It’s in the Eye of the Passenger:

A Psychological Perspective on the Acceptance and Intention to Use of Autonomous Shuttle Vehicles

Inaugural Dissertation for obtaining the PhD Degree

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AI ..... Artificial intelligence

AVs ..... Autonomous vehicles

CRediT ..... Contributor Roles Taxonomy

ITU ..... Intention to use

MAVA ..... Multi-Level Model on Automated Vehicle Acceptance

TAM ..... Technology Acceptance Model

UTAUT ..... Unified Theory of Acceptance and Use of Technology

UTAUT 2 ..... Extended Unified Theory of Acceptance and Use of Technology

Publications within the scope of the dissertation project

In following publications partial results of this dissertation were published:

Study 1

Schandl, F., Fischer, P., & Hudecek, M. F. C. (2023). Predicting acceptance of autonomous shuttle buses by personality profiles: a latent profile analysis. *Transportation.* Advance online publication. https://doi.org/10.1007/s11116-023-10447-4

Study 2

Schandl, F., & Hudecek, M. F. C. (2023c). *Transportation by the Hand of a Ghost: The Influence of Trait Anxiety in the Context of Fear of giving up Control on the Acceptance of Autonomous Vehicles* [Preprint]. https://doi.org/10.31219/osf.io/r2ug5

Study 3

Schandl, F., Lermer, E., & Hudecek, M. F. (in press). If it concerns me: effects of social psychological distance on the acceptance of autonomous shuttle buses. *Collabra: Psychology.* Advance online publication. https://doi.org/10.1525/collabra.118770

Summary

Autonomous vehicles (AVs) have the potential to revolutionize our daily mobility behavior in the coming years (Litman, 2022). One of the central questions is, from a psychological perspective, how human acceptance of AVs can be ensured. The influence of personality and socio-cognitive factors has been widely studied in this context. This research project sets out to complement and expand previous findings by focusing on three so far unexplored aspects that could be decisive for the successful adoption of AVs by humans: Identifying AV user groups, exploring the influence of trait anxiety, and exploring the role of psychological distance in relation to AVs. Accordingly, this dissertation aims to fill important research gaps to understand the preconditions for AV acceptance in these respects and to derive implications for the successful establishment of AVs. This goal was pursued in the context of three study projects.

Study 1 aimed to identify user groups in the context of autonomous driving, in particular autonomous shuttle buses, based on selected personality traits. Using latent profile analysis (N = 388) four user groups that could be clearly distinguished from each other were identified. Membership in a user group significantly predicted the acceptance of autonomous buses. The personality traits anxiety, self-confidence, and affinity for technology were found to be particularly predictive of user group membership. More specifically, profile 1 was characterized by high general anxiety with low technology affinity and ITU. Similarly, profile 2 was characterized by low ITU and high technology anxiety but also with low general anxiety. With average values across all variables, profile 3 showed average ITU. Profile 4 had the highest ITU with low anxiety and high technology affinity. The individual analysis steps were extensively validated to ensure the generalizability of the results. To the research team´s best knowledge, this study is the first to integrate previous findings on personality and acceptance of AVs in this way and to identify valid user groups for autonomous buses. The findings can be used by

manufacturers and providers of autonomous buses to adapt autonomous driving in a more differentiated way to the person and the needs of potential users.

Since the user group with high general anxiety proved to be skeptical of AVs in study 1, in a further step in **study 2** the focus was directed on trait anxiety and its influence on ITU. This was based on findings by Qu et al (2021), who found a positive relationship in this regard (and thus contrary to the results from study 1). They justified this by the explanation that more anxious individuals value the opportunity to hand over control in autonomous buses. In study 2 ($N = 253$), we took up the assumption and investigated whether the association between trait anxiety and ITU was mediated by fear of giving up control. We also quasi-experimentally explored the extent to which this mediation can also be found for traditional buses in which control is handed over to a human driver rather in a traditional bus than to the artificial intelligence (AI) in an autonomous bus. The results confirmed the positive association between trait anxiety and intention to use (ITU) in the overall sample, but not for the subsamples in the traditional and autonomous condition. The association was not mediated by fear of giving up control. Interestingly, the calculated mediation models for the autonomous and traditional condition did not differ significantly. The findings thus extend the understanding on the role of anxiety with respect to AV acceptance and provide suggestions for research based on these findings. However, the results of the first two studies seem to contradict each other: in study 1, the results indicate that the user group with above-average general anxiety was more critical of AVs, whereas in study 2, the positive relationship between trait anxiety and ITU showed an opposite picture. An explanation for this could be that the subjects in the online-based study, in contrast to the real-life driving situation of study 2, were not directly affected by AVs and therefore represented the technology on a more abstract psychological level.

Study 3 was therefore devoted to AV acceptance from the perspective of this phenomenon, psychological distance. Previous studies have already shown in different contexts that psychological distance can influence the acceptance of modern technologies on a social level (e.g., "me" vs. " others) or on a temporal level (e.g., "today" vs. "in 10 years"). At the same time, psychological distance has also been shown to be a useful tool to specifically influence object representation. To date, however, the phenomenon of psychological distance has not been considered in relation to AVs. Study 3 addressed this research gap. In a large-scale 2x2x2 experimental design (N = 2,114), we investigated how psychological distance affects the acceptance of autonomous buses on a social and temporal level using a scenario-based design. For comparison purposes, driving modality (autonomous vs. traditional) was manipulated. The results highlight the role of psychological distance in AV perception: subjects attributed higher ITU to strangers than to themselves, especially when bus use was framed in temporally abstract terms. Autonomous buses were more readily adopted than traditional buses, with psychological distance having a similar effect on traditional buses. For AV providers, this promises a positive outlook: when implementing or marketing autonomous and traditional buses, the focus should be on temporal concreteness and tangibility of bus use.

Overall, the findings highlight the importance of the psychological perspective in the implementation of autonomous driving technology and provide important insights for the production, marketing, and establishment of AVs. Thus, this research project makes an important contribution to the successful introduction and implementation of autonomous buses. The question to what extent the results can be transferred to other autonomous transport modes (e.g., private cars, cabs) or other populations besides public transport in Germany requires research that further extends on these findings. OBJ

Contributions

The contributions to the study projects according to the National Information Standards Organization (2023) Contributor Roles Taxonomy (CRediT) are shown in Tables 1-3.

Table 1

Study 1: Identification of user groups of autonomous shuttle buses: a latent profile analysis

Contribution	Contributor
Conceptualization	Schandl, Hudecek
Data curation	Schandl
Formal analysis	Schandl, Hudecek
Funding acquisition	Hudecek
Investigation	Schandl, Hudecek
Methodology	Schandl, Hudecek
Project administration	Hudecek
Resources	Schandl, Hudecek
Software	Not applicable
Supervision	Hudecek, Fischer
Validation	Schandl
Visualization	Schandl
Writing – original draft	Schandl, Hudecek
Writing – review & editing	Schandl, Hudecek

Table 2

Study 2: Transportation by the hand of a ghost: The influence of trait anxiety in the context of fear of giving up control on the acceptance of autonomous vehicles

Contribution	Contributor
Conceptualization	Schandl, Hudecek
Data curation	Schandl
Formal analysis	Schandl, Hudecek
Funding acquisition	Hudecek
Investigation	Schandl
Methodology	Schandl, Hudecek
Project administration	Hudecek
Resources	Schandl, Hudecek
Software	Not applicable
Supervision	Hudecek
Validation	Schandl
Visualization	Schandl
Writing – original draft	Schandl, Hudecek
Writing – review & editing	Schandl, Hudecek

Table 3

Study 3: If it concerns me: An experimental investigation of the influence of psychological distance on the acceptance of autonomous shuttle buses.

Contribution	Contributor
Conceptualization	Schandl, Hudecek, Lermer
Data curation	Schandl
Formal analysis	Schandl, Hudecek
Funding acquisition	Hudecek
Investigation	Schandl, Hudecek
Methodology	Schandl, Hudecek, Lermer
Project administration	Hudecek
Resources	Schandl, Hudecek
Software	Not applicable
Supervision	Hudecek
Validation	Schandl
Visualization	Schandl
Writing – original draft	Schandl, Hudecek
Writing – review & editing	Schandl, Hudecek

A Psychological Perspective on the Acceptance and Intention to Use of Autonomous Shuttle Vehicles

In the early 20th century, the automobile replaced the horse-drawn carriage, revolutionizing human mobility (Dietsche et al., 2017). From the development of the first roadworthy motor vehicle in 1886 to mass assembly line production took less than 30 years (Dietsche et al., 2017; Scheltus, 2015). From that point on, engine-powered vehicles became an everyday convenience, a status symbol, and a central object in technological research and development. A century later, the vehicle industry is facing a new revolution, the autonomization of driving. Artificial intelligence (AI) is already expected to replace humans as active vehicle drivers in the following two decades (Litman, 2022). Already in the 2030s, autonomously driving buses in local public transport, the so-called microtransit, could become a significant element of our everyday life (Litman, 2022). Currently, pilot systems for autonomous microtransit are being investigated and tested in various contexts and application (e.g., Dai et al., 2021; Nordhoff et al., 2020; Riener et al., 2020). In these test phases, the focus is increasingly shifting to the psychological perspective in addition to the technological component. The passenger, with his or her experience and acceptance, represents a key factor in the establishment of autonomous microtransit systems. The more autonomous driving is adapted to user needs and interests, the easier it can develop into an attractive alternative to non-autonomous driving. In this context, a focus on potential fears, concerns, and uncertainties is necessary to successfully integrate autonomous buses into transportation in the long term (Cunningham et al., 2020; Fraedrich & Lenz, 2016; Gandrez et al., 2020; Hegner et al., 2019). As this development continues, there is an increasing urgency to gain a better understanding of the acceptance of autonomous microtransit systems from a psychological perspective.

Theoretical Background

Autonomous driving: Definition and differentiation

Autonomous driving describes driving behavior that makes technically automated decisions independently of human influence and performs the driving task based on these decisions (Hey, 2019). According to the Society of Automotive Engineers International (2021), this driving automation can be divided into distinct levels depending on their degree of autonomy (see Table 4). Level 0 relates to vehicles without autonomous functions that are at most equipped with warning systems, while level 5 is assigned to fully autonomous vehicles (AVs) that can operate without human vehicle control, regardless of the situation. On July 12, 2021, Germany became the first country in the world to enact the *Road Traffic Act* (*Gesetz zur Änderung des Straßenverkehrsgesetzes und des Pflichtversicherungsgesetzes – Gesetz zum autonomen Fahren, StVG)*, which regulates the participation of AVs in road traffic (Heller & Pfefferle, 2021). Currently, the use of AVs at level 3 is allowed in circumscribed public traffic routes under the accompaniment of a technical supervisor (operator) who takes over the control of the vehicle in an emergency according to § 1d, Paragraph 1-3, Road Traffic Act (StVG). This created an important legal basis for the widespread implementation of AVs. It is assumed, that AVs will largely replace active vehicle control by humans in the coming years (Litman, 2022). In addition to personal vehicles, autonomous driving opens new possibilities, especially for public transport. The innovative technology grants the implementation of modern mobility concepts that allow intelligent and flexible planning of bus routes on-demand (Ainsalu et al., 2018). This enables both a more targeted satisfaction of user needs and a more time- and cost-efficient, sustainable use of public transport.

