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Estimated years until the acceptance and adoption of automated vehicles and the willingness to pay for them in Germany: Focus on age and gender

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ABSTRACT

Automated vehicles (AVs) are expected to enter the market within the next few years. However, their introduction would not only be a technological, but also a societal one – and it is therefore crucial to examine the public's attitudes, opinions, and beliefs about AVs. It is particularly interesting to study when AVs are estimated to be accepted and adopted, and to query the willingness to pay for them. Hence, we applied a mixed-methods approach to collect quantitative and qualitative data and carried out a cross-sectional survey study. We focused on collecting an almost balanced sample across age and gender from 725 respondents (351 female, 374 male) with an age range from 18 to 96 years. Our results revealed that AVs are estimated to be accepted and adopted in about 10 years at SAE level L3 and in about 20 years at L5. Moreover, on average we found that the participants would be willing to pay 10.6 % more for an AV at L3 and 14.5 % at L5, but those estimates are affected by large outlier values. Nevertheless, we also observed that between 40 and 33 % of women and 41 and 33 % of men would not be willing to pay any more for an AV neither at L3 nor at L5, respectively. Ultimately, manufacturers and policy-makers will have to take these findings into account if they really want to establish AVs as a widespread technological and societal revolution.

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1. Introduction

The adoption of automated vehicles (AVs) is expected to affect travel on a societal level (Litman, 2021). While conditionally automated vehicles (i.e., SAE level L3) are expected to perform the entire dynamic driving task under specific conditions (e.g., environmental, geographical or the presence of certain roadway characteristics) with the expectation that a human driver will respond to a request to intervene, fully automated vehicles (i.e., SAE level L5) are predicted to perform all aspects of the driving task on all roadway and environmental conditions (SAE, 2021). Proponents argue that AVs might increase road safety, enhance road-network utilization, reduce undesirable ecological consequences of travel and ultimately improve mobility for all road users (Fagnant and Kockelman, 2015; Gkartzonikas and Gkritza, 2019; Greenblatt and Saxena, 2015;

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Millard-Ball, 2018; Pettigrew, 2017). However, such benefits can only be achieved efficiently if AVs are quickly adopted by the public as soon as they are legally approved and available. It has been argued that "public sentiment [...] will be critical in determining how quickly they are adopted and hence the timeframe in which the anticipated benefits can be achieved" (Pettigrew et al., 2019, p. 20). Thus, insights into public opinion are valuable. Accordingly, several quantitative studies and a small but growing body of qualitative studies exploring public opinion have been published. The quantitative approach has primarily been used to quantify the influence of predictor variables which were hypothesized to be related to opinions on AVs (like age, gender, and personality traits), and measure outcome variables (like intention to use; e.g., Bansal et al., 2016; Kyriakidis et al., 2015; Rödel et al., 2014; Schoettle & Sivak, 2014). The qualitative approach, which is based on open research questions rather than hypotheses, was used to explore the spectrum of sentiments that are salient and important to a specific population (cf. Hilgarter and Granig, 2020; Hwang et al., 2020; McLoughlin et al., 2018; Pettigrew, 2017). It was further employed to deepen our understanding of variables, which are known to be linked to sentiments towards AVs, by revealing their underpinning motivational structures (cf. Merfeld et al., 2019). The authors argued that these insights can inform the actions of governmental institutions and AV developers who are involved with the introduction of AVs.

1.1. Estimated years until acceptance of AVs

AVs are expected to enter the market within the next few years. They are associated with numerous benefits such as the predicted increase of road safety, the reduction of greenhouse gas emissions, or the inclusion of handicapped and elderly people at SAE level L5 (who are not allowed to drive manually on their own). Despite those benefits and the newly emerging challenge because of the forecasted *mixed* traffic (i.e., a time period where traditional vehicles and AVs are sharing the roads), the far more crucial and global hindrance might be societal non-acceptance as well as non-adoption of AVs. As yet, there have been several studies on the public's opinion on the potential acceptance and adoption of AVs. Although critical safety issues have not been resolved so far (e.g., How to enable safe mixed road traffic? – How to deal with cyber crime attacking AVs? etc.) many people expect AVs to enter road traffic within a time horizon up to 2030 to 2050 (Milakis et al., 2015), a decade (Chan, 2017), in the year 2040 to represent urban mobility (Marletto, 2019), in the close future (Beza and Maghrour Zefreh, 2019), in 2030 (median) reported by 18.970 people in 128 countries that AVs drive fully automatically or in 2040 (median) stated by respondents from a technical university (Bazilinskyy et al., 2019), and from 2025 on (NHTSA, 2021).

However, none of those studies has jointly investigated the estimated years until acceptance and approval of AVs at SAE level L3 and L5, age groups, and gender. Therefore, we conducted our study to obtain differentiated results on the public's opinion and perception of AVs across those important parameters (cf. below the 1st research question (RQ1)).

1.2. Willingness to pay for an AV

There exist several studies focusing on age and gender associated with different aspects of AVs (Charness et al., 2018; Faber and van Lierop, 2020; Hohenberger et al., 2016; Liljamo et al., 2018; Nordhoff et al., 2020; Ward et al., 2017; Zhou et al., 2020; Zoellick et al., 2019). While the notion that ride-hailing and car-sharing are primary business models for AVs seems intuitive, there is evidence that even after the approval of AVs, people would be more interested in owning a private vehicle (Pakusch et al., 2018; Saeed et al., 2020). Regarding the purchase of an AV, a study on the willingness to pay for an AV found that the majority of people in the U.S., the U.K., and Australia would not be willing to pay more for an AV than a conventional vehicle (Schoettle and Sivak, 2014b). This was confirmed later in another survey in Australia, where most respondents reported that they were not willing to pay any more for an AV at SAE level L5 than for a manually operated vehicle (Cunningham et al., 2019). Similarly, in another survey 22% of the participants reported that they would not pay more for a fully automated driving system, whereas 5% stated that they would be willing to pay $30.000 more for an AV (Kyriakidis et al., 2015). In line with these, it was reported that around 30% of the respondents in another study indicated that they are not willing to pay more (Elvik, 2020). Additionally, it was found that on average people would be willing to pay $3500 for an AV with partial automation and $4900 for an AV with full automation (Daziano et al., 2017). In those studies, which considered age "people over 60 years old and people between 18 and 25 years old, were found to be the most willing to pay to use AVs" (Gkartzonikas and Gkritza, 2019, p. 328).

