Trust in Autonomous Technologies

A Contextual Comparison of Influencing User Factors

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Abstract. Faced with an increasing automation of everyday life, users' trust in autonomous technologies is a key factor for its successful adoption. Automation of processes, at home or in the transport sector, can offer great advantages (e.g., more comfort and safety), however, transferring control from a human to technology is also a serious challenge for users. Hence, in this study, we examined user diverse trust perceptions and evaluations in contextual comparison. An online questionnaire study was conducted (N = 129), focusing on trust in and the intention to use autonomous driving and smart home environments with regard to different user groups. Results reveal that trust was context sensitive: in particular gender and technical affinity influence users' decision to (dis)trust autonomous technologies. Also, incentives for the usage differed depending on the context. Test environments were perceived as most important incentive for the context of autonomous driving, whereas users strongly appreciated energy efficiency referring to smart home. These results contribute to a deeper understanding of user needs towards the acceptance of autonomous technologies.

Keywords: Trust in automation · Autonomous driving · Smart home · Technology acceptance · User diversity

1 Users' Trust in Autonomous Technologies

In view of technical influence on everyday life, automation plays an important role in the current technological development. Today, automation is integrated in numerous contexts like mobility, ambient assisted living, or energy supply. Assistance systems that aim to support people in certain situations in their everyday lives contribute to the introduction of autonomous technologies.

They represent the highest degree of automation, because they are supposed to solve tasks without human control [1]. Therefore, they offer great potential and risks at the same time. Among other things, they can improve the quality of life of potential users by taking over everyday tasks for them [2]. Here, application contexts vary from autonomous driving, industrial production, health care to smart homes.

However, there are still legal and also technical challenges to be solved, in order to guarantee a failure-free usage of autonomous technologies (e.g., [3, 4]). Also, the use of

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new technologies might cause uncertainties among future users regarding their perceived protection of privacy, controllability, and loss of autonomy (cf. [5]).

For autonomous technologies to be successful, they must be secure, function properly, and be accepted by users. A major obstacle in acceptance of technology is the users trust in the given technology. Since trust as a human social interaction is not only intuitively important [6], but has an significant influence on (technology) acceptance, this factor should be examined in different technology contexts focusing on further possible influencing user factors (cf. [7]). In addition to that, trust is a key factor, on which usage intention is dependent – which was also shown in other contexts before [8]. Therefore, this research focused on: a context comparison with regard to users' disposition to trust. Privacy, security, and trust play an especially important role in the field of **mobility** and **smart home** and are therefore addressed in this work. The following chapter will introduce both contexts and give a definition of the technology as it is understood for this research.

1.1 Autonomous Driving

The technological developments in driving are without any doubt evolving at a high pace. Over the last years more and more advanced driver assistance systems have been introduced, like the adaptive cruise control as well as parking assistance systems, Which steer the vehicle into the desired parking spot automatically [9].

During the next years *autonomous driving* (or highly automated/driverless/self-driving) will be introduced. Here, vehicles equipped with highly connected sensor systems, longitudinal and lateral guidance, cameras, ultra-sonic technology, and more are supposed to "drive themselves on existing roads and can navigate many types of roadways and environmental contexts with almost no direct human input" [10].

Currently there are different systems that classify different degrees of automation to declare a vehicle as autonomous. The National Highway Transport Safety Administration (NHTSA) standard, the SAE standard, or the German Federal Highway Research Institute standard (BASt) are used to classify a vehicle automation level from no intervening vehicle system activity to the system taking over the complete driving task [11, 12]. This study examined vehicles technology at the highest level of automation (no human input necessary).

The possible advantages of integrating autonomous driving technology in our everyday life are enormous: traffic safety and travel efficiency could be increased, CO_2 consumption reduced, and mobility made much more flexible for people with limited mobility [13].