Table 4

Summary of levels of driving automation according to Society of Automotive Engineers International (2021), J3016

Level	Human involvement	Autonomous functions	Example
0	Main takeover of vehicle control and continuous monitoring of functions	None, possibly warning systems	Lane departure warning
1		Steering OR acceleration	Lane departure assistant
2		Steering AND acceleration	Lane departure assistant and distance control in parallel
3	On request Takeover of vehicle control	Takeover of vehicle control under defined conditions	Autonomous vehicle on defined route
4	No takeover of driving control necessary		Local autonomous vehicle
5		Takeover of vehicle control under all conditions	Fully autonomous vehicle

Technology and AV acceptance models

In the initial stages of development of autonomous driving technology, primarily technical and legal issues were relevant. But with the advancing proliferation of AVs in road traffic, psychological factors for adoption by potential users are increasingly moving into the focus of research interest. The major emphasis is on factors influencing the acceptance of AVs and the ITU. In this context, theories and models have been developed, that build on previously established models of general technology acceptance. These combine the diverse influencing factors and organize them into a concise system.

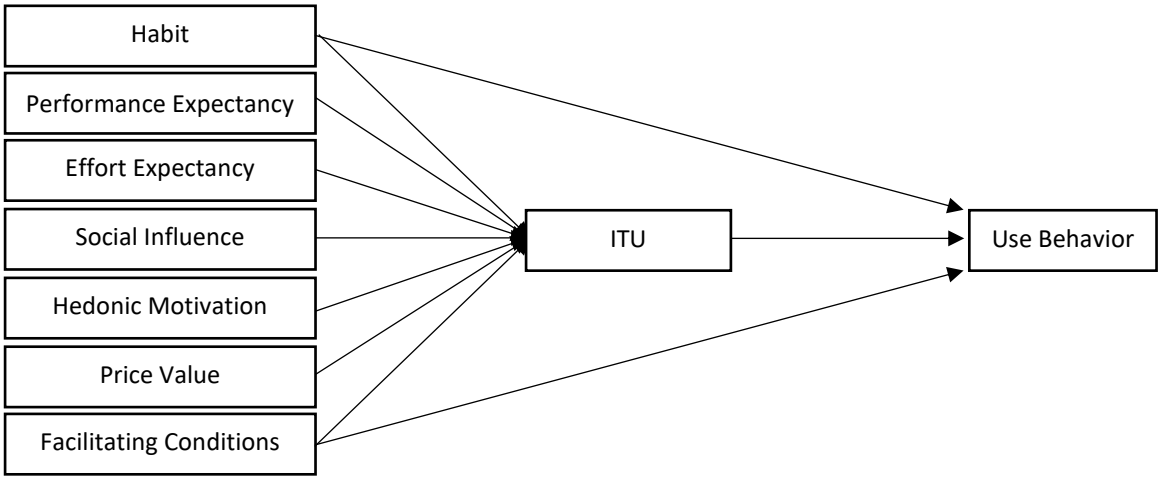
In 1985, Davis laid a cornerstone with the Technology Acceptance Model (TAM), on which numerous modern theories and models for technology acceptance are based. According to the model, external variables (e.g., personality) influence perceived usefulness and perceived ease of use of a technology. In turn, these variables have a causal effect on attitudes toward the technology and thus on ITU. The relationships were found to be replicable in several studies (Adams et al., 1992; Y. Lee et al., 2003) and were also

successfully confirmed in the context of autonomous driving (Yuen et al., 2021). As a result, the TAM was one of the first models to explicitly highlight the relevance of psychological factors to technology acceptance and raise awareness of their impact. However, perceived usefulness and perceived ease of use as crucially influential factors have been repeatedly criticized as too parsimonious to fully explain technology acceptance (Adams et al., 1992; Y. Lee et al., 2003).

A far more comprehensive model based on the findings of the TAM was developed by Venkatesh et al. (2003) with the Unified Theory of Acceptance and Use of Technology (UTAUT). It captures factors influencing the ITU of modern technologies in an organizational context. The UTAUT assumes that performance expectancy, effort expectancy, social influence, and facilitating conditions affect ITU and, through this, the actual use. The theory attributes moderating effects to gender, age, experience, and voluntariness of use. In 2012, the authors extended the UTAUT (UTAUT 2; Figure 1, Venkatesh et al., 2012, p. 160) to predict the use of modern technologies among public consumers rather than just in the organizational context. Therefore, based on previous research findings on consumer behavior, they added hedonic motivation, price value, and habit as factors influencing ITU. The UTAUT 2 could subsequently be found in numerous contexts (e.g., blended learning, Azizi et al., 2020; e-payment, Indrawati & Putri, 2018). The theory was also found to be suitable in the context of AVs (Zheng & Gao, 2021). Korkmaz et al. (2021) found that the UTAUT 2 factors, together with trust, security, and perceived risk, were able to elucidate 71 % of the variance in AV acceptance. The UTAUT 2 thus provides a significant contribution to a deeper understanding of the conditions for ITU of modern technologies, including AVs.

Figure 1

Graphical illustration of the UTAUT 2 according to Venkatesh et al. (2012)

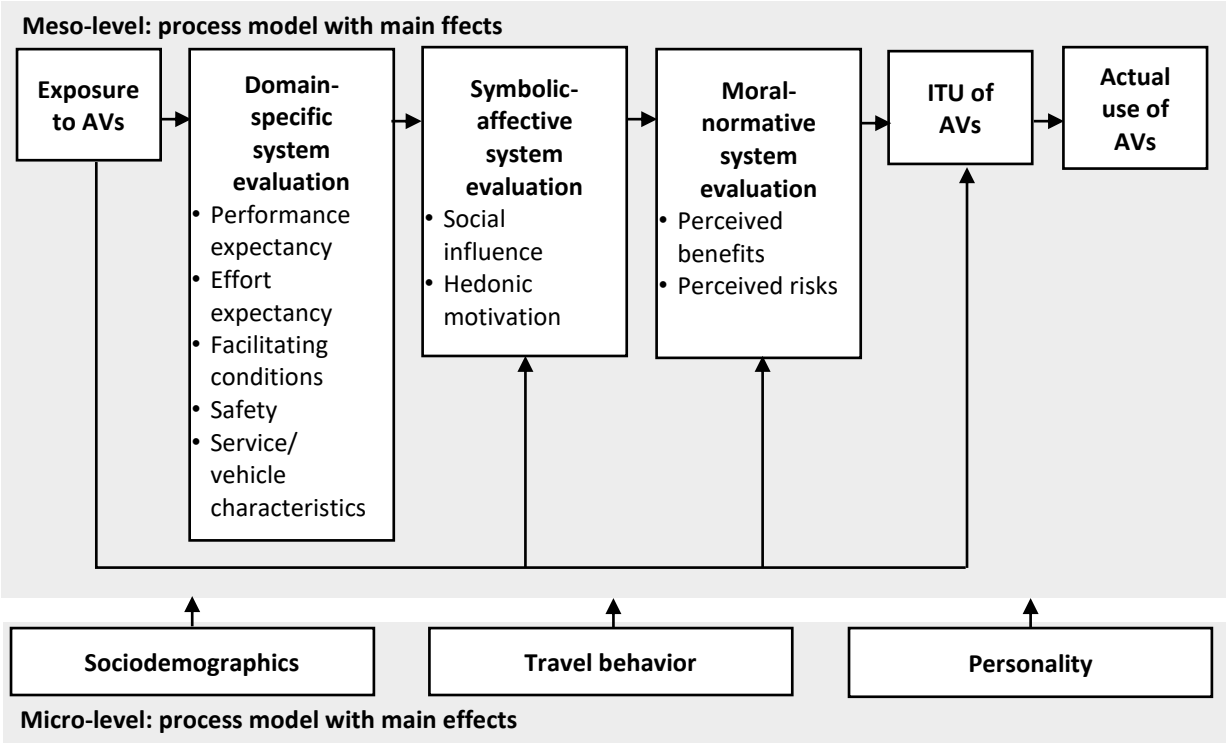


Note. Adapted from Venkatesh et al., 2012, p. 160.
ITU = Intention to use.

With the increasing research interest in autonomous driving technology, the Multi-Level Model on Automated Vehicle Acceptance (MAVA) was introduced (see Figure 2, adapted from Nordhoff et al., 2019), which focuses specifically on factors influencing AV acceptance and builds on the UTAUT 2 (Nordhoff et al., 2019). For the development of the model, an extensive literature review was conducted to identify and rank the most crucial factors. The MAVA distinguishes 28 micro-level (e.g., sociodemographics, personality) and meso-level (e.g., performance expectancy, perceived risk) factors that directly or indirectly affect ITU. The constructs of UTAUT 2 are taken up in the meso-level. With 28 factors, the model is comparatively comprehensive, but at the same time it does not weigh the factors, which according to the authors is dependent on the survey population (Nordhoff et al., 2019).

Figure 2

Graphical illustration of the MAVA according to Nordhoff et al. (2019)



Note. Adapted from Nordhoff et al., 2019, p. 686.
AV = Autonomous vehicle; ITU = Intention to use.

To the best knowledge of the research team, the model has not yet been validated. However, the factors extracted are based on a wide range of previous knowledge on autonomous driving. The MAVA is the first model specifically on vehicle acceptance to consider hedonic motivation as an influencing factor (Mara & Meyer, 2022). In addition, the MAVA is the only one of the aforementioned models to explicitly highlight the role of individual differences at the personal level. The authors illustrate that for a comprehensive understanding and prediction of AV acceptance, it is not sufficient to identify generally applicable influencing factors (at the meso-level). Rather, these factors must be considered in the context of situational framing and user characteristics (micro-level), which decisively influence the meso-level and acceptance of AVs.

Technology and AV acceptance in current research

In this context, the influence of extrapersonal characteristics, e.g., driving behavior or the presence of an operator, has already been extensively studied. An overview of the current state of research on extrapersonal factors can be found, for example, in the reviews by Bornholt and Heidt (2019) or Pigeon et al. (2021). Furthermore, current studies show that the acceptance of autonomous driving systems is also significantly influenced by intrapersonal factors (micro-level), including socio-demographics, personality and individual perception.

Sociodemographic variables and AV acceptance

In fact, older and female respondents were found to be more concerned about autonomous driving technology. With respect to technologies, men primarily value their productivity (Venkatesh & Morris, 2000). Women, on the other hand, consider a complex set of factors when deciding to use a technology (e.g., its usefulness, ease of use, and social norms, Venkatesh & Morris, 2000). Possibly, this makes females a more demanding user group, less convinced about AVs than males. Women are also less likely to pursue technical or engineering careers and thus may be less familiar with the technology behind AVs, making them more uncertain about AVs (Trapani & Hale, 2019). The findings could also be due to Stereotype Threat, which is an internalized prejudice that men are more tech-savvy than women (Koch et al., 2008). Accordingly, Blasko et al. (2020) showed that women attribute lower innovativeness and greater uncertainty in their use of technology to themselves.

