriptions of an L4 AV and an L5 AV. The descriptions were constructed from the definitions of L4 and L5 by SAE International (2018; see the Appendix for the stimuli). Finally, participants were asked to free-write their thoughts and feelings about each vehicle.

Results: Two independent coders identified responses that explicitly pertained to safety concerns (inter-coder agreement: 91%). We performed a McNemar test to compare the frequency of safety concerns for L4 and L5 vehicles. As expected, more participants expressed safety concerns for L5 vehicles than for L4 vehicles ($N_{L5} = 17.4\%$ vs. $N_{L4} = 4.7\%$, $p < .001$). Further, most of the responses that expressed safety concerns about L5 vehicles specifically referred to the lack of control over driving (e.g., *"There isn't enough control for the rider"; "This one does not mandate that a human driver takes over if something goes wrong"*), consistent with our predicted mechanism.

3.1.2. Study 1b

Study 1b extended the findings of study 1a in two ways. First, the study replicated the result using a different measure of perceived safety. Second, we added price information and photos to make the stimuli more realistic.

Method: Participants were 103 adults (53.4% female, $M_{age} = 35.44$) recruited from Amazon MTurk. As in study 1a, participants were provided with two descriptions of self-driving cars (L4 and L5) for evaluation. The descriptions included the same information as in study 1, but we added price information ($40,000 for L5 and $35,000 for L4) and a picture from each vehicle's cockpit to increase the salience of the differences between the vehicles (e.g., L5 does not have a steering wheel or pedals; see the Appendix for the pictures). For the dependent measure, participants rated the safety of each vehicle on a 7-point scale (1 = "very unsafe," 7 = "very safe").

Results: We compared the within-participant safety ratings of the L4 and L5 vehicles with a paired t-test. As expected, participants perceived the full-automation version (L5) as significantly less safe than the high-automation vehicle (L4) ($M_{L5} = 3.97$ vs. $M_{L4} = 5.08$; $t_{\text{paired}} = 6.68$, $p < .001$), replicating the result of study 1a and providing further support for our prediction.

Discussion: Consistent with our prediction, studies 1a and 1b showed that participants perceive full-automation vehicles as less safe than high-automation vehicles, reflecting the predicted "safety paradox." In study 1a, we also found indirect support for the theorized mechanism: full-automation vehicles heighten the perceived lack of control over driving. We propose that the perceived lack of control leads to anxiety, which leads to safety concerns. We test the mechanism directly in study 2.

3.2. Study 2

Study 2 extended the findings of studies 1a and 1b in three ways. First, we sought direct evidence of our theoretical mechanism by measuring the perceived lack of control and anxiety and conducting mediation analyses. Second, the study evaluated the information-based alternative account, which argues that people have excessive safety concerns because they lack information about the objective safety of AVs. We argue that the safety concerns are rooted in the perceived lack of control, not a lack of information, so we expect the negative effect of automation to persist when objective safety information is included in the AV descriptions. Third, as to be described next, we included product pictures and price level in the descriptions of the L4 and L5 vehicles to make the experimental stimuli more engaging and the difference between L4 and L5 AVs in automation level more noticeable. However, it could also introduce some extraneous differences other than the difference in automation level, which might also affect perceived safety. To address this possibility, we measured several additional perceptions about L4 and L5 including perceived sturdiness (Owsley, Stalvey, and Phillips 2003), perceived luxuriousness (Vigneron and Johnson 2004), and futuristic image (Mugge and Schoormans 2012). Finally, we measured purchase intentions as a downstream consequence, and we expected the results to follow the trend in perceived safety.

Method: Participants and design. Participants were 394 adults from Amazon Mturk (M_{age} = 36.15, 59.6% male), randomly assigned to one of two between-subjects conditions (type of safety information: frequency only vs. frequency and severity). As in studies 1a and 1b, we measured the perceived safety of L4 and L5 as a within-subject factor.

Procedure: Unlike in studies 1a and 1b, participants started by watching a 1-min video clip about each vehicle (L4: https://www.youtube.com/watch?v = MWqacPy3r7Q; L5: https://www.youtube.com/watch?v=V6kIeOGQYdQ). The first part of the clips was the same; it showed a vehicle navigating an urban area. Then, the video showed the interior of the vehicle in detail; the L4 video featured a vehicle interior with a steering wheel and a gas pedal, while the L5 video showed an interior that lacked these features. We used video clips to make the experimental stimuli more engaging and to make the differences between L4 and L5 AVs more noticeable.

After watching both clips, participants moved on to the written descriptions. All participants received the same information as in study 1b as well as information about accident rates (specifically, the frequency of accidents per million miles: 3.2 crashes for L5 vs. 4.2 crashes for L4[1]). Participants in the frequency-and-severity condition also received information about accident severity, as we thought it was possible that participants might imagine that L5 is more likely to cause fatal injuries and thus be *less* safe than L4 despite the lower frequency of accidents overall. Specifically, we provided almost identical Poisson distributions of accident severity for each vehicle; severe accidents are similarly rare for L4 and L5. The graphs were paired with a written statement: "*The probability of serious accidents for both vehicles are found to be the same. In other words, the likelihood of getting into a serious accident for both vehicles are the same.*" (For the full stimuli in the frequency-and-severity condition, please see the Appendix.)