Nevertheless, to the best of our knowledge, there exists no study (in Germany) that explored the willingness to pay more in percent for an AV at SAE level L3 and L5 with a special emphasis on age groups and gender, as we examined in our questionnaire survey (cf. below RQ2).

1.3. Governmental contribution to the introduction of AVs

Governments need to decide how they contribute to the introduction of AVs. If they decide to actively engage, they need to determine whether and how to incentivise technological development as well as the adoption by consumers. Ensuring technological readiness of AVs on its own will likely not be enough to generate broad societal acceptance, as many organizational and human related challenges are still present. At a minimum, regulatory efforts are necessary due to the driver's changing role and new technological capabilities, (e.g., Bundesregierung, 2021). Conceptual work included issues regarding liability and insurance, ethical questions, and data privacy and security (Johnsen et al., 2017). When such issues were pointed out in previous survey studies, the participants indicated to care about them (Kyriakidis et al., 2015; Schoettle and Sivak, 2014a). Additionally, it was recently shown that participants indeed raise the issue of responsibility for the AV's actions even when they are not explicitly made aware of it during the research process (Merfeld et al., 2019). Still, Pettigrew et al. (2019) found evidence that some of the aforementioned issues might not be as salient and therefore not as important to the public as previously thought. Thus, we lack an understanding of the contributions the public actually expects from governmental institutions. Policymakers are likely interested in targeting those in future communication strategies in order to facilitate the adoption of AVs (Pettigrew et al., 2019; cf. below RQ3).

1.4. Design features inside AVs

Lastly, it has been pointed out that insights on the way consumers want to utilize the interior of AVs might help developers design a product which is quickly adopted (Merfeld et al., 2019). Previous work on interior design included the identification of design requirements (Lee et al., 2020) and the exploration of novel opportunities for interior design (FutureBridge, 2020). Further, first experimental explorations into possible undesirable effects of changes in conventional cabin design have been conducted (Salter et al., 2019). To the best of our knowledge, however, no study has aimed to uncover the spectrum of internal design features of AVs that are desired by the public and point out the most central ones so far (cf. below RQ4).

1.5. The present study

The present cross-sectional survey study was designed to fill this gap and investigate collective attitudes, opinions, and perceptions on automated driving as well as automated vehicles in a representative sample in Germany across age and gender. Therefore, we studied the following confirmatory RQs, RQ1 and RQ2, with the corresponding hypotheses (H), and the two exploratory RQs, namely RQ3 and RQ4:

RQ1: How is the influence of age and gender on the self-reported and estimated years until acceptance and approval of AVs at the SAE levels L3 and L5, respectively?

H1.1. *We hypothesize that the acceptance and approval of AVs at SAE level L3 is estimated several years earlier than L5, regardless of age and gender.*

H1.2. *We expect no interaction effect between age group, gender, and the SAE levels L3 and L5 on the estimation of years until the acceptance and approval of AVs.*

RQ2: How is the impact of age and gender on the self-reported willingness to pay more for an AV in percent for SAE level L3 and L5, respectively?

H2.1. *We assume that younger and older people report both higher values than middle-aged people, whereas on average all age groups would be willing to pay more in percent for an AV L5 than for an AV L3, with no effect of gender.*

H2.2. *We suspect an interaction effect between age group and the SAE levels L3 and L5 on the willingness to pay more both reported in percent, but no interaction with gender.*

RQ3: In which domain and to what extent do people think that the government should contribute to AVs at SAE level L3 and L5, respectively?

RQ4: Which internal design features of automated vehicles would be chosen by people?

2. Method

2.1. Participants

In total, we recruited 725 participants (351 female; 374 male; 0 diverse) between 18 and 96 years (female: $M = 47.7$, $SD = 20.0$; male: $M = 46.3$, $SD = 20.1$) to our online questionnaire study. Thereby, we put a special emphasis on drawing a sample rather equally balanced across age and gender (cf. Table 1) to obtain a diverse sample to enable more differentiated conclusions in contrast to, for example, querying only young people. Moreover, to ensure high data quality, we did not simply distribute the link to our study somewhere on the Internet. Hence, we invited all of them personally and approached them in various venues in Germany, or we sent them invitations via email and provided assistance on the phone. However, we recruited most of them at Catholic University Eichstätt-Ingolstadt and at Technische Hochschule Ingolstadt, and especially older people in several retirement homes. The data for those open questions on automated driving were sampled together with another online questionnaire with a special focus on acceptance of AVs (Weigl et al., 2021), which is beyond the scope of the present study. All participants held a valid driver's license, were fluent in German, had normal or corrected-to-normal vision, and were not influenced by alcohol or any drugs. One hundred and twenty stated that they were in a relationship, 350 married, 182 unmarried or single, 33 divorced, and 32 widowed (eight did not specify). Thirty-one reported that they lived in the countryside, 145 in a small village or town, 145 near a city, and 402 in a city (two did not answer this question). In daily life, public transport was regularly used by 130 of them and in spare time by 132. As a mode of transport, cycling was regularly used by 156 of the participants in daily life and in spare time by 279 of them. The annual mileage was, on average, 13,470 kilometers (SD = 13450), and car- and/or ride-sharing was used by 61 of them.