This Stereotype Threat could also be a cause of lower ITU in older generations. Sensation-seeking also decreases with age, and innovative technologies may lose their appeal as a result (Zuckerman et al., 1978). Older individuals particularly value the usefulness of AVs and price in relation to AVs (Herrenkind et al., 2019). Especially for

young people, technological security (e.g., in case of hacking attacks) is crucial for the ITU (Charness et al., 2018; Garidis et al., 2020).

In addition, the majority of studies showed that higher education level and income favor technology and AV adoption. Both variables are closely related because higher education enables many people to work in a higher-income occupation (Rojas-Méndez et al., 2017). It is also possible that higher education contributes positively to understanding new, abstract technologies such as AVs and thus being more open to them. High income may also open access to (sometimes expensive) modern technologies such as AVs, which may also be more likely to reduce inhibitions (Rojas-Méndez et al., 2017). Additionally, fair value for money for AV was found to favor ITU, especially among higher-income individuals (Garidis et al., 2020).

Mack et al. (2021) demonstrated that AV acceptance was also related to political orientation, with more politically liberal attitudes associated with higher ITU. Individuals with more liberal orientations saw greater benefits in AVs and worried less in this regard. However, the direction of the effect is not clear. It remains to be seen whether political orientation affects attitudes toward AVs or whether, for example, tech-savvy individuals are more likely to be found in modern parties whose focus is on technological progress, among other things. It is also conceivable that socialization with a party and its attitudes toward technology innovations affects AV acceptance. The findings may also be due to age effects: older individuals have been shown in numerous studies to be more critical of AVs and at the same time more likely to vote for conservative parties (Ahlfeldt et al., 2022; Qu et al., 2021).

Personality and AV acceptance

In addition to these factors, personality traits have been shown to be relevant for the acceptance of modern technologies and AVs at the intrapersonal level. Studies on the

BIG 5 and AVs have shown that particularly extraverted and more open individuals are more likely to accept AVs (Qu et al., 2021). High neuroticism is negatively associated with AV acceptance, possibly due to greater insecurity or worry. Particularly agreeable subjects were also found to be more concerned about AVs in terms of reliability and ease of use. At the same time, agreeableness is positively associated with perceived benefits and purchase intention of AVs (Qu et al., 2021).

Another relevant personality characteristic is innovativeness. Regarding AVs, innovative individuals show higher utilitarian motivation in addition to hedonic motivation and, accordingly, higher ITU (Hegner et al., 2019; Keszey, 2020). Innovativeness is also closely related to potential anxieties about AVs. Innovative users predominantly report specific fears regarding AVs, e.g., data security (Keszey, 2020). In contrast, non-innovative users are more likely to exhibit global fears about new technology (Keszey, 2020). Overall, AVs in general seem to be associated with diverse concerns (Fraedrich & Lenz, 2016). This technology currently has limited availability in public transportation. This prevents corrective experiences in terms of AV related fears (Fraedrich & Lenz, 2016). The perceived risk regarding system reliability, driving safety and data security creates uncertainty among potential users (Jing et al., 2020). In this context, trust in AV technology and perception of safety play a crucial role. Trust in AVs can mitigate perceived risk (Choi & Ji, 2015). However, it is significantly lower compared to trust in a human driving force (Strauch et al., 2019). Trust in AV technology is primarily determined by a person's general trust disposition and affinity for technology (Benleulmi & Blecker, 2017; Moallem, 2019). Furthermore, system transparency and the perceived competence of AVs in managing traffic situations influence trust in AVs. People with high trust in AVs are more willing to use them. In addition to trust, perceived safety has been found to be the most important determinant of ITU in several studies

(Detjen et al., 2020; Garidis et al., 2020). The perception of reliable driving and system safety is fundamental to well-being and comfort during autonomous driving (Detjen et al., 2020).

Autonomous technology may be associated with worry and anxiety due to its novelty and the difficulty of grasping it (Fraedrich & Lenz, 2016). Therefore, another important characteristic related to AV acceptance is trait anxiety. Tan et al.(2022) identified anxiety as one of the key factors for AV acceptance by users. However, in addition to the well-studied situation- or object-related fear (e.g., Keszey, 2020; J. Lee et al., 2016), studies on trait anxiety are still scarce and inconsistent. In a study of blind users, Bennett et al. (2020) showed that higher generalized anxiety is associated with lower ITU. All the more interesting are recent findings that show that more anxious people are more willing to use AVs. According to Qu et al. (2021), this result can possibly be explained by the idea that more anxious people are more willing to relinquish driving control so that they do not have to take it themselves. This implies that, in addition to trait anxiety, the willingness to or fear of giving up control also has a mediating effect on AV acceptance. The effects of trait anxiety on the ITU and the possible role of giving up control in this respect cannot yet be clearly assessed. However, research shows that giving up of control is a determining factor for the acceptance of AVs. A low need for control and an external locus of control also contribute to AV acceptance (Choi & Ji, 2015; Garidis et al., 2020).

Cognitive representation and AV acceptance

In addition to these factors, a further factor determining technology acceptance is the user's individual perception and the associated cognitive representation of the technology. Prior knowledge about or experience with AV technology favors confidence in the technology and willingness to use it in numerous studies (Charness et al., 2018;

Detjen et al., 2020). Acceptance increases already after the first AV ride (Bernhard et al., 2020). Experienced users are less worried about AVs and more willing to relinquish control to AVs (Charness et al., 2018). In this context, construal level theory (CLT) offers a potential explanation for these findings (Trope & Liberman, 2010). It states that with increasing experience, users gain a more comprehensive impression of objects or situations and thus represent them in a more cognitively concrete way. The individual can therefore refer to actual experience and is not dependent on mentally constructing the situation (Trope & Liberman, 2010). Consequently, the user can assess and evaluate the situation more concretely (Charness et al., 2018). This can potentially reduce concerns and uncertainty regarding the technology (Charness et al., 2018). A key factor that affects the concreteness of a cognitive representation is psychological distance, i.e., the extent to which a circumstance is "not part of one's direct experience" (Trope et al., 2007, p. 84). The individual's point of view is always the reference under which psychological distance is assessed and can vary between situations and persons (Trope & Liberman, 2010; Trope et al., 2007). The perceived psychological distance depends, for example, on how physically or geographically close an individual is to an event or how similar an individual feels to a person (e.g., in terms of age or personality characteristics, Trope & Liberman, 2010; Trope et al., 2007). Currently, AVs are hardly widespread and difficult to grasp, i.e., psychologically distant for the majority of the population (Brell et al., 2019; Litman, 2022). This distance in turn results in an abstract, rather than concrete, cognitive representation of AVs. (Trope & Liberman, 2010)

Psychological distance has already been identified as a decisive factor in the acceptance of new technologies (e.g., Abraham et al., 2019; Bagratuni, 2021; Hudecek et al., 2024). Interestingly, many studies show that new technologies (e.g., Bitcoin, Abraham et al., 2019; air cabs, Bagratuni, 2021) are more likely to be accepted when

psychological distance is high, possibly because the technology is perceived as less relevant to the individual and therefore less threatening (Lermer et al., 2016b). Concrete experience that reduces perceived psychological distance would therefore have a negative impact on AV acceptance. However, the latter contrasts with the previous findings on the influence of experience on AV acceptance. To the research team´s best knowledge, psychological distance has not yet been investigated in the context of AVs. It therefore cannot yet be determined whether these findings can also be transferred to AVs and how they are compatible with the findings on experience with AVs. Nevertheless, it can be assumed that the individual cognitive representation and concreteness of AV perception may influence acceptance.

Objectives of the dissertation project

Autonomous driving systems will be playing a growing role in traffic over the next three decades and will fundamentally change the daily driving experience (Kyriakidis et al., 2015; Litman, 2022). This makes passenger acceptance even more decisive for successful implementation. This important topic is therefore the focus of this research project.

This dissertation is structured cumulatively. It comprises three study projects conducted as part of the People Mover Research Project at the Chair of Social, Economic and Organizational Psychology at the Department of Experimental Psychology at the University of Regensburg. The three studies pursue the superordinate goal of contributing to a deeper understanding of the factors related to AV acceptance from a psychological perspective, to adapt AVs precisely to the needs of the users. The focus will be on three key aspects that are worth attention for AV acceptance from a theoretically based point of view, but are still largely untouched in AV research at the current time:

1. the identification of AV user groups
2. the investigation of the effect of trait anxiety on AV acceptance
3. the impact of psychological distance on AV acceptance.

The individual studies with their associated study objectives are based on this goal (see Table 5 for an overview. They are presented and justified below.

Table 5

Overview of focus, approach, and data of the three research projects

	Study 1	Study 2	Study 3
Focus	User group identification	Role of trait anxiety for ITU of AVs	Role of psychological distance (social and temporal) for ITU of AVs
Sample size	*N* = 388	*N* = 253	*N* = 2,114
Explanatory methodology	Exploratory	Confirmatory	Confirmatory
Design	Observational, quasi-experimental	Quasi-experimental	Experimental
Predictors	User group membership based on personality profile	Trait anxiety, fear of giving up control	Social distance, temporal distance, bus modality
Statistical analysis	Latent profile analysis, linear regression	Mediation analysis, Multigroup analysis	ANOVA

Note. AV = Autonomous vehicle; ITU = Intention to use.

Study 1: Research questions and objectives

In previous research, it has been confirmed multiple times and on a broad basis that the personality of users has an impact on the acceptance of AVs (e.g., Charness et al., 2018; Hegner et al., 2019; Qu et al., 2021). For the successful implementation of AVs, it is therefore advisable to address the user's personality as differentiated as possible. On the other hand, the personality of the user is too complex to be met individually. To

address this issue (e.g., in AV marketing), it is necessary to identify typical personality patterns, so-called user group profiles, that are as distinct from each other and as coherent as possible. These profiles may allow a more differentiated perspective on the personality and potential needs of users to derive targeted and practicable measures for successful adoption. In other contexts (e.g., mobile technology integration, Yukhymenko-Lescroart et al., 2021; social media addiction, Stănculescu & Griffiths, 2022) user groups have already been analyzed to better understand the relationship between person characteristics and behavior. In the AV context, this is also relevant, but is still outstanding to the research team´s best knowledge. Therefore, the aim of the first study is to identify AV user groups. We addressed the following questions according to Spurk et al. (2020):

- What is a meaningful and useful number of user groups?
- How can the different profiles be characterized?
- How big are the profiles?
- Is profile affiliation predictive for ITU of AVs?
- Are the results valid?

To the research team´s best knowledge, this study is the first to combine previous findings on AVs and personality in this way, to link them directly to ITU, and then to validate the findings. It provided a comprehensive classification of AV acceptance across the complex personality structure of users.