On the other side, the fear of failure of the technology is relatively high as several studies showed [14, 15]: The question of the *ethics of use* has not yet been finally clarified and the legal regulation debate has not reached a consensus yet. Also, the technical facets still show many (perceived) barriers: Attacks by hackers, mistrust in data protection, and the question of who may use and store the (partly personal) data has not been answered yet [15].

Research focused on user-centered factors, to identify the most influential characteristics. In that way, the user factors may be integrated into the early stages of technology development. Here, it could be shown that user factors (e.g., age and gender) impact acceptance decisions [16, 17] as well as the perceived loss of control or distrust of vehicle dependence, which are seen as serious barriers [15].

Considering the increasing automation of driving, further research is needed to explore if and which user factors – here focusing on trust – are influencing factors for increasing automation, even in different usage contexts: e.g., smart homes.

1.2 Smart Home

In recent years, the domestic integration of information and communication technologies (ICT) has increased and encountered great interest in research [18, 19]. Based on ambient intelligence [20], modern living spaces serve as "digital environments that are sensitive, adaptive, and responsive to human needs" [21], also referred to as *smart home* [22]. In general, smart homes realize the interconnection, collaboration, and automation of infrastructure by means of wireless networks to support residents in their daily life [23]. Technically, smart homes are equipped with sensor and actuator technologies that are unobtrusively integrated into the living environment to collect data (e.g., temperature, pressure, motion) and perform action, respectively [23, 24]. For example, lights can turn on automatically when residents get out of bed [25].

Major fields of application are the automation of domestic tasks (e.g., automatic door opening), energy management (e.g., heating control), communication and entertainment (e.g., smart speaker), security and safety enhancement (e.g. camera monitoring), as well as health care assistance (e.g., floor sensors for fall detection) [18, 26]. Besides pre-programmed tasks, users can control and interact with their smart home environment through natural communication (e.g., voice control) and well-known interfaces (e.g., smartphones) [26]. Hence, residents can, for example, open the front door remotely when a camera displays visitors at the entrance [25].

Smart home environments facilitate daily activities, provide more comfort, flexibility, and sustainability, even though their acceptance is not given without restrictions. In fact, it is dependent on, the type of monitoring system and recorded data (e.g., visual vs. auditive) as well as the usage location (e.g., bathroom vs. living room), which may cause distrust due to the feeling of "being observed" [27, 28]. Major perceived barriers are privacy concerns and the system's reliability, as data transfer and technical errors pose serious uncertainties for users [29–31]. Hence, trust in smart technology is a key factor to its successful adoption at users' home [32].

Previous studies showed that the perception and evaluation of a smart home system's trustworthiness differ with regard to diverse user factors, such as gender, living situation, and family background [33–35]. However, the focus so far has been predominantly on medical technologies for the elderly to support aging in place. Yet, research intensity concerning trust in autonomous technologies for daily use, in particular with regard to younger users, who have learnt and experienced the use of technology from an early age and may have different perspectives, is comparatively sparse. Considering the increasing automation of domestic tasks, further research is needed to explore under which conditions and to what extent diverse user groups trust smart systems in their personal living environment.

2 Method

The aim of this study was to examine user factors that influence trust in autonomous technologies, with special regard to autonomous driving and smart home environments. For this purpose, a quantitative online questionnaire study was conducted addressing the following research questions (RQ):

RQ1 Does users' trust in and intention to use autonomous technologies differ with regard to autonomous driving and smart home?

RQ2 Does user diversity impact users' trust in and intention to use autonomous technologies with regard to autonomous driving and smart home?

The empirical study was conducted in Germany. Participation was on voluntary basis, and data security and anonymity were guaranteed. The participants were predominately acquired by social media and were not compensated in any way. Pretests ensured an overall understanding of the material and a maximum response time of 20 min.

2.1 Empirical Design

Based on preliminary qualitative studies in form of focus groups, two different user scenarios were identified to understand the influence of context (autonomous vehicles vs. smart home) towards trust and the intention to use a technology. The further research presented here shows the results of the online study, which was constructed to look closely into user patterns. With former results in mind, we questioned different user dispositions: trust, privacy, and control (see Fig. 1).