2.2. Materials

We developed the questionnaire with the following nine open-ended questions to assess quantitative and mostly qualitative data in order to explore in depth which issues are salient in the public and to depict a wider spectrum of thoughts and attitudes on automated driving. In this regard, we want to mention that we were particularly interested in the participant's views of wider public acceptance, and not when they would accept and approve AVs themselves.

1. In how many years do you think that **highly automated driving – Level 3 –** will be accepted and approved in daily road traffic? Why do you think exactly then?
2. In how many years do you think that **fully automated driving – Level 5 –** will be accepted and approved in daily road traffic? Why do you think exactly then?
3. How much money in Euros would you be willing to pay more for a **highly automated vehicle – Level 3 –** than for a current vehicle?
4. And what percentage would you be willing to pay more for a **highly automated vehicle – Level 3 –** than for a current vehicle?
5. How much money in Euros and would you be willing to pay more for a **fully automated vehicle – Level 5 –** than for a current vehicle?
6. And what percentage would you be willing to pay more for a **fully automated vehicle – Level 5 –** than for a current vehicle?
7. In which domain and to what extent do you think that the government should contribute to **highly (Level 3)** and **fully automated vehicles (Level 5)**?
8. Choose a special internal design features in an automated vehicle?
9. What else would you like to tell us about this topic?

We want to mention that the willingness to pay more in percent (cf. items 4 and 6) is more important and better comparable across different countries with different currencies than the willingness to pay more in Euros (cf. items 3 and 5). Although we statistically analyzed the willingness to pay more in Euros in supplementary analyses, we only provide those results on the open science platform OSF: https://osf.io/ak3tg/.

All questions were non-compulsory and could also be skipped. However, we instructed the participants to complete all questions if possible. Before those questions were presented, they were introduced to the SAE levels of driving automation (SAE_J3016, 2014), both verbally and with a figure showing the SAE levels with easy explanations (Shuttleworth, 2019). The questions and the explanations of the SAE levels were translated to German by two native speakers fluent in English and German.

We deployed the questionnaire on LimeSurvey, Version 3.12.1 + 180616 (Limesurvey Project Team and Schmitz, 2021), and collected the data online and anonymously. We provide the data set (.sav and.csv), the statistical and the MAXQDA results on OSF (cf. link above).

2.3. Design

After we had developed the nine items, we conducted a cross-sectional online questionnaire study and sampled data rather equally balanced across age and gender (cf. Table 1). Therefore, we adopted a three-factorial design with the two between-subjects factors *gender* (female vs. male) and seven *age groups* (cf. Table 1) and the within-subjects factor *SAE levels* (L3 vs. L5) as independent variables, respectively. Our nine open questions (cf. Materials) constituted our dependent variables of interest.

Table 1
Frequencies across the seven age groups and gender.

Years								
	18–24	25–34	35–44	45–54	55–64	65–74	75+	
Female	78	44	24	57	51	72	25	351
Male	80	68	25	48	63	52	38	374
	158	112	49	105	114	124	63	725

2.4. Procedure

Our online survey was approved by the ethics committee of the Department of Psychology at Catholic University Eichstätt-Ingolstadt and conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013). After welcoming the participants, all of them provided their written informed consent prior to participation in the study. The study examiners were present all the time and introduced the participants to the SAE levels of driving automation (cf. section 2.2). When all questions were answered, they began with the questionnaire study. Additionally, they were informed that they could ask questions any time and that they are allowed to abandon the study at any time without receiving any consequences.

Initially, we conducted a pilot study (N = 98) to optimize the items. In the preliminary questionnaire, we only queried the willingness to pay more in Euros for L3 and L5, respectively. However, after the pilot phase was completed, we realized that it is even more important to additionally query the percentage because the currency in Euros is tied to certain countries within the European Union. Therefore, we included the two open-ended questions number 4 and number 6 on the willingness to pay more in percent (cf. section 2.2). Despite that, we highlighted "**highly automated driving – Level 3**" and "**fully automated driving – Level 5**" in boldface, because a few respondents, who did not carefully read those questions, asked us in the pilot phase whether we assess L3 or L5. After we had highlighted those phrases in boldface, we did not receive any questions in the main phase on this issue of the pilot phase. Therefore, we did not include the data from the pilot study in our main data set.

Then, we queried 725 participants in the main phase of our study, although not all of them answered all open-ended questions because they were non-compulsory (cf. section 2.2) in contrast to additional closed-ended questionnaire items (beyond the scope of the present study). The subjects were not paid, but they were invited to provide their email address in case they were interested in the findings of the study. Finally, the contact details of the examiner were provided in case of any questions and the participants were thanked for their participation. The study duration for the open-ended questions lasted between approximately 5 to 15 minutes, depending on the length of their answers and the age of the participant.

2.5. Statistical analyses

To study our research questions, we performed two main analyses. First, we performed statistical analyses to investigate the quantitative findings of the first six questions (1. to 6.), which resulted in a numerical value. Second, we applied content analysis to investigate the qualitative (string) answers of the consecutive three open questions (7. to 9.) and the concluding question of the items 1. and 2. "Why do you think exactly then?", respectively.