Study 2: Research questions and objectives

In the second study, we deepened the perspective on the level of a trait that is, according to the user group analysis, particularly influential for AV acceptance: trait anxiety. Among all personality variables, trait anxiety proved to be a crucial influencing factor on AV acceptance in previous research, including user group analysis (e.g., Bennett et al., 2020; Qu et al., 2021). It first seems plausible that people who are more fearful of

AVs are more skeptical of new autonomous driving technology. This assumption has already been confirmed in some studies and could be found in the user group analysis as well (e.g., Hohenberger et al., 2017; Keszey, 2020). However, there are surprising study findings that suggest that more anxious people are more open to AVs (Qu et al., 2021). The authors explain the finding by suggesting that more anxious individuals prefer to relinquish driving control rather than take it on themselves. The reasons for the at first sight opposing findings are still unexplained. To understand the preconditions for AV acceptance from a differential psychological perspective, the role of trait anxiety as a contributing influencing factor needs to be clarified. Therefore, with the second study, the aim was to re-examine the relationship between trait anxiety and AV acceptance and, at the same time, to address the role of two factors that may be causal for the inconsistent findings on the direction of the relationship.

- Qu et al. (2021) assumed that more anxious people prefer to hand over control to external entities rather than take control themselves. This could explain why more anxious people are more willing to use AVs. This explanation was tested in study 2 by addressing the following research question: Is the relationship between trait anxiety and ITU mediated by fear of giving up control?
- Building on this, we also examined the role of bus modality. In the bus context, control is always handed over, either to a bus driver in a traditional bus or to the AI in an autonomous bus. We wanted to use this context to investigate to what extent the relationships are dependent on the bus modality, i.e., to what extent it has an influence whether control is handed over to a human driver or an AI. We therefore pursued the following research question: How does this relationship depend on the bus modality (autonomous vs. traditional)?

Study 3: Research questions and objectives

In the third study we analyzed AV acceptance from a different angle. So far, AVs are still the exceptional in Germany. As a result, the tangibility of this technology for the general population is still limited. The first two studies are therefore based on the hypothesis that AVs, as a modern technology, are still very abstract in society. At the same time, both studies showed that anxiety and uncertainty play a significant role for AV acceptance. However, inconsistent results emerged regarding the direction of this relationship: in the online-based study 1, the user group with particularly pronounced anxiety showed lower ITU, whereas in study 2, which was surveyed under real-life conditions, trait anxiety was positively (although not significantly) related to ITU. Both results are consistent with findings from previous studies (e.g., Bennett et al., 2019; Qu et al., 2021). This contradiction opened an interesting new and previously unstudied question about underlying causes. A reasonable explanation for this could be that the participants in the online based study 1, in contrast to the real-life study 2, did not directly experience autonomous driving. It may be possible that, therefore, they represented AVs on a more abstract psychological level. In a study on AI-based medical findings, Hudecek et al. (2024) showed that the extent to which the person is directly affected is crucial for technology acceptance. This phenomenon, the so-called psychological proximity or distance to an object or situation, influences the cognitive representation and thereby the perception and judgment of it (Peng et al., 2013; Trope & Liberman, 2010). The influence of psychological distance on the acceptance of modern technologies has already been confirmed at several dimensions in various studies (social, e.g., Abraham et al., 2019; temporal, Bagratuni, 2021, etc.). So far, the extent to which the mechanisms of psychological distance can be found for AVs is unexplored. Insights into how psychological distance influences AV adoption may help to identify

and target important psychological pathways to promote AV adoption, e.g., by intentionally creating or reducing psychological distance. Therefore, in the third study, we examined the role of psychological distance in the AV context, particularly at the social and temporal levels. We posed the following research questions.

- How is AV acceptance influenced by temporal and social distance?
- Can the results be found exclusively for autonomous buses or also for traditional buses?

Studies

Study 1: Predicting acceptance of autonomous shuttle buses by personality profiles: A latent profile analysis

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Abstract

Autonomous driving and its acceptance are becoming increasingly important in psychological research as the application of autonomous functions and artificial intelligence in vehicles increases. In this context, potential users are increasingly considered, which is the basis for the successful establishment and use of autonomous vehicles. Numerous studies show an association between personality variables and the acceptance of autonomous vehicles. This makes it more relevant to identify potential user profiles to adapt autonomous vehicles to the potential user and the needs of the potential user groups to marketing them effectively. Our study, therefore, addressed the identification of personality profiles for potential users of autonomous vehicles (AVs). A sample of 388 subjects answered questions about their intention to use autonomous buses, their sociodemographics, and various personality variables. Latent Profile

Analysis was used to identify four personality profiles that differed significantly from each other in their willingness to use AVs. In total, potential users with lower anxiety and increased self-confidence were more open toward AVs. Technology affinity as a trait also contributes to the differentiation of potential user profiles and AV acceptance. The profile solutions and the correlations with the intention to use proved to be replicable in cross validation analyses.

Introduction

In recent years, psychological research on the acceptance of autonomous driving has increased significantly. In local public transport, the so-called micro-transit, autonomous buses are expected to be part of everyday life as early as 2030 (Litman, 2022). Currently, autonomous micro transit pilot systems are being tested in various fields of application worldwide (e.g., Bernhard et al., 2020). In these test projects, in addition to the technological component, the psychological perspective is increasingly becoming the focus of interest. With their experience and acceptance, the passenger is crucial for establishing autonomous micro-transit systems. By adapting AVs to the needs and interests of potential users, the autonomous driving technology can become an appealing alternative to non-autonomous driving (Haboucha et al., 2017). It is becoming increasingly clear that personality traits, e.g., extraversion or self-efficacy of potential users are significant factors influencing the intention to use (ITU, Du et al., 2021; Qu et al., 2021; Venkatesh et al., 2012). To map the complexity of personality factors and thus respond best to the needs of potential users, we aim to analyze patterns in personality characteristics and identify potential user profiles from them. To the best of our knowledge, there are no extensive empirical studies on this topic until now. The goal of this study is therefore the explorative analysis and identification of profiles for

potential users of autonomous vehicles (AV) based on selected personal characteristics and dispositions.

Literature Review and Research Framework

The characteristic of the potential passenger must be taken into account when promoting the acceptance of autonomous driving systems. A vast body of research shows that intrapersonal factors contribute to AV acceptance and ITU. For example, acceptance of autonomous vehicles is significantly related to sociodemographic variables, such as gender (Lemonnier et al., 2020), age (Qu et al., 2021), region of living (Lemonnier et al., 2020), education (Yuen et al., 2022), and income (Y. Ding et al., 2022). Several previous studies consistently show that males and younger subjects are more receptive to AVs (e.g., Y. Ding et al., 2022; Dong et al., 2019). Gender effects may be due to men reporting a higher general affinity for technology and being more likely to pursue technical careers (Trapani & Hale, 2019). Women, on the other hand, attribute greater discomfort and uncertainty with technology to themselves, possibly due to stereotypical biases (Blasko et al., 2020; Koch et al., 2008). However, acceptance of new technologies such as AVs also appears to be a generational issue. Younger individuals are less concerned about this change in transportation (Charness et al., 2018), but on the other hand have greater concerns about hacking attacks (Garidis et al., 2020). Bonem et al. (2015) found that older individuals rate risks particularly high when the risk addresses health or ethics. It is possible that AV technology, in which artificial intelligence (AI) is responsible for accident-free driving and ethical decision-making, is experienced as more threatening due to its novelty (Cui et al., 2019; Sankeerthana & Raghuram Kadali, 2022). In addition, relevant differences in AV acceptance also emerge in relation to region of living. Thus, individuals from urban regions are more

likely to adopt AVs than individuals from rural regions (Deb et al., 2017). This is plausible in that people in urban regions may be less likely to own a car or parking may be more difficult in cities (Nielsen & Haustein, 2018; Nordhoff, Winter, Kyriakidis, et al., 2018). Therefore, Avs may appear attractive especially for people who have their center of living in a city. High levels of education and income are also associated with higher technology acceptance (Yuen et al., 2022). Individuals with higher education are in many cases more familiar with new technologies such as AVs due to broader knowledge of technical functions and developments (Yuen et al., 2022). In addition, high levels of education are often associated with higher socioeconomic status and income (Rojas-Méndez et al., 2017). Moreover, the often expensive technological innovations, e.g., the newest smartphones or laptops, can often only be financed if income permits. As a result, individuals with high levels of education and income often have better access to technology, which in turn favors familiarity and adoption (Rojas-Méndez et al., 2017).

In addition to sociodemographics, there is now particularly insightful evidence on personality variables in relation to the adoption of autonomous driving technology. Various studies show significant relationships between classic personality traits such as the Big Five (neuroticism, extraversion, openness, agreeableness, and conscientiousness; Costa & McCrae, 1989) and attitudes toward AVs (e.g., T. Zhang et al., 2020). As demonstrated in a study by Qu et al. (2021), individuals with high scores in extraversion and openness are more open to AVs, whereas high neuroticism scores negatively affect acceptance. However, Charness et al. (2018) also showed that particularly open-minded users are more willing to relinquish control to the AI in an autonomous vehicle. Particularly conscientious and agreeable users showed more

concern in this regard, e.g., regarding the reliability and usability of AVs (Charness et al., 2018; Qu et al., 2021).

In addition to these classical personality traits, constructs related to one's attribution of control seem to have an impact on AV acceptance. However, a look at the studies on control beliefs and self-efficacy reveals partly contradictory results. Control beliefs can be located as a construct on a dimension whose extremes are internal and external control beliefs. People differ individually in whether they generally attribute control over situations or facts to themselves (internal) or to external factors (external; Rotter, 1966). According to Choi and Ji (2015), an external control belief contributes positively to ITU. The authors explain this by the fact that, for example, people who do not feel able to participate in traffic under their control or responsibility (e.g., due to physical impairment) prefer to use autonomous vehicles as a means of transportation. Another reason for this could be that people with external control beliefs generally attribute low levels of their control to themselves and thus experience the relinquishment of control to AI as less drastic (Takayama et al., 2011). This is contrasted with a finding by Du et al.(2021) showing that high self-efficacy has a positive effect on trust in AVs and thus ITU. The authors explain this result by the fact that people with high self-efficacy prefer to accept challenges rather than avoid them and thus react more openly to AVs (Graham, 2011). Since high self-efficacy is associated with internal rather than external locus of control beliefs, the results contradict the finding of Choi and Ji (2015), who found external locus of control beliefs to be a predictor of ITU (H. Chen & He, 2014). A low general need for control also contributes positively to the ITU (Garidis et al., 2020).