For the primary dependent measure, we used the same 7-point scale as in study 1b (1 = "very unsafe," 7 = "very safe"). As a downstream consequence, we measured participants' purchase intentions for each vehicle on a 7-point scale (1 = "not at all," 7 = "very much"). For the two hypothesized mediators, we measured perceived control over driving (1 = "no control at all," 7 = "very much in control")[2] and anxiety (1 = "not anxious at all," 7 = "very anxious"). Finally, we measured several additional perceptions of the vehicles to evaluate their possible influences: the vehicle's sturdiness (1 = "not sturdy at all," 7 = "very sturdy"), luxuriousness (1 = "not luxurious at all," 7 = "very luxurious"), and futuristic image (1 = "not futuristic at all" 7 = "very futuristic"). None of these factors accounted for the effect of the automation level on perceived safety, so we will not discuss them further.

Results: According to our theorization, the negative effect of the automation level on perceived safety should be significant in this study even though all participants received one or more types of objective safety information. Also, the negative effect of the automation level on perceived safety should be mediated by the perceived lack of control. Both predictions were supported.

Perception of safety: A mixed ANOVA on perceived safety as a function of the automation level (L4 vs. L5; within-participant factor) and type of safety information (frequency-only vs. frequency-and-severity; between-participants factor) yielded a significant main effect of the automation level (F(1, 392) = 48.30, $p < .001$). As in studies 1a and 1b, and as expected, participants perceived the full-automation vehicle (L5) as less safe than the high-automation vehicle (L4) (M_{L5} = 4.36 vs. M_{L4} = 4.88, t_{paired} = 4.77, $p < .001$), even though the study 2 participants received objective safety information. Moreover, the effect did not interact with the type of information (F(1, 392) = .27) (Fig. 1). These results are against the information-based account. Next, we show evidence of our perceived-control account with mediation analyses.

Mediation analyses: We conducted separate within-participant mediation analyses for the perceived lack of control and anxiety, with the automation level as the independent variable and perceived safety as the dependent variable. We used the MEMORE macro for SPSS (Montoya and Hayes 2017) to conduct a bootstrapping procedure with 5000 resamples for each analysis. Fig. 2 shows all coefficients.

The first analysis yielded a significant indirect effect of the automation level on perceived safety via the perceived lack of control (b = −.4271, 95% CI: −.5833 to −.2708), while the direct effect of the automation level on perceived safety was non-significant (b = −.0983, 95% CI: −.2916 to .0950). The

[1] The crash rates were based on data from Virginia Tech (2016). The crash rate for L5 (3.2 crashes per million miles) was based on the actual crash rate of the AVs in the report. The crash rate for L4 (4.2 crashes per million miles) was adopted from the reported average crash rate of more traditional vehicles.
[2] We reverse-coded the perceived control rating to reflect the participant's perception of *lacking* control (i.e., higher numbers represent less control).

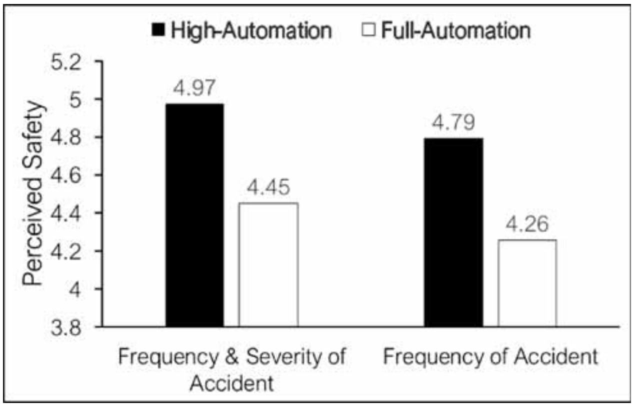


Fig. 1. Perceived safety by automation level and information amount (study 2).

second analysis yielded a significant indirect effect of the automation level on perceived safety via anxiety (b = −.2444, 95% CI: −.3614 to −.1398), while the direct effect of the automation level was also significant (b = −.2810, 95% CI: −.4318 to −.1302).

Finally, we tested whether the effect of the automation level on anxiety was mediated by the perceived lack of control. A bootstrapping procedure of 5000 resamples revealed a significant indirect effect via the perceived lack of control (b = .7349, 95% CI: .5417 to .9405), while the direct effect of the automation level on anxiety was non-significant (b = .0545, 95% CI: −.1468 to .2557).

The mediation results above in combination provide support for the proposed mediation mechanism: the negative effect of the automation level on the perceived safety of self-driving cars is mediated by the perceived lack of control and the resultant increase in anxiety.