Hence, for the quantitative analyses, we applied repeated measures analyses of variances (rmANOVA) to investigate the influence of the independent variables (IVs) *age group* (cf. seven age groups in Table 1), *gender* (female vs. male), and the two *SAE levels* (L3 vs. L5) on the dependent variables (DVs) such as (1) estimated years until acceptance and approval of AD, (2) willingness to pay more for an AV in percent. Variance homogeneity (Levene test) was met in 3 of 4 cases. We chose the Greenhouse-Geisser correction of the degrees of freedom because sphericity (Mauchly's test of sphericity) was not given. Despite the large data sets (N = 725), exceeding 30 cases corresponding with the central limit theorem in 11 of the 14 cells (cf. Table 1) and therefore relaxing the assumption of normally distributed data, we investigated the distributional assumptions with Shapiro Wilk's test, skewness, and kurtosis. Skewness revealed good distributional findings, but kurtosis in only about half of all cases. However, we applied rmANOVA which enabled us to study any interaction effects (of the IVs), which would not be possible with nonparametric procedures. Although we could confirm all our identified main effects of the IVs with nonparametric procedures in additional statistical analyses (not additionally listed here), we are aware that those findings have to be interpreted with caution because of the rather small effect sizes η_p^2 (partial η^2). The overall significance level was set to $\alpha = 0.05$ and all results with $p < \alpha$ were reported as statistically significant. The quantitative statistical analyses have been performed with IBM® SPSS® Statistics, Version 25 (IBM Corp., 2017).

For the qualitative content analysis, we applied MAXQDA (VERBI Software, 2021). The complete dataset was analyzed word by word in an inductive, data-driven way in order to capture the complete spectrum of thoughts (Mayring, 2015; Rädiker and Kuckartz, 2019; Schreier, 2014; Schreier et al., 2019). Each question received its own coding frame. Segments, which represented the same concepts, were subsumed (Schreier, 2014, p. 176). This allowed for a quantization and frequency analysis on an ordinal scale (Lamnek and Krell, 2016). In a consequent step, related but discrete concepts were clustered into more abstract supercategories. This was repeated until a further abstraction was not possible any more. While the domains on the top level were mutually exclusive, one participant's answer to a question could be assigned multiple subdomains (e.g., a participant could either list wishes for a certain internal design in AVs or not. The explicit wishes could be assigned to multiple subdomains like different specific furnishing and technological features). After the complete dataset was exhaustively coded, a summative evaluation of all coding frames was conducted. The content analysis yielded a total of 2693 codings.

3. Results

3.1. Estimated years until acceptance and approval of AD (RQ1)

First, we tested our two hypotheses that the acceptance and approval of AVs for SAE level L3 is estimated several years earlier than L5, regardless of age and gender (H1.1) and that we expect no interaction effect between those three IVs age group, gender, and the SAE levels (H1.2). Our findings revealed a significant main effect for the within-subjects factor SAE levels, $F(1, 561) = 537.27$, $p < .001$, $\eta_p^2 = .49$, indicating a large effect according to Cohen (1988), whereas L3 (M = 10.2, SD = 6.8) is estimated almost 10 years earlier than L5 (M = 19.7, SD = 12.6; cf. Fig. 1). However, we found no significant main effect for the between-subjects factors age group, $F(1, 561) = 0.37$, $p = .901$, and gender, $F(1, 561) = 0.29$, $p = .588$, and no interaction effects, neither for SAE levels × gender, $F(1, 561) = 0.12$, $p = .733$, nor SAE levels × age groups, $F(6, 561) = 1.80$, $p = .096$, nor age groups × gender, $F(6, 561) = 0.50$, $p = .810$, nor SAE levels × age groups × gender, $F(6, 561) = 0.41$, $p = .870$. Thus, we could accept H1.1 and H1.2.

In the following content analysis, we coded 505 units, in which the participants justified their estimates. There were 491 mentions of factors that impede approval and acceptance and 24 mentions of facilitative factors. The impeding factors were grouped into 11 clusters. Fig. 2 illustrates their relative frequency. As can be seen, a perceived lack of technological maturity and legal issues were mentioned most often. These two clusters accounted for 65.0% of all mentions regarding potential barriers. There was a consensus that the technology will eventually mature, but more time is needed. In a similar vein, the participants assumed that legal issues will be resolved but the process of legal approval as well as the creation of a legal framework for AVs on public roads will take additional time even after technological maturity has been reached. The remaining 35.0% of codings on barriers related to the sentiment that AVs will only be accepted after their safety has been proven to potential users (13.1%), that road infrastructure needs to be developed before AVs can operate and consequently be accepted (8.6%), that acceptance will only arise as soon as AVs are affordable (the first available AVs were expected to be too expensive; 5.0%), that many ethical questions need to be answered first (4.7%), that potential users will be unwilling to surrender control of the vehicle's maneuvers or the enjoyment from driving, especially in case of L5 automation (3.6%), that an unspecified lobby opposes the introduction of AVs (2.6%), that only following generations will accept AVs (1.9%), that mixed traffic is impossible and AVs will only be approved and accepted as soon as they are the sole vehicles on roads (0.7%), and that acceptance will take time because there is simply no need for AVs (0.7%).

In terms of facilitating factors, eco-friendliness (n = 7), a special appeal to seniors (n = 5), prior successes in other jurisdictions (n = 4), a reduction of individual transport (n = 3), support from the political realm (n = 2), and gains in road safety (n = 1) were named.

There was a consensus that acceptance will follow regulatory approval in the case of L3 (n = 58) as well as L5 (n = 63) – and not the other way around.

3.2. Willingness to pay for an AV (RQ2)

Second, we studied our next two hypotheses that younger and older people report both higher values than middle-aged people, whereas on average all age groups would be willing to pay more in percent for an AV L5 than for an AV L3, with no effect of gender (H2.1), while we suspected an interaction effect between the IVs age group and the SAE levels, but no interaction with gender (H2.2).