One reason for the contradictory results on own control attribution might be the interaction with other personality traits. Among other things, the acceptance of AVs is

also determined by the general disposition to trust (Benleulmi & Blecker, 2017). It is plausible that individuals who have a fundamentally higher level of trust also trust AVs more strongly without needing a high level of their own experience of control. Thus, people with high general trust are more willing to use AVs (Benleulmi & Blecker, 2017). In addition, technology affinity contributes positively to trust in new technologies, which in turn lowers perceptions of potential risks (Choi & Ji, 2015). High technology confidence, in the sense of confidence in one's technological capabilities, is in turn considered a basis for trust in human-machine interaction (Jian et al., 2000). According to Venkatesh (2000), this type of trust also influences the perceived ease of use, which in turn favors the ITU of AVs (Jing et al., 2020).

Another major determinant of AV acceptance is anxiety, although the study results still differ regarding the direction of the relationship. For example, contact with AV technology can create anxiety among potential users due to the novelty of the technology (Fraedrich & Lenz, 2016). Fears about AVs can also reduce the willingness to use AVs (Hohenberger et al., 2017). Based on these results, it would be plausible to assume that high trait anxiety as a stable personality trait is also associated with low AV acceptance. In contrast, the results of Qu et al. (2021) showed a positive correlation between trait anxiety and the acceptance of autonomous driving systems. Anxious people rate the reliability of AVs higher. The authors explain these expected findings by arguing that anxious people would rather hand over control to an autonomous system because they are more afraid of human errors than AI errors (Qu et al., 2021). Regardless of the direction of the association, trait anxiety seems to play a role in AV acceptance. Similar findings also emerged for the so-called technology anxiety. Kopeć et al. (2022) found that higher technology anxiety impairs the acceptance of an autonomous working environment. This association can also be applied to AVs. Keszey

(2020) found that both fears of technology in general and specific technological fear (e.g., related to hacking attacks) have a negative impact on AV adoption.

The answer to the question which needs are important for the potential users of autonomous driving systems and how these can be satisfied is correspondingly complex and cannot be given in a generalized way. Previous research has already identified some personality traits that are predictive of ITU. As described before, it was found that both classic personality traits such as the Big Five (i.e., neuroticism, extraversion, openness, agreeableness, conscientiousness), as well as traits related to technology affinity (e.g., technology competence, acceptance, confidence, and anxiety), are positively related to the acceptance of AVs. In addition, especially variables related to self-confidence (e.g., self-efficacy expectancy, control belief), the disposition to trust, and trait anxiety have a significant effect on the acceptance of AVs. However, to the best of the authors' knowledge, no attempt has yet been made to combine these characteristics and to investigate whether typical response patterns for different types of potential users can be identified. To address interindividual requirements and expectations in AV development and to further adapt AVs to potential passengers, it is important to analyze patterns in selected characteristics of potential users and thus identify profiles. These profiles can present the complex set of characteristics and needs of potential users abstractly and at the same time allow AV providers a more differentiated perspective on their potential passengers. In other contexts, e.g., general public transport (Shrestha et al., 2017) or Bitcoin (Kang et al., 2020), user profile analysis has already been successfully applied to better understand target groups from a marketing point of view and thus to better target their needs. Thus, the analysis of different profiles is also desirable in the context of AVs, especially because this technological innovation is expected to affect the general population (Litman, 2022). The aim of this study is, therefore, to identify and

exploratively analyze profiles of potential AV users with respect to the ITU AVs. Personality, in particular, which also proved to be crucial for the acceptance of AVS in our research, is widely used for the identification of person profiles within a society (e.g., Perera & McIlveen, 2017; Rzeszutek & Gruszczyńska, 2020). Due to its relative stability, it allows reliable and consistent predictions of distal outcomes, as in our case of ITU (Diener & Lucas, 2019). Therefore, the analysis is based on variables found to be relevant to AV acceptance in previous research: the Big Five, the dispositional technology affinity variables, the self-confidence variables, disposition to trust and trait anxiety. Following the approach of Spurk et al. (2020), our study addresses the following research questions:

1. What is a meaningful and useful number of personality profiles based on which to examine the ITU of potential AV users?
2. How can the different profiles be characterized?
3. How big are the profiles?
4. To what extent is profile affiliation predictive for ITU of AVs?
5. How valid are the results?

Method

Sample

A sample of 388 volunteers (111 male, 276 female, 1 diverse) aged between 18 and 64 was recruited via different online platforms of universities, social media, and personal approach. Therefore, when we refer to bus users in our study context, we always refer to potential users, since the data were collected online and independently of actual bus use. At the same time, this allows us to identify groups of people who are less willing to use AVs. To provide the participants with a vivid and detailed idea of the ride in an

autonomous bus the participants watched a video of an autonomous bus and then answered the questionnaire. Two people were pre-excluded because they had processed less than 80 % of the questionnaire. *Table 1* shows the sociodemographic characteristics of the final sample. Participation in the study was without payment; students received course credit for participation (students must take part in studies and experiments carried out by researchers of the universities).

Table 1

Sample characteristics based on gender

Characteristics	Total (*N* = 388)	Male (*n* = 111)	Female (*n* = 276)	Divers (*n* = 1)
Average Age (SD)	26.19 (7.25)	26.67 (6.05)	26.02 (6.69)	22.00 (0.00)
Training (%)				
No degree	1 (0.3 %)	1 (0.9 %)	-	
High School Diploma, i.e., German Mittelschulabschluss [a]	1 (0.3 %)	-	1 (0.4 %)	
High School Diploma, i.e., German Realschulabschluss[a]	13 (3.4 %)	6 (5.4 %)	7 (2.5 %)	
University of applied sciences entrance qualification, i.e., German Fachhochschulreife	49 (12.6 %)	17 (15.3 %)	32 (11.6 %)	
University entrance qualification, i.e., German Abitur	274 (70.6 %)	76 (68.5 %)	197 (71.4 %)	1 (100 %)
Academic degree, i.e., bachelor, master or higher	19 (4.9 %)	3 (2.7 %)	16 (5.8 %)	
No answer	22 (5.7 %)	5 (4.5 %)	17 (6.2 %)	
Annual income (%)	9 (2.3 %)	3 (2.7 %)	6 (2.2 %)	
< 20 000 €				
20 000 € – 30 000 €	124 (32.0 %)	22 (19.8 %)	101 (36.6 %)	1 (100 %)
30 000 € – 40 000 €	80 (20.6 %)	25 (22.5 %)	55 (19.9 %)	
40 000 € – 50 000 €	71 (18.3 %)	27 (24.3 %)	44 (15.9 %)	
50 000 € – 60 000 €	37 (9.5 %)	14 (12.6 %)	23 (8.3 %)	
> 60 000 €	17 (4.4 %)	7 (6.3 %)	10 (3.6 %)	
No answer	13 (3.4 %)	5 (4.5 %)	8 (2.9 %)	

Note. [a] The terms correspond to German school diplomas. Mittelschulabschluss and Realschulabschluss are equivalent to a High School diploma after nine and ten years.

Instrument and profile indices

Based on the current state of research, we selected 16 variables as possible indices for personality profiles by which the ITU is to be predicted: 15 of the indices refer to personality, and one variable to age. Age has a significant effect on the acceptance of AVs (Charness et al., 2018). We, therefore, consider it useful to include age when analyzing potential user groups, because it can contribute to a deeper understanding of characteristics of potential users. This combination should later enable us to place the ITU of potential customers on AVs in the context of individual personality characteristics. The questionnaires and instruments used are shown in *Table 2*. A detailed overview of all items and scales used in the study is available in the OSF repository, https://osf.io/87vr4/?view_only=83b3b4922da54a37861efee7c4d1142e (Schandl & Hudecek, 2023a). The basis for the present study was the data of a larger survey on the first impression of autonomous vehicles. Therefore, in addition to the variables mentioned, the following variables were collected: education, area of work, working hours, income, political orientation, neighborhood, motivation for AV use, AV knowledge, expectations, and suggestions for improvement (all self-developed), transport usage habits (adapted from Nordhoff et al., 2019), Satisfaction-with-Travel-Scale (Ettema et al., 2011), facilitating conditions (van der Laan et al., 1997), performance expectations (based on Nordhoff, Winter, Madigan, et al., 2018), effort expectations (based on Venkatesh et al., 2012), service and vehicle characteristics (based on Nordhoff et al., 2019), social influence (based on Venkatesh et al., 2012), hedonic motivation (based on Venkatesh et al., 2012), the perceived benefits and risks (Liu et al., 2019), the willingness to share (Nordhoff et al., 2019) and the perceived safety (based on Z. Xu et al., 2018).

Table 2

Used constructs and inventories with item characteristics, Cronbach's Alpha and source

Construct / Inventory	Item Count	Range	α	Source	Example Item
Age	1				
Neuroticism	6	1 (strongly disagree) to 5 (strongly agree)	.84	NEO-FFI-30, Körner et al., 2008	I often feel tense and nervous.
Extraversion	6		.75		I am a cheerful, good-humoured person.
Openness	6		.80		I often enjoy playing with theories or abstract ideas.
Agreeableness	6		.70		I always try to act considerate and sensitively.
Conscientious-ness	6		.78		I keep my things neat and clean.
Self-efficacy	3		.85	Allgemeine Selbstwirksamkeitskurzskala (ASKU), Beierlein et al., 2012	I can cope well with most problems by my own efforts.
Internal Control Belief	3		.62	Jakoby & Jacob, 1999	I like to take responsibility.
External Control Belief	3		.47		Success often depends less on performance and more on luck.
Trait Anxiety	3	1 (strongly disagree) to 7 (strongly agree)	.78	Skalen zur Messung manifester Angst (MAS); Lück & Timaeus, 1969	I am almost always afraid of something or someone.
Disposition to Trust	6		.91	Gefen & Straub, 2004	I generally trust other people.
Technology Acceptance	4		.92	Kurzskala Technikbereit-schaft, Neyer et al., 2012	I am very curious about new technical developments.
Technology Competence	4		.91		When dealing with modern technology, I am often afraid of failing.
Technology Control Belief	4		.81		Whether I am successful in using modern technology depends mainly on me.
Technology Anxiety	3		.63	Based on Venkatesh, 2000	New technology doesn't scare me at all.
Trust in Technology	2		.81	Based on Jian et al., 2000	I trust new technologies.
Intention to Use	1			Self-developed based on Venkatesh et al., 2012	I plan to use autonomous shuttles like the People Mover in the future if they were available to me.

Note. α: Cronbach´s Alpha

Procedure

The data was collected via an online questionnaire using the *soscisurvey* online application. Driverless buses are too rare in Germany to assume that the respondents have any experience in this area. The video format has already proven to be a useful alternative to the presentation of AV technology in previous studies (e.g., Bjørner, 2015). For this reason, participants who were interviewed online watched a video of 4.5 minutes of a trip with the autonomous bus before answering the questionnaire to get the most comprehensive first impression of the bus possible. This video provides the perspective of a passenger boarding an autonomous bus with other passengers, looking around the shuttle, sitting down, riding in it through several stops, getting off, and watching the autonomous bus drive away. The video is accessible in the online repository. Before processing the actual questionnaire, all participants were informed about the study objective and the protection of their data and then had to confirm their consent for participation. The datasets generated during the current study are available in the OSF repository, https://osf.io/87vr4/?view_only=83b3b4922da54a37861efee7c4d1142e (Schandl & Hudecek, 2023a).