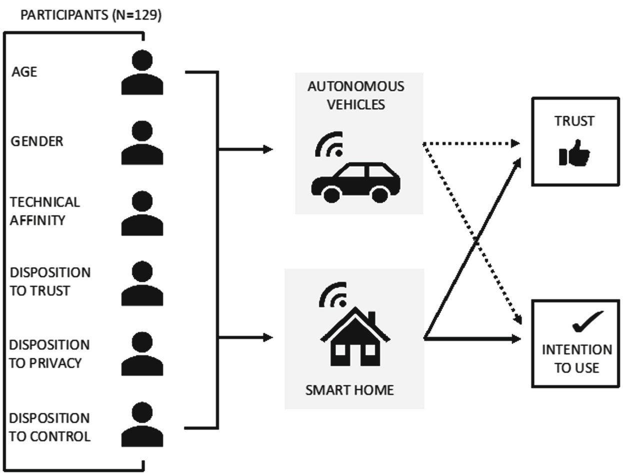

Fig. 1. Empirical design of the online study.

Demographics. The first part of the questionnaire addressed demographic data: age, gender, information about the highest education level, and area of living (city, rural area). In addition to the area, the current state of living (single, flat-sharing community, etc.) and the monthly income was questioned. Given the technological context, the perception of the participants of their self-assessment in handling technology was measured (according to [36]).

User Perception Towards Trust, Privacy, and Control. The second part focused on the participants according to their perceptions. A set of nine items (6-point Likert scale, 6 = full agreement) questioned the participants' disposition to trust. Further, a set of nine items (also 6-point Likert scale) measured the disposition to privacy (see Table 1).

Table 1. Items of disposition to privacy.

To what extent do you agree with the following statements regarding the use of your data?
It is important to me to know what happens to my data
I do not mind, if my data is shared with third parties
I am happy to provide information on my habits and preferences, so that products and services can be developed that really interest me
I want an overview at all times about which data is stored about me
The idea that detailed profiles of me exist, scares me It is important to me that politics attaches a high priority to privacy
There are situations where it is important that information about me is on the internet I have no problem revealing my data
I would disclose information, if I could get any financial benefit from its use

A last set of six items (6-point Likert scale) questioned the participants' disposition to control. All disposition sets (based on [37–39]) had a high internal consistency, as the reliability analysis with Cronbach's α reveals: trust (α = .788), privacy (α = .827), and control (α = .713).

Scenarios. The third part was divided into two beforehand identified user scenarios with autonomous driving (I) and smart home (II) technology. First, a short introduction to the technology and the understanding of the level of automation was given. After that, a scenario description helped the participants envision the possibilities of the addressed technology (see Figs. 2 and 3):

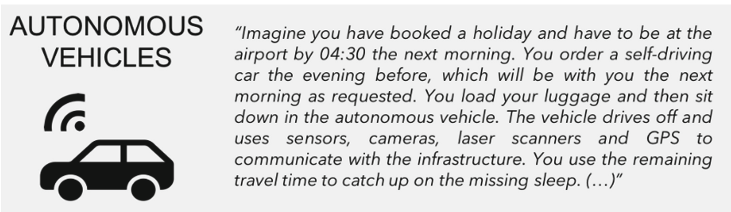

Fig. 2. Short version of the scenario introduction for the autonomous driving scenario.

A further detailed description of possible actions (e.g. traffic light stop, traffic-jam recognition or electronic door lock, camera surveillance etc.) was given as well as a conceptual sketch to deepen the users' understanding of technology-based possibilities.