Our findings revealed a significant main effect for SAE levels, $F(1, 526) = 38.99$, $p < .001$, $\eta_p^2 = .07$, indicating a small effect according to Cohen (1988), whereas the participants would be willing to pay almost 3 percent points less for an AV at L3 (M = 10.6, SD = 13.5) than for an AV at L5 (M = 14.5, SD = 17.7; cf. Fig. 3). In addition, we observed a significant main effect for age groups, $F(6, 526) = 4.83$, $p < .001$, $\eta_p^2 = .05$, referring to a small effect according to Cohen (1988), whereas younger participants until 24 years of age (EMM = 18.2, SEM = 1.4) would be willing to pay significantly more than participants between 35 and 44 (EMM = 8.8, SD = 2.5) and between 45 and 54 (EMM = 8.6, SEM = 1.7) and between 55 and 64 years (EMM = 10.2,

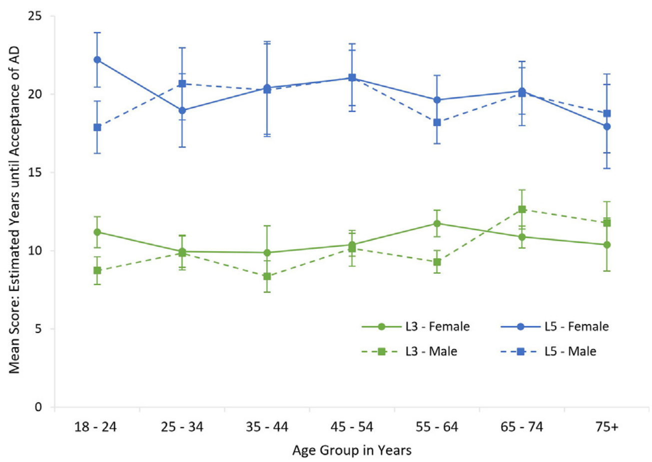

Fig. 1. Mean scores and standard error of the mean (SEM) for the estimated years until acceptance and approval of AD differentiated for women and men as well as for L3 and L5, respectively.

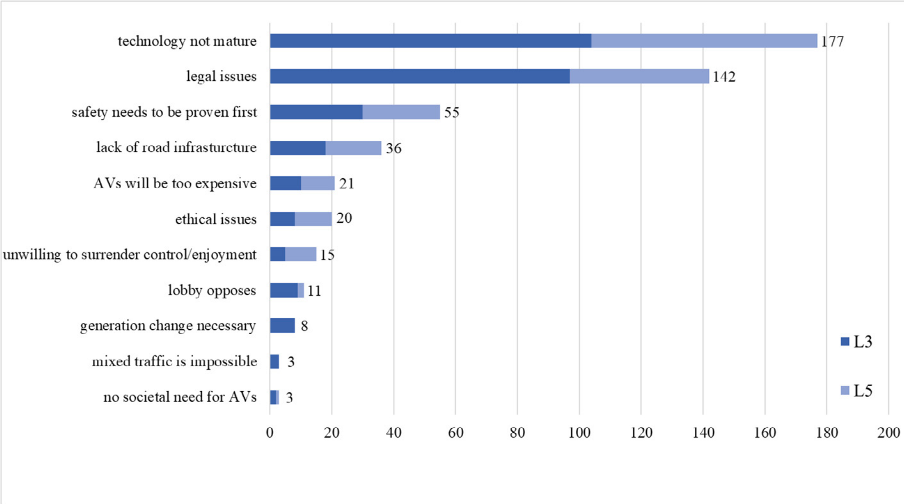

Fig. 2. Factors impeding the legal approval and acceptance of AVs, number of mentions, $N_{codings}$ = 491.

SEM = 1.6; cf. Fig. 3; The detailed post-hoc table is supplied on OSF, cf. 2.2). Additionally, we found a significant interaction effect between SAE levels × age groups, $F(6, 526) = 3.51$, p =.002, η_p^2 =.04, corresponding with a small effect according to Cohen (1988). Nevertheless, in this case it has to be noted that despite the fact that younger people until 24 years of age reported on average 14.6 (SD = 13.0) for L3 and 21.8 (SD = 18.5) for L5 yielding a difference of almost 7 percent points the participants between 25 and 34 years of about 5 percent points (L3: M = 9.9, SD = 13.5; L5: 15.3, SD = 15.8), also all other five age groups (cf. Table 1) consistently reported less percent points for L3 than for L5, but within a range of about only 2 percent points (The detailed table with descriptive statistics is supplied on OSF, cf. 2.2).

However, we identified no significant main effect for gender, $F(1, 526) = 0.19$, p =.664, and observed no interaction effects, neither for SAE levels × gender, $F(1, 526) = 0.47$, p =.494, nor age groups × gender, $F(6, 526) = 0.39$, p =.888, nor SAE levels × age groups × gender, $F(6, 526) = 0.51$, p =.798. Hence, for (b) the willingness to pay for an AV in percent, consistently with (a), we could only partly accept H2.1 for younger people. However, and in contrast to (a), we could confirm H2.2.

Accompanying our inferential statistical findings, in Table 2, we supply the descriptive statistics for the estimated years until acceptance and approval of AD, and the willingness to pay more for an AV in percent, each differentiated for women (f) and men (m) and the SAE levels L3 and L5, respectively. Despite the mean, the median, the minimum and maximum, the modal value is particularly interesting. The modal values pinpoint the clear tendency that most women and most men want to pay exactly the same price for an AV at L3 and L5 as for a traditional car (cf. "0″). Nevertheless, the medians and especially the means draw a different picture and indicate the willingness to pay more in percent as mentioned above and depicted in Table 2.