Statistical analysis

The focus of this study is on a Latent Profile Analysis with subsequent analysis of the relationship between profile affiliation and ITU as well as a validation of the results. For preliminary and descriptive analyses, we used *SPSS* (version 26). The LPA was conducted in *R* (Version 4.1.3; R Core Team, 2022) with the *tidyLPA*- and the *caret-package* via Gaussian mixture modelling (Rosenberg et al., 2018). Possible outliers were checked in advance in boxplots. We did not exclude outliers because the values were within the plausible range, did not represent error outliers, and thus are part of the

normal distribution in the population (Leys et al., 2019; Wiggins, 2000). The graphical analysis indicated the normal distribution of the residuals. All data were z-standardized in advance to determine the interpretability of the profiles.

We opted for an LPA followed by regression to investigate differences in ITU in the identified profiles. LPA is a person-centered procedure that identifies latent profiles based on similar response patterns. In contrast to factor or regression analytic methods, LPA focuses on relationships between individuals rather than relationships between variables (Bauer & Curran, 2004). This enables the probabilistic assignment of each potential user to the profile with the best fit based on the individual response pattern (Tein et al., 2013). Thus, LPA provides a differentiated insight into profile-specific characteristics within a diverse network of variables. The method is therefore particularly well suited for our goal of identifying and distinguishing personality profiles of potential users (Howard & Hoffman, 2018; Woo et al., 2018). The approach allows a subsequent description of various empirically determined personality profiles in relation to the ITU. Our study thus contributes to mapping the knowledge about the characteristic of potential users as well as their needs about AVs in a differentiated and multidimensional manner and on this basis to be able to respond more purposefully to their needs, e.g., in the marketing of AVs. For later validation of the profile solution, we randomized the dataset into a training dataset (80 %, $n = 315$) and a test dataset (20 %, $n = 73$). To identify the correct number of profiles, we calculated several models in *R* based on the training data set, each with a different number of profiles. We followed the recommendation of Nylund-Gibson and Choi (2018) and started with the model calculation for a single latent profile, after which we gradually increased the number of profiles. We ended this increase after the four-model solution when the profile size fell below the limit of 5 % of the data set for the first time. This procedure, which is

common in LPA research (e.g., Kircanski et al., 2017; Ricketts et al., 2018), preserves the practical applicability and interpretability of the profiles because small profile sizes are considered difficult to replicate. We compared the resulting four profile solutions based on predefined criteria with regard to their model fit (Nylund-Gibson & Choi, 2018; Ricketts et al., 2018). We followed the recommendation of Lubke and Neale (2006) and considered the Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) adapted to the sample size in the form of the Sample-Size-Adjusted Bayesian Information Criterions (saBIC), where low values suggest a better model fit. We also examined the Lo Mendell Rubin Likelihood Test (LMR; Lo et al., 2001). This compares the solution of k profiles with a solution with k-1 profiles. A significant test indicates a better fit of the model with k profiles (Lo et al., 2001; Pastor et al., 2007). The entropy was additionally tested as a measure of the separation reliability of the profiles (Clark & Muthén, 2009). It reflects the mean probability that a person can be correctly classified based on their response pattern within the model with values from .80 being considered very separable (Araújo et al., 2018; Celeux & Soromenho, 1996; Muthén, 2008; Tein et al., 2013). In addition to the statistical parameters, we considered all model solutions under the condition of theoretical plausibility and applicability (Celeux & Soromenho, 1996; Clark & Muthén, 2009). All characteristic values are interpreted with regard to the smallest profile size. To maintain the replicability and practicability of the profile solutions, the minimum accepted profile size is set at 5 % of the data set. Solutions with profiles below this minimum size were declined according to the recommendation of Ferguson et al. (2020). In contrast, profiles above the 5 % threshold indicate remarkable proportions of the profile in the total sample and, accordingly, the relevance of the user group. Subsequently, the procedure was repeated using the test data set to check whether the profile solution

found can be replicated. Based on the determined profile solution, the test persons were assigned to the profile to which they are most likely to belong according to their response pattern. In complementary analyses, the identified profiles were examined descriptively for differences in gender, region of living, share, degree, income, public transportation use, car ownership, and driver's license ownership. We refrain from introducing names for the profiles because bare designations would be too general and too simple given the probabilistic, complex response patterns. Instead, we assign numbers (1 to 4) to the identified profiles.

To test the predictive validity of the personality profiles found in relation to the ITU, a regression under 10-fold cross-validation was performed (Reguera-Alvarado et al., 2016). We again randomly split the LPA training data set and performed the regression with a new training data set (80 %, n = 253), and validated the solution using a new test data set (20 %, n = 60). To ensure the highest possible validity within the data sets, we also carried out a 10-fold cross-validation in both data sets. The 10-fold cross-validation is a machine learning method in which the data set is randomly divided into ten blocks. Nine of the blocks would again be used together as a training data set, the tenth block serves as a test data set to validate the results. This procedure was repeated ten times, each time a different block becomes the test data set. Repeating it several times increases the accuracy of the measurement (Wong & Yeh, 2020). In this way, we performed a regression with the independent variable profile and the dependent variable ITU. The mean squared error provides information about the validity of the analysis results as the average distance between the result coefficients of the training and test data sets (Steyerberg et al., 2001).

Results

Latent Profile Analysis

Selection of the most suitable profile solution

The means, standard deviations, and correlations of the variables are shown in *Table 3*. Using latent profile analysis, we identified the solution that best fits the data among several possible profile solutions (training data set) and then validated this solution (test data set).

We first analyzed a model with one profile within the training data set and gradually added a profile, observing the change in the profile indices. We ended this procedure after the five-profile solution when the smallest profile size fell below the predetermined limit of 5 %. *Table 4* shows the fit indices for the different profile solutions.

Table 3

Correlations of the central variables studied

Variable	*M*	*SD*	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
1. Gender	0.72	0.47																	
2. Age	26.19	7.25	-.05																
3. ITU	5.14	1.28	-.12	.02															
4. Neuroticism	1.63	0.79	.24**	-.14**	-.14**														
5. Extraversion	2.69	0.61	.01	.04	.19**	-.33**													
6. Openess	2.43	0.75	.05	.05	.13**	-.04	.09												
7. Agreeableness	2.88	0.62	.24**	-.03	.00	-.09	.10*	.02											
8. Conscientiousnes	3.23	0.55	.14**	-.02	.08	-.25**	.22**	.03	.24**										
9. Self Efficacy	3.96	0.58	-.07	.05	.17**	-.37**	.30**	.18**	.02	.42**									
10. Internal Control Belief	3.84	0.62	.15**	-.02	.00	.01	.02	-.07	.03	-.02	.-.01								
11. External Control Belief	3.39	0.64	-.04	.03	.10*	-.03	-.02	.04	-.02	-.04	.05	.25**							
12. Trait Anxiety	4.10	1.36	.26**	-.21**	-.11*	.61**	-.20**	-.05	.07	-.01	-.20**	.04	-.03						
13. Disposition to Trust	4.50	1.09	.07	.01	.11*	-.10	.30**	-.00	.27**	.08	.10*	.05	-.02	-.10					
14. Technology Acceptance	4.59	1.43	-.12**	-.01	.25**	-.17**	.24**	.08	-.10*	.07**	.22**	.03	.09	-.11*	.05				
15. Technology Competence	5.78	1.09	-.13**	-.09	.19**	-.27**	.10	.04	.14**	.16**	.19**	.01	.05	-.19**	-.01	.35**			
16. Technology Control Belief	5.22	0.95	-.11*	-.05	.20**	-.12‘	.06	.07	.02	.12**	.24**	-.01	.02	-.07	.10	.29**	.29**		
17. Technology Anxiety	2.64	0.99	.14**	.02	-.30**	.28**	-.22**	-.02	-.06	-.16**	-.26**	-.01	-.02	.22**	-.07**		-.63**	-.39**	
18. Trust in Technology	5.02	1.04	.03	-.01	.36**	-.11*	.16**	.01	.05	.11**	.18**	09	.11*	-.14**	.33**	.40**	.16**	.26**	-.41**

Note. $N = 388$;
* $p < .05$;** $p < .01$

Table 4

Fit indices of the different LPA profile solutions for the training and test data set

Record	Model	AIC	BIC	saBIC	LMR	Entropy	Smallest profile (%)
Training	1	14260	14380	14278	-	1	1
(*n* = 313)	2	13751	13934	13779	514.17**	.79	45.0
	3	13624	13871	13662	151.23**	.80	21.4
	4	13515	13826	13562	136.11**	.83	11.5
	5	13368	13743	13426	170.13**	.86	4.5
Test	1	3453	3528	3427	-	1	1
(*n* = 75)	2	3364	3477	3323	115.19**	.84	.37
	3	3319	3472	3264	74.31**	.95	.16
	4	3328	3520	3259	22.29**	.89	.13
	5	3297	3529	3213	61.31**	.89	.04

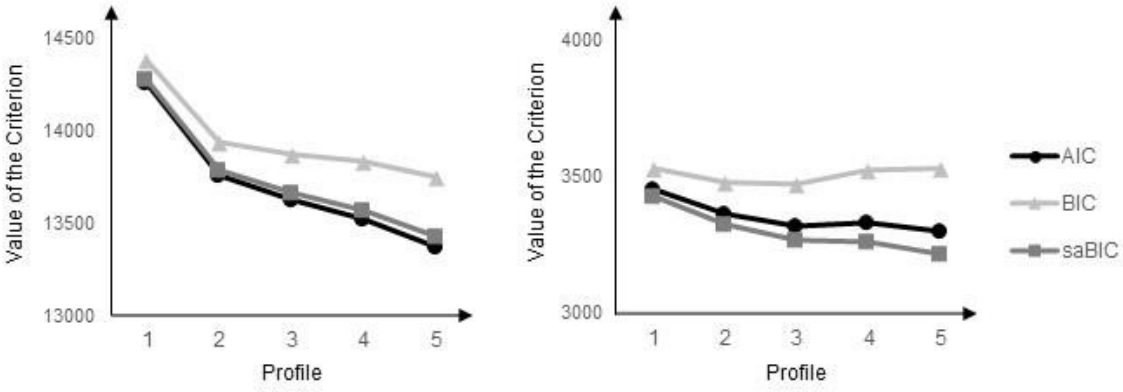
Note. *N* = 388; LPA = Latent Profile Analysis; AIC = Akaike's Information Criterion; BIC = Bayesian Information Criterion; saBIC = adjusted BIC; LMR = Lo Mendell Rubin Likelihood Ratio Test.
** *p*-Value < .01

Thus, the saBIC, the BIC, and AIC decreased as the number of profiles increased, without reaching a low point. We found a similar pattern for the LMR, which reached significance for all profile solutions, indicating a robust model fit. This is a known phenomenon in the literature on LPA and is caused by the fact that adding further profiles provides more information (Masyn, 2013). There is no fixed value above which a reduction in the information criteria is considered insignificant, which affects the interpretability of the indices (Ferguson et al., 2020). Therefore, in these cases, the course of the indices is visualized in so-called Elbow plots (Nylund-Gibson & Choi, 2018). The kink or elbow of the plot reveals the profile solution from which the decrease of the index flattens out. This profile solution, therefore, promises the highest possible, if not the maximum, model fit with the simultaneous economy of the profiles (Masyn, 2013). Therefore, based on the results, during the evaluation we decided to consider elbow plots for the information criteria, which are shown in *Fig. 1a*.