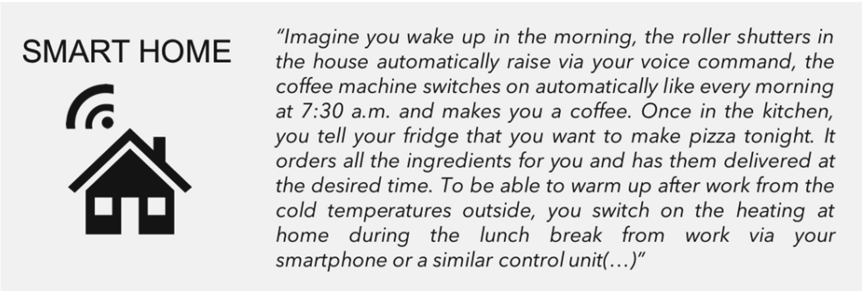

Fig. 3. Short version of the scenario introduction for the smart home scenario.

2.2 Participants

In total, 129 participants took part in the online survey. The age ranged from 18 to 77 years (Mean (**M**) = 29.87; Standard Deviation (**SD**) = 13.60). The gender distribution was asymmetrical with 69.8% women (n = 90) and 30.2% men (n = 39). The sample contained 28.7% with a university degree or higher education level (n = 37). 13.2% had completed a vocational training (n = 17), while further 47.3% (n = 61) answered to have the A-level. The remaining participants reported a secondary school diploma.

When asked about the area of living, 27.1% stated to live in the inner city, 30.2% in the suburban area, 18.6% in outlying districts near the city and 24.0% in rural areas. Further, a large part of the sample stated own a driver's license (97.7%). The mean of the technical affinity was M = 4.01 (SD = 1.23) on a scale from 1 to 6 (max.). Therefore, the sample can be assumed to be slightly tech-savvy.

For a better understanding of possible influencing user factors, the beforehand described disposition to trust (M = 3.59, SD = 0.66), privacy (M = 4.37, SD = 0.86), and control (M = 4.56, SD = 0.65) was also questioned on a scale from 1 to 6. A closer look was also given to the correlations between the investigated user factors and the trust in automation and usage intention (as can be seen in Table 2):

Table 2. Correlation (r_s) between user factors and trust in automation (TiA) as well as use intention ($^{**}p < 0.01$).

	Gender	Age	Technical affinity	Trust disposition	Privacy disposition	Control disposition
TiA	−.270**	.030	.285**	.124	−.235**	−.073
Use intention	−.240**	−.060	.222**	.002	−.228**	−.040

3 Results

This chapter summarizes the obtained research results. First, general findings are outlined with regard to the whole sample. Then, the influence of gender, technical affinity, and privacy disposition on users' trust in and intention to use autonomous technologies is presented in detail.

Next to descriptive analyses, inferential statistics were conducted to measure context differences and user diversity effects. Regarding technical affinity and privacy disposition as independent variables, user groups were formed based on median split.

The level of significance (p value) was set at 5%. For effect sizes, the partial eta-squared (η^2) was reported. Mean values above the scale center ($M > 3.5$) indicated acceptance, whereas mean values below the average ($M < 3.5$) were interpreted as rejection.

3.1 General Findings

In general, with regard to the whole sample, results revealed that the participants were willing to use autonomous technologies. In particular, the intention to use smart home environments was slightly higher compared to autonomous driving, whereas trust concerning both contexts was rather low (see Table 3). Faced with a decision scenario, the majority preferred to use a living environment equipped with smart home applications (64.3%; n = 83) in contrast to an autonomous car (35.7%; n = 46).

Table 3. Evaluation of the intention to use and trust by context (N = 129).

	Intention to use	Trust
Smart home	M = 3.60; SD = 1.18	M = 3.29; SD = 0.92
Autonomous driving	M = 3.51; SD = 1.30	M = 3.06; SD = 1.04

To validate these context differences, a repeated measures analysis of variance was conducted. Results revealed a significant main effect of trust ($F_{1,128} = 49.063$; $p = .000$; $\eta^2 = 0.277$). Hence, users' trust differed significantly in both contexts, provided that smart home environments achieved higher evaluation patterns than autonomous driving. However, both contexts failed to reach the trust threshold of $M > 3.5$ (see Table 3).