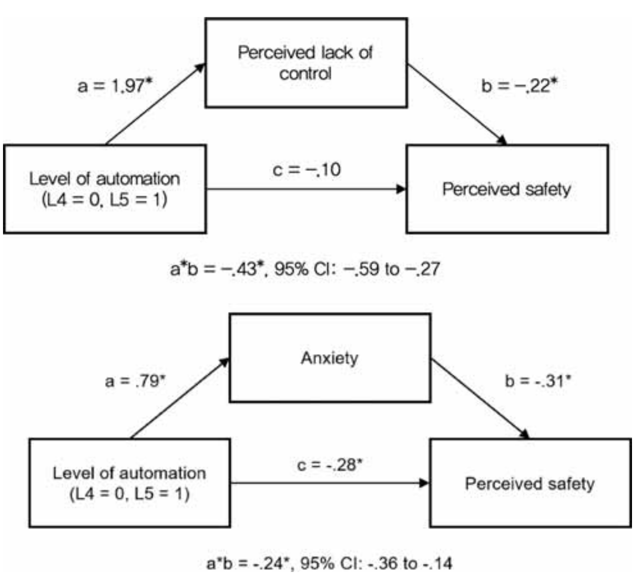


*Fig. 2. Bootstrapping Analyses for Mediation in Study 2. (Note: *p < .05, significance levels are two-tailed.).*

Purchase intention: Participants' purchase intention was analyzed by a mixed ANOVA as a function of the automation level and type of safety information. This analysis yielded a significant, negative main effect of the automation level that was not contingent upon the type of information ($F < 1$). Specifically, participants expressed a higher purchase intention for the full-automation vehicle (L5) than the high-automation vehicle (L4) ($M_{L5} = 3.97$ vs. $M_{L4} = 4.38$; $t_{\text{paired}} = 6.96$, $p < .001$), as expected.

Discussion: Study 2 replicated the negative effect of the automation level on the perceived safety of self-driving cars in the presence of objective safety information about the frequency of accidents, with or without information about the severity of those accidents. This finding is inconsistent with the information-based account but is consistent with our control-based account. Further, the results of mediation analyses directly confirmed the mediation process through the perceived lack of control and associated anxiety. In the final study, we use a mediation-by-moderation approach (Lee et al. 2008) to provide complementary evidence of the mechanism and test a boundary condition with practical applications for marketing managers.

3.3. Study 3

In study 3, we manipulated the salience (high vs. low) of the importance of having control over driving. If the negative effect of the automation level on perceived safety is indeed driven by the perceived lack of control (as indicated by study 2), then the negative effect should attenuate in the low-salience condition. In addition, we orthogonally manipulated the availability of objective safety information (available vs. unavailable) to provide a stronger test of the information-based account. (Note that all participants in study 2 received some amount of objective safety information, though the type of information varied.)

Method: Participants and design. Participants were 195 adults recruited from Amazon MTurk ($M_{age} = 35.17$, 57.9% male). They were randomly assigned to four conditions of a 2 (objective safety information: available vs. unavailable) x 2 (salience of having control: high vs. low). Seven participants who failed to follow the instructions were excluded from analyses.

Procedure: As in study 2, participants received both a 1-min video clip about each vehicle and descriptions of L4 and L5 AVs. However, the descriptions varied by the safety-information condition. The descriptions in the information-available condition were identical to the frequency-only condition in study 2 (i.e., the accident rate data was included as the objective safety information). In the information-unavailable condition, no objective safety information was provided.

We manipulated the salience of having control over driving by varying the participant's perspective: a driver in the high-salience condition vs. a passenger in the low-salience condition. Specifically, participants in the high-salience condition were asked to evaluate the self-driving cars for a possible purchase, so they were envisioning themselves as potential drivers. Participants in the low-salience condition were asked to evaluate the self-driving cars as taxi alternatives, so they were envisioning themselves as potential passengers.

Results: We performed a mixed ANOVA on perceived safety as a function of the automation level (L4 vs. L5, within-participant), objective safety information (available vs. unavailable, between-participants), and salience of having control (high vs. low, between-participants). Table 1 shows the cell means pertaining to this analysis.

First, as expected, participants perceived L5 as less safe than L4 ($M_{L5} = 4.50$ $M_{L4} = 4.90$; $F(1,183) = 14.46$, $p < .001$). Further, this difference was not moderated by the availability of objective safety information ($F(1,183) = 1.03$, $p > .10$), which is inconsistent with the information-based account and corroborates the results of study 2.

Importantly, we found a significant interaction effect of the automation level and the salience of having control ($F(1,183) = 6.90$, $p < .05$). As shown in Fig. 3, participants in the high-salience (driver) condition perceived L5 as significantly less safe than L4 ($M_{L5} = 4.47$ vs. $M_{L4} = 5.13$, $t(89) = 4.26$, $p < .001$), but participants in the low-salience (passenger) condition rated L5 and L4 as similarly safe ($M_{L5} = 4.55$ vs. $M_{L4} = 4.68$, $t(96) = 1.01$, $p > .10$). This interaction effect supports the theorized mechanism via the perceived lack of control.