Figure 3

Elbow plot for fit indices across the profile solutions for training analysis (a) and test analysis (b)

a b



The graph follows a consistent downward trend. A slight elbow can be seen for the model with two profiles, suggesting that the two-profile solution fits better. This finding was contrasted with the analysis of the smallest profile size. While the smallest profile in the two-profile solution accounted for 45.0 %, the smallest profile in the three-profile solution at 16.0 %, and in the four-profile solution at 11.5 %, each still account for a substantial portion of the data set. With the addition of a fifth profile, the share of the smallest profile dropped to 4.5 % of the data, i.e., below the predefined 5.0 % limit. Entropy exceeded .80 as a measure of classification confidence only for the four- and five-profile solutions above which it is classified as highly discriminative (Celeux & Soromenho, 1996; Muthén, 2008; Tein et al., 2013). Our goal to identify personality profiles of potential users as differentiated and precisely as possible while maintaining economic efficiency is thus best met by the four-profile solution since it has a high degree of classification reliability. In addition, the fourth profile takes up significant proportions that we want to consider. Given the continuously decreasing information criteria and the permanently significant LMR value, we opted for the four-profile solution in the training data set.

Validation of the profile solution

To validate the profile solution, we conducted the LPA analogously with the test data set. The fit indices are shown in *Table 4*. As with the training data set, we ended the analysis with the four-profile solution, in which the smallest profile fell below the minimum share of 5 % for the first time. The analysis of the fit indices also revealed a similar picture that supports our decision for the four-profile solution. Again, the LMR value remained significant across all solutions. The AIC and the saBIC decreased as the number of profiles increased (see elbow plot in *Fig. 1b*). In contrast to the training analysis, the BIC for the three-profile solution reached a low point. The BIC was therefore explicitly in favor of the three-profile solution, as was the Elbow plot of the AIC and the saBIC. The entropy, whose value was recognizably higher than those of the training analysis, exceeded the critical value of .80 for all profile solutions and thus confirmed the classification reliability. In addition to the three-profile solution (16.0 %), the smallest profile still took a remarkable share in the four-profile solution with 13.3 %. With 4.0 %, the size of the fifth profile was again below the acceptance threshold. Although the information criteria of the test data were in favor of the three-profile solution, the addition of the fourth profile granted a higher differentiation with at the same time very good classification reliability and represented with its size of 13.3 % a remarkable share of the data. Under these aspects, the choice fell again on the four-profile solution. With the aforementioned limitations regarding the information criteria, our profile decision thus proved to be replicable and valid.

Description of profiles

The LPA allows the probabilistic classification of each person to a profile based on their response pattern. In the next step, each training data set was thus assigned to the profile to which it belongs with the highest probability according to its response pattern.

The four identified profiles were then compared and interpreted based on their underlying personality traits. *Fig. 2* provides an overview of the mean variable expressions of the four different profiles. All four profiles differ in their characteristics. This supports the decision that the number of four profiles is necessary to represent the profiles in a sufficiently differentiated way. We refrain from introducing names for the profiles because naming would be too simplistic with regard to the probabilistic, complex response patterns.

Profile 1 accounted for the smallest proportion of the examined sample, with $n = 36$. It was characterized by increased levels in the anxiety-related scales (neuroticism, trait anxiety, and technology anxiety), while the remaining variables were rather low in comparison. Complementing the high anxiety, individuals most likely to be assigned to profile 1 exhibited lower-than-average self-efficacy and internal control beliefs. The group also turned out to have a rather low affinity for technology, although the scores of the technology-related variables were within one standard deviation. The group with profile 1 was with $M = 24.89$ ($SD = 4.83$) years the youngest group. Further analysis of sociodemographics showed that this group also had the highest proportion of females (86.11 %) and the highest educational qualification ($M = 5.02$, $SD = 1.04$). At the same time, the proportion of people with a car (55.56 %) or a driver's license (83.33 %) was the lowest in this group. This is consistent with the fact that the proportion of individuals from urban regions was the highest (80.56 %).

Profile 2 ($n = 66$) was also characterized by increased anxiety-related scores. Unlike profile 1, neuroticism and trait anxiety were less pronounced. Rather, this profile showed the highest values of technology anxiety. This corresponded with a low affinity for technology, especially with a strikingly low technology competence. In addition, individuals most likely to be classified to profile 2 attributed relatively low levels of

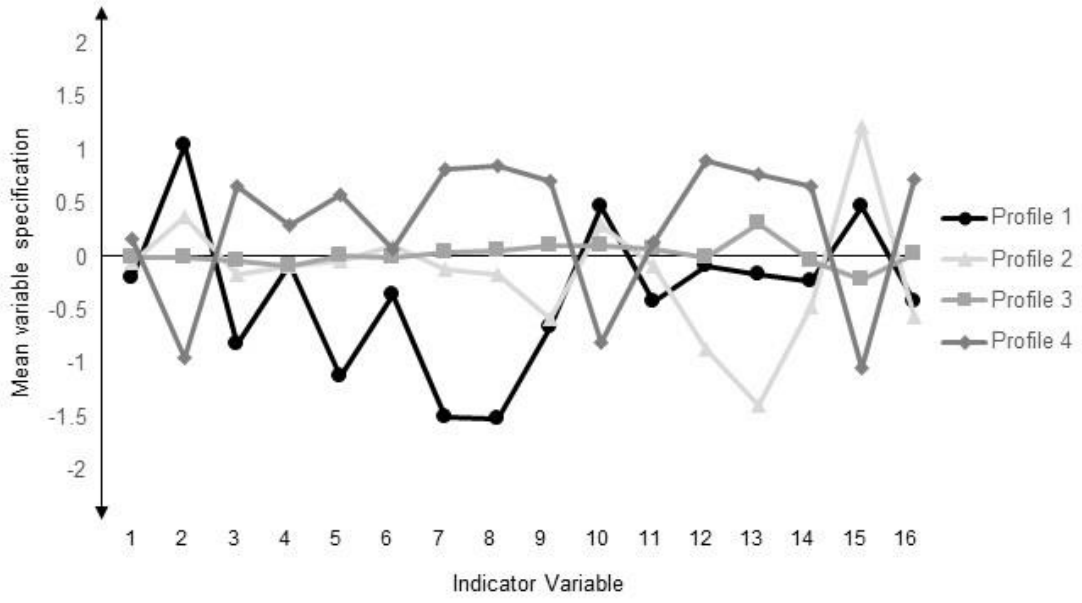
control to the external environment. At 25.95 (*SD* = 7.61) years, the age of the associated individuals was in line with the sample average, with again a relatively high proportion of women (80.30 %). Individuals most probably to be assigned to profile 2 also reported the highest level of acceptance of using public transportation compared to the other profiles (*M* = 4.22, *SD* = 1.73). They showed the largest proportion of people from rural areas (31.82 %).

The response pattern of profile 3 (*n* = 145) was primarily characterized by average expressions in all variables. Nevertheless, it showed slightly increased technology competence and relatively low technology anxiety, with both expressions within one standard deviation. The age of the group of individuals most probably to be associated with profile 3 was also close to the sample average with *M* = 26.26 (*SD* = 7.16). Further analyses revealed that this group enjoyed public transportation use the least compared to the other profiles (*M* = 3.52, *SD* = 1.74).

Profile 4 (*n* = 66) showed a response pattern that was opposite in its characteristics to the pattern of profile 1. It was noticeably less anxious. A particularly noteworthy difference was the strikingly low technology anxiety and high technology affinity of profile 4, which clearly distinguished it from the first two profiles. This corresponded with increased openness to change, extraversion and conscientiousness. In addition, self-efficacy and internal and external control beliefs were higher in this profile. The group of individuals who are most likely to be classified to profile 4 was also the oldest group on average (*M* = 27.55, *SD* = 7.75) with the highest proportion of men (42.42 %) and the highest income (10.61 % earned more than 60,000€). Individuals with this profile were more likely to own a driver's license (95.45 %) and own a car (77.27 %) compared to other profiles.

Figure 4

Response patterns of the four profiles showing differences across the z-standardized indices



Note. N = 315; Profile 1: n = 66, Profile 2: n = 36, Profile 3: n = 66, Profile 4: n = 145; 1 = Age, 2 = Neuroticism, 3 = Extraversion, 4 = Openness, 5 = Conscientiousness, 6 = Agreeableness, 7 = Self-efficacy, 8 = Internal Control Belief, 9 = External Control Belief, 10 = Trait Anxiety, 11 = Disposition of Trust, 12 = Technology Acceptance, 13 = Technology Competence, 14 = Technology Control Belief, 15 = Technology Anxiety, 16 = Trust in Technology.

Relationship analysis between profile affiliation and ITU

We next used regression analyses to check the extent to which the four profiles were predictive of ITU. For this purpose, we again divided the training data set used in the LPA into a new training data set (80 %, n = 253) and a new test data set (20 %, n = 60), the latter serving for validation purposes. Within the training data set, we used ten-fold cross-validation to validate the results. Profile membership significantly predicted ITU, $F(3, 249) = 7.36$, $p < .001$, $R^2 = .08$.

Compared to profile 1, individuals most likely to be assigned to profile 2 had a 0.33 lower ITU, $t(249) = -1.15$, $p = .252$, and individuals most likely to be assigned to

profile 3 had a 0.18 higher ITU, $t(249) = 0.69$, $p = .492$, although the differences were not significant. For profile 4, ITU was significantly higher by 0.78, $t(249) = 2.75$, $p = .001$. The ITU of individuals who are most probably to be classified to profile 2 was again significantly different from the ITU of individuals considered most likely to belong to profile 3, $b = 0.51$, $t(249) = 2.46$, $p = .015$, and from the ITU of individuals considered most likely to be assigned to profile 4, $b = 1.12$, $t(249) = 4.61$, $p < 001$. The difference between profile 3 and 4 was also significant, with the ITU for profile 3 being 0.61 lower, $t(249) = -2.98$, $p = .003$. Thus, profile 4 showed the highest ITU, followed by profiles 3 and 1. Persons most likely to be assigned to profile 2 had the lowest ITU.

Using the regression coefficients, we next predicted the ITU for the test data set as a function of profile membership. The RMSE revealed an average difference of 1.26 between the predicted and the actual value of ITU (James et al., 2021).