Besides from that, the participants evaluated incentives for use, based on preceding focus group discussions, for both contexts (see Fig. 4). Considering autonomous driving, the opportunity to experience an autonomous car ride in a *test environment* was mostly appreciated (M = 4.33; SD = 1.48), followed by *environmental benefit* (M = 4.01; SD = 1.57), *free provision* (M = 3.96; SD = 1.66), and *cost benefit* (M = 3.61; SD = 1.53), whereas *trust in the manufacturer* (M = 3.30; SD = 1.54) and *recommendation* (e.g., by the media or friends) (M = 3.28; SD = 1.46) were not perceived as fitting incentives for use. For comparison, *energy efficiency* (M = 4.20; SD = 1.38) was identified as a major incentive to use smart home environments, next to *free provision* (M = 3.88; SD = 1.64), *cost benefit* (M = 3.73; SD = 1.46), and *test* *environment* (e.g., smart house visiting) (M = 3.55; SD = 1.57), provided that *trust in the manufacturer* (or installer) (M = 3.34; SD = 1.41) and *recommendation* (M = 3.40; SD = 1.42) were not considered as incentives as well.

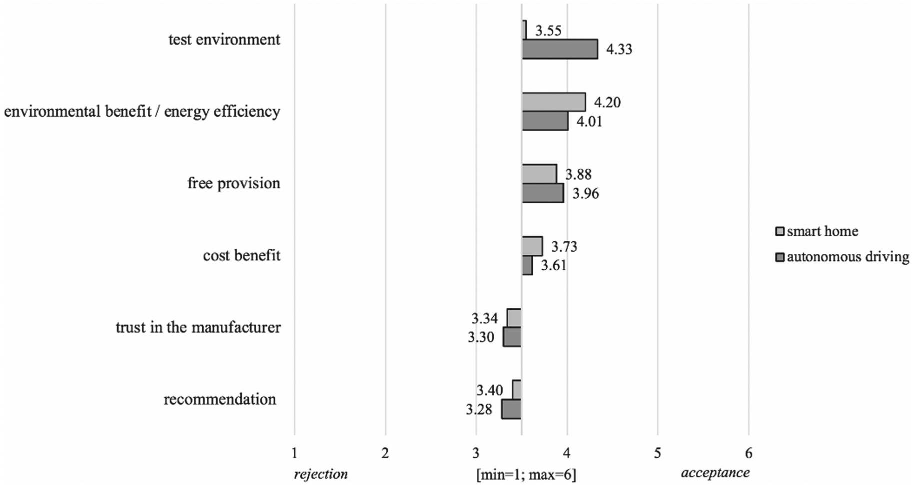

Fig. 4. Evaluation (mean) of incentives for use by context.

3.2 Gender

Trust. Analyses revealed a connection between gender and trust in smart home ($r_s = -.211$; p = .016) as well as trust in autonomous driving ($r_s = -.260$; p = .003), indicating that trust was more important to men than women in both contexts. MANOVA measurements confirmed a significant main effect of gender ($F_{2,126} = 5.150$; p = .007; $\eta^2 = .076$). In detail, trust perceptions of women and men varied significantly regarding either smart home ($F_{1,127} = 6.300$; p = .013; $\eta^2 = .047$) and autonomous driving ($F_{1,127} = 9.153$; p = .003; $\eta^2 = .067$). Overall, men trusted autonomous technologies to a greater extent, whereas women were more likely to express distrust, in particular, concerning autonomous driving (see Table 4).

Table 4. Trust evaluation of context by gender.