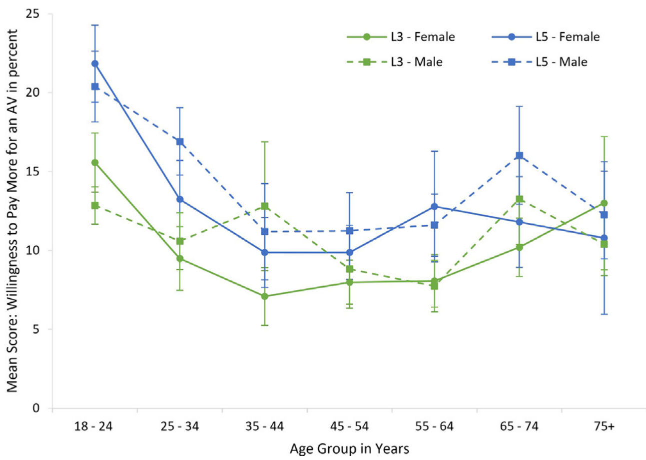

Fig. 3. Mean scores and SEM for the willingness to pay more for an AV in percent differentiated for women and men as well as for L3 and L5, respectively.

Only a few participants used the chance to elaborate on their willingness to pay. Eight stated they would be willing to pay more as soon as automation enhances their personal mobility, i.e. when their ability to steer a vehicle is limited, for example in case of disabilities or senior age. Some stated that their willingness to pay depends on a future proof of safety ($n = 5$), proof of eco-friendliness ($n = 4$), their future salary ($n = 4$), the range of AVs ($n = 2$), their cost of operation ($n = 1$), and the possibility to partake in a ride-sharing model ($n = 1$). One person stated that their willingness to pay varies between different brands. Two participants tied their willingness to pay for L5 to their future experiences with L3.

3.3. Governmental contribution to the introduction of AVs (RQ3)

Five hundred and nine participants commented on governmental contribution to the launch of automated vehicles. Of these, 432 (84.9 %) saw a need for governmental contribution. Four domains were identified. The creation of a legal framework was referred to most frequently (73.0 % of codings). Further, there were calls for financial aid (20.0 % of codings), the provisioning of necessary infrastructure (5.0 % of codings), and the promotion of public acceptance (2.0 % of codings). An overview of the subdomains which were subsumed under these four domains is provided in Table 3. By contrast, 77 (15.1 % of those who commented) stated that they prefer as little as possible governmental interference or none at all. Eleven stated that they oppose any governmental interference with their personal choice concerning means of transportation. Five wrote that they do not see the need for any governmental support of the automotive industry. Another five were afraid any governmental interference would constrain the free market.

3.4. Internal design of AVs (RQ4)

Of the 632 who commented, 32.1 % of participants stated that they do not wish for any specific amenities in AVs. The remaining 62.8 %, expressed wishes. These were clustered into five domains, which are illustrated in Fig. 4 with their subdomains. As can be seen, most mentions referred to the AV's furnishing (n = 201). The two most frequently requested features were comfortable seating (n = 122) and a place to lie down (n = 65). Comfortable seating subsumes wishes for comfortable seats (n = 71) which feature a massage function (n = 26), are rotatable (n = 11), and heatable (n = 6) as well as wishes for a couch (n = 4). Requests for either a table or desk (n = 14) were added to this cluster. Requests regarding technological amenities within AVs were second most frequent. Within this cluster, 60 participants requested some form of audiovisual info- or entertainment. Forty-five participants mentioned connectivity, like the possibility to dock one's smartphone or laptop to the AV and to use one's telecommunication devices hands-free inside the AV (n = 25). Twenty participants asked for internet access. There further were 22 requests for screens and 5 requests for a power outlet or charger connections. The remaining requests referred to the availability of cold and hot drinks, spaciousness and finally a good view outwards as well as interior lighting and dimming. Another 30 participants expressed more general desires regarding the interior design of AVs. Seventeen wished for AVs that can be utilized as a mobile office. In contrast, 13 participants expressed the desire for a design which is optimized for relaxation.

4. Discussion

The present cross-sectional online survey study was conducted to investigate the public's opinion on AVs at SAE level L3 and L5 to shed light on the latent societal attitudes and beliefs on this rapidly emerging technology. In doing so, we applied a mixed-methods approach and randomly sampled quantitative and qualitative data in Germany, both at SAE level L3 and L5, respectively. Hence, we quantitatively assessed the estimated years until acceptance and approval of AVs (RQ1) and the will-

Table 2
Descriptive statistics for the estimated years until acceptance and approval of AD and the willingness to pay more for an AV in percent.

	Years until Acceptance				Pay More in Percent			
	L3		L5		L3		L5	
	f	m	f	m	f	m	f	m
N	299	329	280	319	287	315	274	306
M	10.8	10.1	20.4	19.4	10.7	10.8	13.8	14.9
SEM	0.4	0.4	0.7	0.8	0.8	0.8	1.1	1
SD	6.5	7.4	12.3	13.9	13.4	14.0	18.2	16.6
Mdn	10	10	20	15	10	10	10	11
Mod	10	10	20	15	0 (40%)	0 (41%)	0 (33%)	0 (33%)
Skew	1.7	2.3	1.3	2.3	1.6	1.9	1.9	1.6
Kur	5	7.8	1.5	8	3.5	7.4	4.3	3.8
Min.	1	0	0	1.5	−20	−50	−10	−10
Max.	50	50	75	100	75	75	100	100

Note. n=frequencies; M=mean; SEM=standard error of the mean; SD=standard deviation; Mdn=Median; Mod=Modal value with the corresponding percentage of the respective subsample; Skew=Skewness; Kur=Kurtosis; Min.=Minimum; Max.=Maximum.

Table 3
Domains and subdomains of requested governmental contribution to the introduction of AVs.