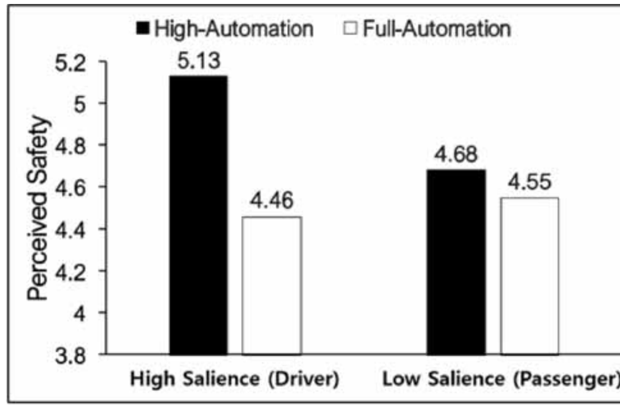


Fig. 3. Perceived safety by automation level and salience of having control (study 3).

4. General discussion

4.1. Summary and implications

The impending commercialization of self-driving cars holds the promise of many benefits for safety, efficiency, and accessibility, but many consumers remain wary of the vehicles (Morning Consult 2021; Pew Research Center 2017). The most common concern involves the safety of self-driving cars (Choe et al. 2015; Howard and Dai 2014; Hwang and Cho 2016; Piao et al. 2016; Schoettle and Sivak 2014). People perceive that self-driving cars are less safe than traditional vehicles (Morning Consult 2021) even though the opposite is true. Self-driving cars are safer primarily because they can avoid accidents that are caused by human errors, so the safety of the vehicle increases with its level of automation, such that L5 (full-automation) vehicles are safer than L4 (high-automation) vehicles.

The present research provides insight into consumers' excessive safety concerns and strategies for mitigation. Four studies support our proposition that consumers are excessively concerned about safety because an increase in the automation level leads to a perceived lack of control over driving, which heightens anxiety. Participants in all four studies perceived the L5 vehicle as less safe than the L4 vehicle, contrary to the actual superiority of L5.

Table 1. Cell means of perceived safety in study 3.

	Driver (having control: high salience)		Passenger (having control: low salience)	
	Information available	Information unavailable	Information available	Information unavailable
High-automation (L4)	5.09_a (1.46)	5.18_a (1.76)	4.70_a (1.53)	4.66_a (1.68)
Full-automation (L5)	4.61_b (1.91)	4.32_b (2.25)	4.58_a (1.74)	4.51_a (1.89)

(Note: Within each column, means with different subscripts are significantly different from each other at p < .05. Standard deviations are in parentheses. Significance levels are two-tailed).

In fact, this finding (of people's greater concern about safety for L5 vs. L4 vehicles) nicely fits with and also extends the prior research finding that autonomous driving is negatively correlated with the adoption of AVs (Heinrichs and Cyganski 2015; Hohenberger, Sporrle, and Welpe 2017; Sommer 2013; Zmud, Sener, and Wagner 2016).

In addition, we tested the mechanism via perceived control in studies 2 and 3. In study 2, we measured the perceived control and anxiety associated with L4 and L5 vehicles, and mediation analyses confirmed that a perceived lack of control (and subsequent anxiety) fully mediates the negative effect of the automation level on perceived safety. In study 3, we used a mediation-by-moderation approach; we manipulated the salience of having control over driving, and we found that the negative effect of the automation level on perceived safety disappeared when participants imagined being passengers (low salience) rather than drivers (high salience).

Studies 2 and 3 also tested an alternative, and more intuitive, information-based account, which posits that excessive safety concerns about AVs are attributable to a lack of information about the actual safety of AVs. However, our results from studies 2 and 3 contradict this account. In study 2, we replicated the negative effect of the automation level on perceived safety even though we gave participants objective safety information (specifically, the rate of accidents, with or without the distribution of accident severity). In study 3, we found no difference in the negative effect between participants who received objective safety information and those who received no safety information. Both findings call into question the validity of the information-based account, while the results of the mediation and mediation-by-moderation analyses support the proposed control-based mechanism.

Our finding that the *perceived* safety of self-driving cars deviates from the *actual* safety (thus resulting in excessive safety concerns) has important implications for both policy makers and AV manufacturers and marketers. Excessive safety concerns are likely to deter many consumers from adopting AVs (once commercialized), depriving society of the benefits of this new technology. Thus, strategies for rectifying misperceptions about safety have both theoretical and practical importance. The attenuation of the effect in the "passenger" (low-salience) condition of study 3 suggests that marketers may have more success by framing AVs as self-driving *taxis* (i.e., "robotaxis") rather than as vehicles for personal use. Then, as consumers gain "safe" experiences with robotaxis, they may come to appreciate the excellent safety profile of AVs and may become more interested in purchasing their own self-driving car. Further, auto manufacturers may consider creating interior features that imbue AV users with a sense of control over driving (Langer 1975; Wohl and Enzle 2002). Also, manufacturers may want to offer a variety of automated driving styles to accommodate individual variation in the desire for control over driving (Hartwich, Beggiato, and Krems 2018).

4.2. Limitations and future research

Some limitations in the present research suggest areas for future research. First, although our results consistently contradicted the information-based account, future research should test other explanations such as the general perception of technology as unreliable and the general fear of automation (Mokyr et al. 2015). In addition, future research may attempt to provide support for our control-based mechanism by examining variables that might moderate the impact of perceived control on safety perception, such as people's political orientation (Han, Park, and Lee 2021).