	Smart home	Autonomous driving
Men (n = 39)	M = 3.59; SD = 0.91	M = 3.47; SD = 1.09
Women (n = 90)	M = 3.16; SD = 0.90	M = 2.88; SD = 0.98

Intention to Use. According to analyses, gender was related to the intention to use autonomous driving ($r_s = -.249$; p = .004), indicating that men were more willing to use autonomous cars than women. MANOVA measurements confirmed a significant main effect of gender ($F_{2,126}$ = 3.692; p = .028; η^2 = .055), and, in detail, with regard to autonomous driving ($F_{1,127}$ = 7.226; p = .008; η^2 = .054). Hence, the use intention was greater with men (M = 3.96; SD = 1.46), whereas women (M = 3.31; SD = 1.17) rather rejected autonomous driving.

3.3 Technical Affinity

For the analysis of group differences, based on technical affinity (Mdn = 4.25; SD = 1.24), participants with low (M = 3.15; SD = 0.88) and high technical affinity (M = 5.13; SD = 0.55) were compared.

Trust. Correlation analyses revealed a connection between technical affinity and trust in smart home technology (r_s = .265; p = .002) as well as trust in autonomous driving (r_s = .230; p = .009). The greater the affinity for technology, the more trust could be observed. MANOVA measurements confirmed a significant main effect of technical affinity ($F_{2,126}$ = 4.547; p = .012; η^2 = .067). In detail, the participants evaluated trust significantly differently depending on their technical affinity regarding either smart home ($F_{1,127}$ = 8.094; p = .005; η^2 = .060) and autonomous driving ($F_{1,127}$ = 5.578; p = .020; η^2 = .042). Overall, participants with high technical affinity trusted autonomous technologies to a greater extent, whereas participants with low technical affinity were more likely to express distrust, in particular, concerning autonomous driving (see Table 5).

Table 5. Trust evaluation of context by technical affinity (KUT).

	Smart home	Autonomous driving
KUT low (n = 73)	M = 3.09; SD = 0.91	M = 2.88; SD = 0.91
KUT high (n = 56)	M = 3.55; SD = 0.88	M = 3.30; SD = 1.16

Intention to Use. Technical affinity correlated with the intention to use autonomous driving (r_s = .223; p = .011), indicating that participants with high technical affinity were more willing to use autonomous technologies in this context. However, MANOVA measurements revealed no significant omnibus effect of technical affinity on users' intention to use autonomous technologies ($F_{2,126}$ = 2.349; p = .100; n.s.).

3.4 Privacy Disposition

For the analysis of group differences, based on privacy disposition (Mdn = 4.33; SD = 0.86), participants with rather low (M = 3.61; SD = 0.56) and high privacy concerns (M = 4.96; SD = 0.53) were compared.

Trust. Based on correlation analyses, privacy disposition was related to trust in smart home (r_s = −.283; p = .001), indicating that participants with low privacy concerns expressed higher trust levels in this context. However, MANOVA measurements revealed no significant omnibus effect of privacy disposition on users' trust in autonomous technologies ($F_{2,126}$ = 2.881; p = .060; n.s.).

Intention to Use. Privacy disposition correlated with the intention to use smart home environments ($r_s = -.251$; $p = .004$), indicating that participants with low privacy concerns were more willing to use autonomous technologies in this context. Again, MANOVA measurements revealed no significant omnibus effect ($F_{2,126} = 2.087$; $p = .128$; n.s.).

4 Discussion

In this chapter, the obtained research results are summarized and interpreted. In addition to that, an overview of limitations and future research tasks is given.

4.1 Interpreting Results

This study's aim was to examine trust in automation under consideration of influencing user factors in two contexts: autonomous driving and smart home. Key findings revealed that trust was context sensitive, provided that users' perception and evaluation differed with regard to gender and technical affinity.

In general, the intention to use autonomous technologies was affirmative, whereas users' trust in automation was comparatively low. Our study revealed that trust differed significantly with regard to context, with greater trust in smart home than autonomous driving (RQ1). This could lead to the conclusion that there is a sense of attachment to the technology: the technology is used at home and not in public space. This may lower the threshold of trust in the technology.