Domain	Subdomain	*n*
Legal Framework (*n* = 309)	safety criteria and oversight over legal approval	97
	liability and insurance	85
	ethical questions	14
	quick legal approval	12
	ecological standards, sustainability	12
	speed limits	12
	revision of driver's license laws	3
	compatibility-standards among manufacturers	2
	prohibition of AVs	2
	compulsory AV-use for accident-prone persons	1
Financial Aid (*n* = 85)	for buyers	38
	for research and development	33
	for development and use of automated public transport	4
Infrastructure (*n* = 21)	road infrastructure	8
	cellular network coverage	3
Promotion of Public Acceptance (*n* = 8)	-	-

ingness to pay for an AV in percent (RQ2). Additionally, we assessed qualitative data and queried the respondents to what extent they think that the government should contribute to AVs (RQ3) and which special internal design features they would choose in an AV (RQ4). In total, we collected data from 725 respondents and focused on a representative and almost equally balanced sample across the seven age groups and gender to particularly assess the attitudes and opinions of elderly people and to avoid an unequally distributed sample with mainly young people.

4.1. Estimated years until acceptance and approval of AVs (RQ1)

Our first statistical analyses revealed that AVs at SAE level L3 (conditional automation) are estimated to be accepted and adopted by people in Germany in about 10 years and AVs at SAE level L5 (full automation) in about 20 years. These findings were stable regardless of age and gender (H1.1), without an interaction effect between the IVs age group, gender, and the SAE levels (H1.2). Hence, we could not only accept our hypotheses H1.1 and H1.2, but our results were also pretty similar to previous empirical findings in questionnaire studies observed in other countries that AVs may be accepted and adopted within a time horizon up to 2030 to 2050 (Milakis et al., 2015), a decade (Chan, 2017), in the year 2040 (Marletto, 2019), in 2030 by lay people that AVs drive fully automatically or in 2040 stated by participants from a technical university (Bazilinskyy et al., 2019). When asked for the reason for their estimate, 95.0% of mentions by our participants related to factors which, in their opinion, impede AV approval and acceptance. Only 5.0% of mentions related to possible facilitative factors. One might therefore assume that barriers are currently more salient than facilitative factors. Nevertheless, despite several concerns and unresolved issues on AVs, most respondents expect them to be both accepted and approved within the next 10 to 20 years. It is important to keep in mind, however, that this estimate does not reflect the expected time until AVs are prevalent in road traffic, as there will likely be a time gap between AV acceptance and adoption.

4.2. Willingness to pay for an AV (RQ2)

In our consecutive statistical analyses, we observed that *on average* the participants would be willing to pay about 3 percent points less for an AV at SAE level L3 (i.e., 10.6 %) than for an AV at L5 (i.e., 14.5 %). In this regard, it has to be emphasized

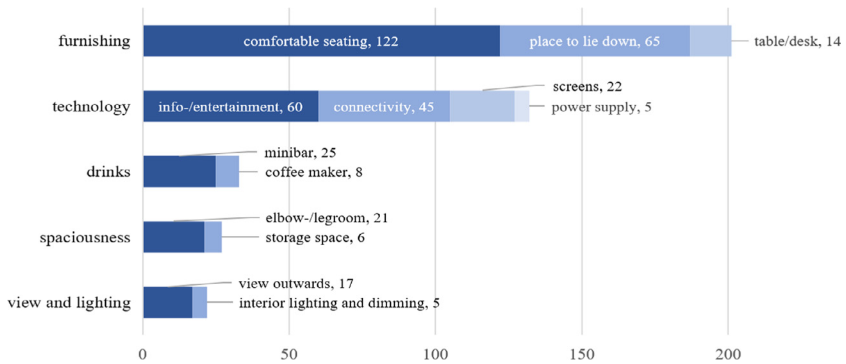

Fig. 4. Requests for desirable internal design features in future AVs, $n_{codings} = 415$.

that between 33 and 41 % of the respondents reported that they were not willing to pay more for an AV (cf. modal value and the corresponding percentage in Table 2).

Moreover, we found a significant main effect for age groups associated with a small effect size according to Cohen (1988), whereas younger participants until 24 years of age would be willing to pay significantly more than participants between 35 and 44 years, more than participants between 45 and 54, and more than participants between 55 and 64 years. However, we identified no significant main effect for gender. Therefore, these findings only confirmed our predictions stated in H2.1 with regard to gender that we did not observe a gender effect, but not for age group, where we also postulated that younger *and* older people might report a higher willingness to pay in percent points. We assumed this because people older than 50 years of age purchase most premium cars (Frison et al., 2017). Nevertheless, our findings are similar for age groups, but slightly different in terms of gender to those observed in the followings studies on AVs, where young men reported less anxiety and more joy towards AVs than women which decreased with the participants' age (Hohenberger et al., 2016), or where young males (18–34) were more willing to use driverless buses than females and participants of older age groups (Dong et al., 2019), or where young men reported fewer concerns on AVS (Charness et al., 2018), and where females, non-drivers, and the elderly reported negative opinions on shared AVs (Zhou et al., 2020). However, these studies and our results differ from the findings identified by Zoellick, Kuhlmey, Schenk, Schindel and Bühler (2019) who observed gender differences in all constructs on AVs, whereas young men were not accepting, trusting, or intending to use AVs more in contrast to other combinations of age groups and gender, but in a rather small sample with only 125 participants.

However, although those aforementioned studies were focusing on age and gender with similar age effects as in our study, we want to stress that they did not query the willingness to pay for an AV. In other studies on AV focusing on the willingness to pay it was found that most respondents reported that they were not willing to pay any more for an AV at SAE level L5 (Cunningham et al., 2019) or that 22% of the respondents stated that they would not pay more for an AV at SAE level L5 (Kyriakidis et al., 2015).