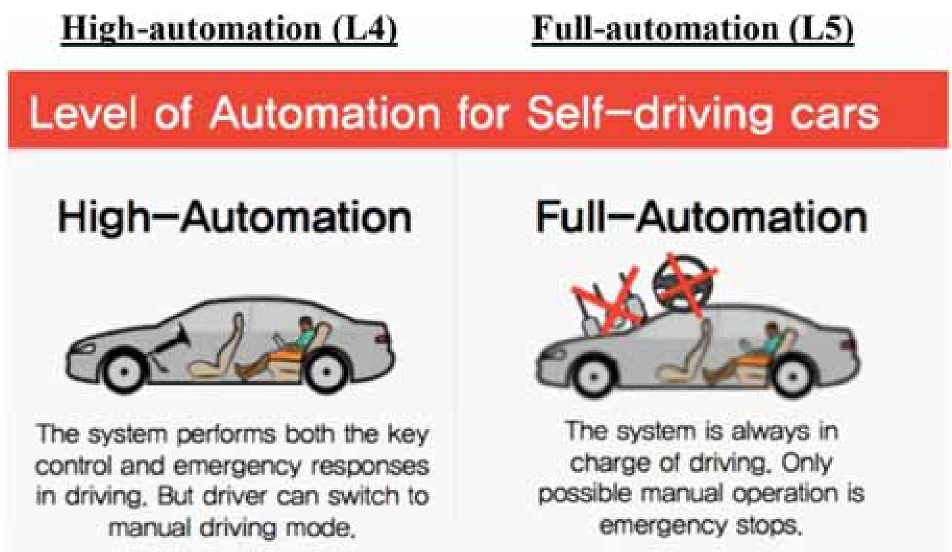
Second, all of our studies used a within-subject comparison of the perceived safety of L4 and L5. Although the within-subject design has several statistical advantages, the joint evaluation mode may have amplified the difference in the perceived safety of the two vehicles. To alleviate this concern, we ran a small follow-up to study 2 with a between-subjects design ($N = 50$), and we replicated the significant negative effect of the automation level on perceived safety ($M_{L5} = 3.75$ vs. $M_{L4} = 4.63$, $t = 2.067$, $p < .05$). Nevertheless, future research should use the between-subjects design more extensively and with larger sample sizes.

Third, we assume that L5 vehicles provide a greater objective safety than L4. However, such claim can be generalized only with more data. To this extent, our conclusion of the safety paradox (i.e., people's safety perception of AVs with different automation levels contradicts to the objective safety levels of the vehicles) should be taken with a caution.

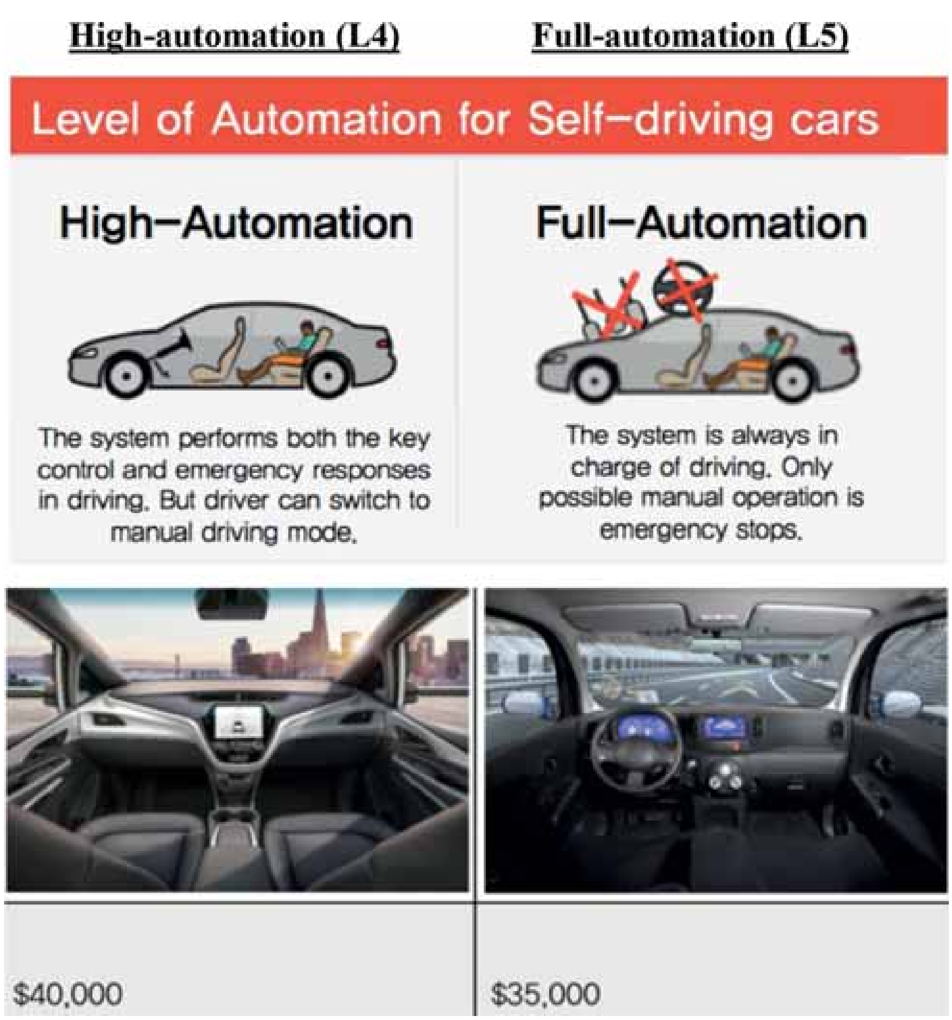
Finally, our studies focused on the difference in the perceived safety of L4 and L5, the two highest levels of automation and the target of most ongoing concerns about safety and liability. Our findings may not seem immediately relevant, but even L5 vehicles are expected to be on the market soon, by 2030 at the latest (Litman 2017). Nevertheless, consumers will have a wider array of choices, so future research may include L3 and even traditional vehicles for comparison with L4 and L5.