For comparison, no significant context difference could be found for the intention to use, which was positive overall. Hence, users' trust seemed to rely to a greater extent on the specific usage situation and type of technology, provided that autonomous driving appeared as a more polarizing issue than smart home.

Considering incentives for use, the opportunity of a test environment was mostly agreed upon in the context of autonomous driving, whereas energy efficiency was perceived as the strongest motivation for smart home. One implication here is, that potential users of autonomous vehicles primarily focused on the experience, which complements studies that have also found an impact of user experience on the perceived benefits and barriers (e.g., risk perception) in this context [40]. Also to keep in mind: autonomous driving cannot be tested "at home". There are spacial requirements to use the technology properly, indicating that the test environment is a logical choice for users as an attractive incentive.

Regarding smart home, participants were predominately concerned with energy management, which goes in line with previous findings (e.g., [30]). In this case, future smart home users emphasized resource motives more strongly, probably for cost and environmental reasons, but also because they were not confronted with the perceived necessity to use technology due to high safety risks, as frequently reported in ambient assisted living scenarios [28]. Overall, trust in the manufacturer or installer as well as recommendations by the media or friends did not influence the decision to use autonomous technologies in either context.

Concerning user diversity, significant effects of gender and technical affinity were found (RQ2), according to which men and participants with high technical affinity expressed stronger trust in autonomous technologies, especially in the context of smart home. In contrast, women and participants with low technical affinity showed limited trust levels and were particularly suspicious of autonomous driving. In this respect, especially men were willing to use autonomous cars, which confirms previous research in the field of new automotive technologies and their adopters [41]. Concerning the participants' privacy disposition, no significant group differences were found. However, a trend could be seen that participants with low privacy concerns were more willing to trust and use autonomous technologies compared to participants with high privacy concerns, in particular with regard to smart home. A reason for that could be the group of low privacy concerns already has profound understanding of the benefits of the technology. Therefore, cross-analysis should look upon a connection of low privacy concerns and high technical affinity. An important point for follow-up studies, focusing on more and different influencing user-diversity factors. Interestingly, trust disposition and trust in automation were not related at all in this study, indicating that interpersonal and human-computer trust depict individual processes, which in turn emphasizes the relevance of research in this area.

4.2 Limitations and Future Research

The research results revealed profound insights into users' trust in automation with regard to different contexts. Yet, the study involved few limitations, which are discussed below, together with future research tasks.

First, regarding the sample, the number of participants and age distribution were adequate, as they allowed to complement previous research, especially in the context of smart home, which was so far rather health care and aging oriented (cf. [35]). However, the proportion of women was considerably high. In particular with regard to the obtained gender effects, our results should be validated in a broader sample, which also addresses further user factors, such as privacy and trust disposition, as well as individual needs for data security. Another point concerns that most of the participants hold a driver's license. Regarding autonomous driving, it would be interesting to know, how people without a driver's license or ability to drive (e.g., because of mobility restrictions) perceive and evaluate trust and use intention in this context.

Furthermore, it was particularly striking that the participants were willing to use autonomous technologies, while indicating at the same time that they rather distrust them in both contexts. This implies, on the one hand, that follow-up studies should investigate the influence of trust on the intention to use automation more closely, also with regard to other contexts (e.g., work and industrial production). On the other hand, the scenario-based questionnaire used in the present study may influenced the participants' response behavior. To prevent method bias (cf. [31]), additional approaches should be used, in particular experimental research designs and simulations, in which participants can experience and evaluate the use of autonomous technologies in real life settings.

Finally, the study was conducted in the western part of Germany. Therefore, the obtained results are to be understood against the cultural background of Germany with its specific system of norms and values. For example, this could be relevant as regards the image of cars and traffic, which might differ from other countries, as well as the perception and dealing with privacy concerns. In this respect, it would be interesting to see, how participants with diverse cultural perspectives, which are probably also expressed in people's perception and behavior, evaluate trust in and the intention to use autonomous technologies according to their increasing integration in everyday life.

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