Additionally, for the willingness to pay more for an AV in percent we found a significant interaction effect between SAE levels and age groups, although it was only associated with a small effect size (η_p^2 =.04). In this regard, it has to be noted that despite that younger people (until 24 years) reported on average 14.6 for L3 and 21.8 for L5 and participants between 25 and 34 years stated on average 9.9 for L3 and 15.3 for L5, also all other five age groups consistently reported about 2 percent points less for L3 than for L5. Thus, we could accept H2.2, but only for the willingness to pay more for an AV in percent (based on a small effect size).

4.3. Governmental contribution to the introduction of AVs (RQ3)

We further showed that a large majority of the public wants the government to engage actively in the introduction of AVs. The need to create a legal framework is perceived as the primary concern by the German public. Within this domain, we identified a wide spectrum of regulatory expectations ranging from supervision over the technological functionality of AVs, the regulation of their behavior in traffic (like speed limits or decisions in ethical dilemmas), to the achievement of overarching societal goals (like sustainability). In terms of importance, ensuring safety of AVs and resolving questions regarding liability in case of malfunctions were seen as central duties of the government. This is both consistent with the aforementioned perception of technological immaturity of AVs and in line with most of prior research (Hilgarter and Granig, 2020; Kyriakidis et al., 2015; Merfeld et al., 2019; Schoettle and Sivak, 2014a). There is a wish for thorough testing and oversight over criteria that must be met before legal approval. Overall, our data suggests that safety is currently considered an issue rather than a chance of AVs (other studies identified more ambivalence, Becker & Axhausen, 2017; Merfeld et al., 2019). In order to prevent perceived problems with safety and liability from becoming barriers of AV adoption, there should be an effort to pass (and communicate) transparent and understandable legislation regarding the enforcement of technological maturity and liability (cf. advances by the German government, Bundesregierung, 2021). Further, public financial investments into the development of AVs as well as monetary incentives for users of AVs were seen as desirable. These were of secondary concern compared to the legal framework.

4.4. Internal design of AVs (RQ4)

In accord with prior studies, we found that our participants want to utilize the time inside AVs differently (Merfeld et al., 2019). However, convenient furnishing (allowing for rest and/or work) as well as interconnected technological features (which can be utilized for different means like entertainment, social interaction, and work) were requested most frequently. As the same persons named multiple design features, which do not serve one single specific purpose (e.g., a place to lie down but also a desk for work), we conclude that AVs should be designed in a way that can be utilized flexibly. While our findings certainly provide insights into the spectrum of internal design features deemed desirable by the public, one should keep in mind that they were generated by spontaneous mentions of consumers who have not interacted with AVs so far.

4.5. Limitations and future research

Using a mixed-methods approach to investigate economic and internal design aspects of AVs, we were able to test hypotheses based on prior research and explore open research questions. Policymakers and AV developers are likely interested in the gained insights. However, there are certain limitations regarding the generalizability of our findings. Our data suggests that most participants thought of privately owned AVs when commenting on our questions. They might have been primed by the ones on willingness to pay. Therefore, our findings may not generalize to sharing models or public transport. Considering the exploratory nature of our study, the sample size is substantial. This enabled us to identify the spectrum of issues salient to the public and derive their ordinal sequence arranged according to importance. Our methods do not allow generalizing the recorded proportions, however. Although our open questions were non-compulsory and were skipped by about 100 to 200 subjects (depending on the open question; cf. Table 2), in total our overall sample consisted of 725 respondents, which yielded about 500 to 600 completed open questions. Therefore, our data set constitutes a rather representative sample, enabling reliable results.

Finally, our findings are limited to the German public and should not be viewed as universally generalizable. Therefore, future research is needed to investigate the sentiments present in other populations.

5. Conclusion

The evidence from this cross-sectional online survey study suggests that the estimated and anticipated acceptance and adoption of AVs is expected within the next 10 to 20 years at SAE level L3 and L5, respectively. Furthermore, despite the fact that 33 to 41 % of the respondents are not willing to pay any more for an AV either at L3 or at L5, on *average* the willingness to pay more for an AV was rather high with 10.6 % more for an AV at L3 (when compared to a traditional vehicle at SAE level L0 to L2) and 14.5 % at L5. These results are of course affected by outlier values reported by respondents, who, however, answered plausibly to all other questions. Hence, we did not exclude them. Nevertheless, the real, unobserved, and unknown willingness to pay more on average is very likely to be smaller than numerically identified in our results. Additionally, our qualitative findings indicate that most respondents expect the government to contribute to the introduction of AVs. The introduction of a legal framework is of primary concern to the public. Further, requests relate to financial aids for the development and purchase of AVs, the provisioning of necessary infrastructure, and the promotion of public acceptance. Regarding the interior design of AVs, most are interested in a convenient interior which can be individually personalized to their customer needs.

Despite several unresolved issues on AVs, the findings of the present study are quite remarkable and may indicate that most respondents expect AVs to enter our road traffic within the next 10 to 20 years, whether the participants see and rate them positively, negatively, or critically. Hence, we believe that information dissemination campaigns will be necessary to better educate the public about the potential benefits and drawbacks, if AVs might become commercially available within the next 10 to 20 years.

However, the sole technological readiness is definitely not enough and the broad societal acceptance and adoption might not be given. Therefore, the manufacturers and the policymakers will have to address the public's attitudes, opinions, beliefs, and the consumer needs if they want not only a technological, but also a societal revolution with AVs in our road traffic in the future.

Data statement: Open Science, Results, and Data Sharing

We provide the data set (.sav and.csv), the statistical and the MAXQDA results on the open science platform OSF: https://osf.io/ak3tg/.

CRediT authorship contribution statement

Klemens Weigl: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft. **Daniel Eisele:** Formal analysis, Investigation, Visualization, Writing – original draft. **Andreas Riener:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

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