APPENDIX. – Stimuli Used in the Experiments

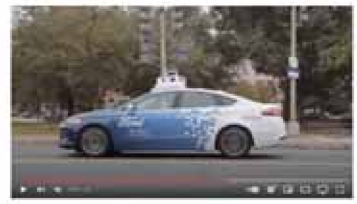
Study 1a



Study 1b



Study 2 (“frequency and severity” condition)

Full-automation (L5)	High-automation (L4)
	
https://www.youtube.com/watch?v=MWqacPy3r7Q	https://www.youtube.com/watch?v=V6kIeOGQYdQ

		
Features	• This vehicle is capable of complete hands-off, driverless operation under all circumstances. • The system is always in charge of driving - Steering wheel and gas pedals are not included, and the only possible manual operation is emergency stops. • Emergency stops will be activated when the driver pushes the button located at the front.	• The system performs both the key control and emergency responses in driving. But driver can switch to manual driving mode. • This vehicle is capable of completing an entire journey without driver intervention, but the vehicle does have some constraints. • This vehicle still maintains driver controls like a steering wheel and gas pedals.
Frequency of accidents	3.2 times / million miles	4.2 times / million miles
Probability chart for severity of accidents	 	
Price	$40,000	$35,000

The probability of serious accidents for both vehicles are found to be the same.
In other words, the likelihood of getting into serious accidents for both vehicles are the same.

References

Bansal, Prateek and Kara M. Kockelman (2018), "Are we ready to embrace connected and self-driving vehicles? A case study of texans," *Transportation*, 45 (2), 641–75.

Beiker, Sven A. (2012), "Legal aspects of autonomous driving," *Santa Clara Law Review*, 52 (4), 1145–56.

Bertoncello, Michele and Dominik Wee (2015), "Ten ways autonomous driving could redefine the automotive world," McKinsey & Company.

Blanco, Myra, John Atwood, Sheldon Russell, Tammy Trimble, Julie McClafferty, and Miguel Perez (2016), "Automated vehicle crash rate comparison using naturalistic data," Virginia Tech.

Burger, Jerry M. and Harris M. Cooper (1979), "The desirability of control," *Motivation and Emotion*, 3 (4), 381–93.

Carleton, R. Nicholas, Myriah K. Mulvogue, Michael A. Thibodeau, Randi E. Mccabe, Martin M. Antony, and Gordon J.G. Asmundson (2012), "Increasingly certain about uncertainty: Intolerance of uncertainty across anxiety and depression," *Journal of Anxiety Disorders*, 26 (3), 468–79.

Chapman, Richard C. and Judith A. Turner (1986), "Psychological control of acute pain in medical settings," *Journal of Pain and Symptom Management*, 1 (1), 9–20.

Choe, Nam Ho, Hyo Chang Kim, Jong Kyu Choi, and Yong Gu Ji (2015), "Driver's trust and requirements study for autonomous vehicle policy," *Journal of Korean Institute of Industrial Engineers*, 41 (1), 50–8.

Clements, Lewis M. and Kara M. Kockelman (2017), "Economic effects of automated vehicles," *Transportation Research Record: Journal of the Transportation Research Board*, 2606, 106–14.

Crew, Bec (2015), "Driverless cars could reduce traffic fatalities by up to 90%, says report," *Science Alert*. https://www.sciencealert.com/driverless-cars-could-reducetraffic-fatalities-by-up-to-90-says-report.

Dixon, Graham, P. Sol Hart, Christopher Clarke, Nicole H. O'Donnell, and Jay Hmielowski (2020), "What drives support for self-driving car technology in the United States?" *Journal of Risk Research*, 23 (3), 275–87.

Douma, Frank and Sarah A. Palodichuk (2012), "Criminal liability issues created by autonomous vehicles," *Santa Clara Law Review*, 52 (4), 1157–69.

Fagnant, Daniel J. and Kockelman Kara (2015), "Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations," *Transportation Research Part A: Policy and Practice*, 77, 167–81.

Friedland, Nehemia, Giora Keinan, and Yechiela Regev (1992), "Controlling the uncontrollable: Effects of stress on illusory perceptions of controllability," *Journal of Personality and Social Psychology*, 63 (6), 923–31.

General Motors. (2021), "Transforming transportation, without shortcuts,," (accessed October 10, 2021), https://www.getcruise.com/technology/.

Greenblatt, Jeffery B. and Susan Shaheen (2015), "Automated vehicles, on-demand mobility, and environmental impacts," *Current Sustainable/Renewable Energy Reports*, 2 (3), 74–81.

Han, Sang-Lin and Hyo-Ju Park (2016), "Effects of technology readiness on user perceptions and use intention of mobile social commerce," *Asia Marketing Journal*, 18 (2), 25–44.

Han, Haejoo, Sujin Park, and Kyoungmi Lee (2021), "Does political orientation affect the evaluation of artificial intelligence?" *Asia Marketing Journal*, 23 (2), 50–67.

Hartwich, Franziska, Matthias Beggiato, and Josef F. Krems (2018), "Driving comfort, enjoyment and acceptance of automated driving–effects of drivers' age and driving style familiarity," *Ergonomics*, 61 (8), 1017–32.

Heinrichs, Dirk and Rita Cyganski (2015), "Automated driving: How it could enter our cities and how this might affect our mobility decisions," *The Planning Review*, 51 (2), 74–9.

Hohenberger, Christoph, Matthias Spörrle, and Isabell M. Welpe (2017), "Not fearless, but self-enhanced: The effects of anxiety on the willingness to use autonomous cars depend on individual levels of self enhancement," *Technological Forecasting and Social Change*, 116, 40–52.

Howard, Daniel and Danielle Dai (2014), "Public perceptions of self-driving cars: The case of berkeley, California," in *Transportation Research Board 93rd annual meeting*, Vol. 14, pp. 1–16), 4502.

Hwang, S.G. and S. Cho (2016), "Policy implications through analysis of acceptance of future cars," *Monthly KOTI Magazine on Transport*, 216 (February), 5–13.

Kalra, Nidhi and Susan M. Paddock (2016), "Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability?" *Transportation Research Part A: Policy and Practice*, 94, 182–93.

Klein, William M. and Ziva Kunda (1994), "Exaggerated self-assessments and the preference for controllable risks," *Organizational Behavior and Human Decision Processes*, 59 (3), 410–27.

Kohl, Christopher, Dalia Mostafa, Markus Böhm, and Helmut Krcmar (2017), "Disruption of individual mobility ahead? A longitudinal study of risk and benefit perceptions of self-driving cars on twitter," in *Wirtschaftsinformatik 2017 Proceedings*.

Koller, Paul S. and Robert M. Kaplan (1978), "A two-process theory of learned helplessness," *Journal of Personality and Social Psychology*, 36 (10), 1177–83.

König, Michael and Neumayr Lambert (2017), "Users' resistance towards radical innovations: The case of the self-driving car," *Transportation Research Part F: Traffic Psychology and Behavior*, 44, 42–52.

KPMG (2019), "Autonomous vehicles readiness index: Assessing countries' preparedness for autonomous vehicles,". https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf.

Langer, Ellen J. (1975), "The illusion of control," *Journal of Personality and Social Psychology*, 32, 311–28.

Lee, Backjin (2017), "Consumer preference for autonomous vehicles and challenges in transportation planning," *KRIHS Policy Brief*, 600 (January), 1–8.

Lee, Jihye, Hyungsik Chang, and Young Il Park (2018), "Influencing factors on social acceptance of autonomous vehicles and policy implications," in *2018 portland international conference on management of engineering and technology (PICMET)*. IEEE, 1–6.

Lee, Hyun Jung, Jongwon Park, Jin Yong Lee, S. Robert, and Jr Wyer (2008), "Disposition effects and underlying mechanisms in e-trading of stocks," *Journal of Marketing Research*, 45 (June), 362–78.

Lin, Patrick (2015), "Why ethics matters for autonomous cars," in *Autonomous driving: Technical, legal and social aspects*, Markus Maurer, J. Christian Gerdes, Barbara Lenz, and Winner Hermann, eds. Berlin, Heidelberg: Springer, 69–85.

Litman, Todd (2017), "Autonomous vehicle implementation predictions," " Victoria, Canada: Victoria Transport Policy Institute.

MacKenzie, D., Z. Wadud, and P. Leiby (2014), "A first order estimate of energy impacts of automated vehicles in the United States," in *Proceedings of the transportation research board annual meeting, Washington, DC*, 12–6.

McAuley, Edward, Terry E. Duncan, and Daniel W. Russell (1992), "Measuring causal attributions: The revised causal dimension scale (CDSII)," *Personality and Social Psychology Bulletin*, 18 (5), 566–73.

McEvoy, Peter M. and Alison E.J. Mahoney (2012), "To Be sure, to Be sure: Intolerance of uncertainty mediates symptoms of various anxiety disorders and depression," *Behavior Therapy*, 43 (3), 533–45.

Mineka, Susan and Kelly A. Kelly (1989), "The relationship between anxiety, lack of control and loss of control," in *Stress, personal control and health*, A. Steptoe and A. Appels, eds. John Wiley & Sons, 163–91.

Mokyr, Joel, Chris Vickers, L. Nicolas, and Ziebarth. (2015), "The istory of technological anxiety and the future of economic growth: Is this time different?" *Journal of Economic Perspectives*, 29 (3), 31–50.

Montoya, Amanda K. and Andrew F. Hayes (2017), "Two-condition within-participant statistical mediation analysis: A path-analytic framework," *Psychological Science*, 12 (5), 413–7.

Morning Consult. (2021), "National tracking poll #2108149, August 25-28, 2021," (accessed October 10, 2021), https://assets.morningconsult.com/wp-uploads/2021/09/01114300/2108149_crosstabs_MC_TECH_AUTONOMOUS_VEHICLES_Adults_v1_AUTO.pdf/.

Mugge, Ruth and Jan PL. Schoormans (2012), "Newer is better! The influence of a novel appearance on the perceived performance quality of products," " *Journal of Engineering Design*, 23 (6), 469–84.

NHTSA (2021), "Automated vehicles for safety,". http://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

Nordfjærn, Trond, Stig Halvard Jørgensen, and Torbjørn Rundmo (2012), "Safety attitudes, behavior, anxiety and perceived control among professional and non-professional drivers," *Journal of Risk Research*, 15 (8), 875–96.

Nordgren, Loran F., Joop Van Der Pligt, and Frenk Van Harreveld (2007), "Unpacking perceived control in risk perception: The mediating role of anticipated regret," *Journal of Behavioral Decision Making*, 20 (5), 533–44.

Oh, Jong-Chul, Sung-Joon Yoon, and Yuen Wu (2010), "A study on factors of intention toward using mobile internet service: Revised TRAM," *Service Management Society*, 11 (5), 127–48.

Owsley, Cynthia, Beth T. Stalvey, and Janice M. Phillips (2003), "The efficacy of an educational intervention in promoting self-regulation among high-risk older drivers," *Accident Analysis & Prevention*, 35 (3), 393–400.

Pew Research Center (2017), "Automation in everyday life," (accessed October 4, 2017), https://www.pewresearch.org/internet/wp-content/uploads/sites/9/2017/10/PI_2017.10.04_Automation_FINAL.pdf.

Piao, Jinan, Mike McDonald, Nick Hounsell, Matthieu Graindorge, Tatiana Graindorge, and Nicolas Malhene (2016), "Public views towards implementation of automated vehicles in urban areas," *Transportation Research Procedia*, 14, 2168–77.

Rothbaum, Fred, John R. Weisz, and Samuel S. Snyder (1982), "Changing the world and changing the self: A two-process model of perceived control," *Journal of Personality and Social Psychology*, 42 (1), 5–37.

Rupp, Jeffrey D. and Anthony G. King (2010), "Autonomous driving – a practical roadmap," *SAE Technical Paper*.

SAE International. (2018), "Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles,," (accessed October 10, 2021), https://www.sae.org/standards/content/j3016_201806/.

Schoettle, Brandon and Michael Sivak (2014), "A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia," University of Michigan, Ann Arbor, Transportation Research Institute.

Sommer, Klaus (2013), "Continental mobility study 2011," *Continental AG*, 19–22.

Sun, Yuchao, Doina Olaru, Brett Smith, Stephen Greaves, and Andrew Collins (2016), "Road to autonomous vehicles in Australia: A comparative literature review," *Australasian Transport Research Forum*, 16–8.

Syahrivar, Jhanghiz, Tamás Gyulavári, Melinda Jászberényi, Katalin Ásványi, László Kökény, and Chairy. (2021), "Surrendering personal control to automation: Appalling or appealing?" *Transportation Research Part F: Traffic Psychology and Behavior*, 80 (July), 90–103.

Taylor, Joanne and Frank P. Deane (2000), "Comparison and characteristics of motor vehicle accident (MVA) and non-MVA driving fears," *Journal of Anxiety Disorders*, 14 (3), 281–98.

Vigneron, Franck and Lester W. Johnson (2004), "Measuring perceptions of brand luxury," *Journal of Brand Management*, 11 (6), 484–506.

Watson, David (1967), "Relationship between locus of control and anxiety," *Journal of Personality and Social Psychology*, 6 (1), 91–2.

Weinstein, Neil D. (1984), "Why it won't happen to me: Perceptions of risk factors and susceptibility," *Health Psychology*, 3 (5), 431.

Whalen, J. Paul (1998), "Fear, vigilance, and ambiguity: Initial neuroimaging studies of the human amygdala," *Current Directions in Psychological Science*, 7 (6), 177–88.

Whitson, A. Jennifer and Adam D. Galinsky (2008), "Lacking control increases illusory pattern perception," *Science*, 322 (5898), 115–7.

Wohl, Michael J.A. and Michael E. Enzle (2002), "The deployment of personal luck: Sympathetic magic and illusory control in games of pure chance," *Personality and Social Psychology Bulletin*, 28, 1388–97.

Zmud, Johanna, Ipek N. Sener, and Jason Wagner (2016), "Consumer acceptance and travel behavior: Impacts of automated vehicles (No. PRC 15-49 F)," Texas A&M Transportation Institute.