Discussion

Summary and practical implications

Our study aimed to identify personality profiles and their predictive power in relation to the ITU. For this purpose, we have performed an LPA with subsequent validation. Our study differs from previous research in several aspects. First, we did not focus on a specific area of personality but tried to depict the personality profiles as comprehensively as possible. Based on current research and theories on AVs, we selected the most crucial personality traits for the ITU and used them in an LPA as indices for rich, meaningful profiles. Second, we tested these profiles directly for their predictive power for AVs' ITU to ensure their practical relevance. As a result, our profiles have already been confirmed for the first time in their practical applicability concerning AVs. Third, we underpinned each of our analysis steps with a validation

analysis to ensure the reliability of our results and thus the quality of our study. The validation confirmed our findings almost completely and thus supports the replicability and validity of our results. We put great emphasis on differentiating the profiles as much as possible while maintaining clarity and practicality. We were able to identify four personality profiles and placed them in the context of their ITU. The profiles have characteristic differences, but also similarities. Regarding ITU, it is relevant to which of the identified profiles a potential user belongs. The profiles and their predictive power for the ITU proved to be valid in our analyses.

The core and largest contribution of our study was the identification of four profiles that differed in their personality characteristics and their ITU. Particularly important indices of profile affiliation were the variables of self-confidence (i.e., self-efficacy, internal and external control belief), general anxiety (i.e., neuroticism, trait anxiety, and technology anxiety), an affinity for technology (i.e., technology acceptance, competence, and control belief), technology anxiety and trust in technology. This resulted in four different profiles.

People most probably to be assigned to profile 1 were characterized by a high level of general anxiety and insecurity, with a slightly below-average affinity for technology and increased technology anxiety. Thus, self-insecurity in this group might have a negative impact on perception, or new technologies could be more likely to be experienced as threatening or risky. AV marketing could address the needs of this relatively anxious group by emphasizing the safety-related benefits of AVs (e.g., reducing the likelihood of accidents; Yu et al., 2019). In this context, it should be made clear to what extent AV technology contributes positively to road safety. To reduce potential fears with corrective (positive) experiences, it is necessary to encourage this group to actively use AVs. However, perhaps due to general anxiety, people who are

most likely to be classified to profile 1 may be more likely to avoid AV use. It is interesting to note that profile 1, which in our study was associated with the proportionally lowest car and driver's license ownership, was associated with a comparatively low ITU of autonomous buses. This link is surprising because it could be expected that people with reduced possibilities for private mobility are more likely to use public transport services such as autonomous shuttle buses. It is possible that people most likely to be associated with profile 1 are less familiar with autonomous driving assistance systems (e.g., parking assistant in private cars) due to lower car use and are therefore also more skeptical of the autonomous technology. AV providers should accordingly create ride offerings that are as low-threshold as possible and promise high utility for the group so that the benefits of the ride outweigh the costs of anxiety. Autonomous buses, for example, could be offered temporarily or permanently as a free alternative to paid public transit. Transit agencies could also use reinforcement mechanisms, such as distributing small reinforcing giveaways at the end of a test ride (Angermeier et al., 1994). Similarly, autonomous buses could be offered as free transportation to positively associated destinations, e.g., to the swimming pool or cinema, to generate or increase a positive perception of the bus trip. For this group in particular, a temporary deployment of service personnel in the bus interior could also make the switch to AV technology easier, to mitigate the potentially anxiety-inducing transition to driverlessness (Dong et al., 2019)

In contrast to profile 1, profile 2 was characterized less by general anxiety and more by strong technology anxiety and a low affinity for technology. The external control belief was low (analogous to profile 1). It is possible that individuals most probably to be classified to profile 1 and 2 attributed less control to the external AI technology than to themselves and were therefore less convinced of AVs. To give

potential users control options in the autonomous bus, warning systems could be installed in buses, for example, so that passengers can contact the transport operations center in an emergency (Dong et al., 2019). Nordhoff et al. (2020) have shown in a qualitative setting that an emergency button inside the vehicle contributes to the perceived safety in autonomous buses. Information on driving safety and AV functionality could also be helpful for potential users who are most likely to be associated with profile 2. Manufacturers could provide training to help users to better understand AVs and reduce potential technology anxiety. Compared to the profile 1 group, however, the focus in this group should be on providing simple and understandable information, taking into account the low affinity for technology. Manufacturers should also make the handling of AVs as intuitive as possible due to the lower level of technical competence. They should also counter the low confidence in new technologies by making AVs as predictable as possible for this group, e.g., by using monitors inside the vehicle that transmit the stimulus detection and response of the AV sensors in real-time (Yuen et al., 2022). In addition, transit agencies should focus primarily on reliable, trusted manufacturers to increase the AV trust of the technology-critical group (Yuen et al., 2022).

For profile 3, a relatively average response pattern emerged across the variables, with slightly increased technology competence and slightly decreased technology anxiety. People who are most probably to be classified to profile 3 showed an average ITU, although they were less likely in general to use public transport. It is possible, therefore, that the ITU for autonomous cars would be even higher than in our study related to autonomous buses. This group is thus likely to be more of a target group for autonomous cars. Overall, people who are most likely to be classified to profile 3 can nevertheless be expected to adopt autonomous buses. From a marketing perspective,

little consideration of potential fears or skepticism is necessary according to our model. Rather, this group could be further encouraged in their motivation to use AVs by highlighting possible benefits and the fun of driverless driving, e.g., in advertising. However, no in-depth knowledge of AV technology should be assumed.

Profile 4 differed from profile 1 in almost all variables. People most likely to be associated this profile are characterized by pronounced self-confidence, low anxiety, and a high affinity for technology in every respect. It seems plausible that members of profile 4, i.e., people who are more likely to have higher self-confidence on average attribute better coping skills to themselves and are less anxious. As a result, they may be more open to new technology. Accordingly, this profile group was most likely to use AVs. Complementary to profile 1, which had a comparatively low ITU with the lowest proportion of car and driver's license owners, we found the highest ITU for profile 4 with the highest proportion of car and driver's license owners. It is possible that people most likely to be assigned to profile 4 (in line with our rationale for profile 1) have more experience with autonomous driving assistance systems and are therefore more open to autonomous driving. Another explanation for the comparatively high ITU may be that people most likely to be associated with profile 4 had on average the highest income and thus have better access to (often expensive) new technologies or are more familiar with them (Gallo et al., 2022; Yuen et al., 2022). Given their high extraversion and openness, persons with profile 4 could be further encouraged to use AVs by highlighting social and sustainable aspects of autonomous ridesharing services. With their openness to technologies and AVs, this group also has great potential to act as a multiplier for AVs. I. Sharma and Mishra (2022) showed in their study that peer influence can have an even greater impact on AV adoption than media marketing. Accordingly, individuals who are most likely to be assigned to profile 4 could be

suitable for introducing skeptical target groups, such as people who are most probably associated with profiles 1 and 2, to AVs and motivating them to use it. This could be both, for example, in private or via public reports of positive experiences in social media.

It is noteworthy that our profiles, taken individually and also in their overall constellation, provide a thoroughly consistent, coherent picture. The characteristic response patterns of the single profiles follow a logical, reasonable constellation, e.g., for the positive association between anxiety- and insecurity-related variables. Overall, the four profiles form a holistic pattern in that they complement each other in a meaningful way and can be clearly differentiated from each other. Thus, our profiles are not only plausible in their respective logic, but they also complement each other to form a comprehensive overall concept. Overall, the four profiles showed a very heterogeneous pattern of characteristics and willingness to use AVs. Specially for profiles 1 and 2, anxiety was still associated with a low ITU. These results are a sign that the transition from conventional vehicles to AVs must be gradual to pick up AV-skeptical groups and get them accustomed to the new technology. A too abrupt changeover could lead to overwhelming people most likely to be associated with profile 1 or 2 and thus frustrating them right from the start. Manufacturers and public transport operators should therefore not implement the system too quickly and should define specific measures in advance to meet the needs of each of the four profile groups.

Limitations and outlook

To be able to classify the results of our study in a well-founded manner, possible limitations of our study must be reflected, too. First, it should be noted that our sample was not balanced in terms of gender, age, or experience with AVs. To ensure a meaningful analysis of potential users, we aimed for the largest possible sample, for

which we were dependent to a significant extent on the recruitment of students who completed the study participation as part of their studies. This is due to the relatively young sample and is presumably also responsible for the predominance of female participants due to the focus on psychology Particularly due to the limited age variance, our profiles show relatively homogeneous age structures. This made it difficult for us to interpret the profiles in terms of age differences. We were therefore not able to address differences, e.g., in technology affinity, which may have been caused by age (Blut & Wang, 2020). To further deepen the research on profiles of potential AV users, the profiles should be considered in future studies in samples with greater age variance. Due to the high proportion of participants with a comparatively high level of education, it can also be assumed that the sample tends to have more knowledge or experience with new technologies and was therefore relatively open to AVs (Y. Ding et al., 2022). In addition, several studies showed that different cultures differ in their AV acceptance. For example, Asian areas show higher acceptance of AVs than European areas, possibly due to a higher willingness to accept circumstances (e.g., AV adoption), especially if they benefit society (Potoglou et al., 2020; Yun et al., 2021). We, therefore, consider it important to replicate the study in different socio-demographic contexts and, in addition, to examine the cultural generalizability through studies in other countries. Furthermore, the study findings should be verified under real-life conditions as soon as autonomous buses are widely available. In our study, the recruitment of test persons under real conditions with the desired sample size proved to be almost impossible due to the anti-Coronavirus measures applicable at the time of the survey and the limited availability of autonomous shuttle buses. For this reason, data was collected online regardless of whether individuals had prior experience with autonomous buses. This enabled us to also survey individuals who would not use autonomous buses and to

assess them in terms of their personalities. However, our study thus refers exclusively to potential and not actual users. This must be taken into account when interpreting the results. As soon as autonomous buses are available on a large scale, this study should be conducted with actual users. To provide the participants with an impression of driving an autonomous bus that is as close to reality as possible, we opted for a sample, which was shown a video of the autonomous bus. In previous studies, this type of presentation has also proven to be representative (e.g., Lemonnier et al., 2020) and ensures an equal experience base across all participants (Kettle & Lee, 2022). However, we cannot guarantee that relatively abstract technologies such as AI and AVs have been sufficiently illustrated by the videos in this study. It will be the necessary task of future studies to investigate this question.

In terms of statistical analysis, our studies have the characteristic limitations of LPA. On the one hand, LPA is a probabilistic procedure. Therefore, the results of the LPA represent probabilities and not absolute values. Our class assignments are highly likely to apply, but LPA does not guarantee the correctness of our solutions. LPA enabled us as a procedure to initially simplify complex personality dimensions by forming profiles to derive practical implications for the introduction of AVs. However, it must also be noted that this procedure entails a loss of information in two aspects: First, in order to perform the regression, it was important to assign each subject to the profile to which he or she belongs with the highest probability based on the personality pattern (Clark & Muthén, 2009). However, the profile assignment means that this probability no longer can be taken into account in the subsequent regression. For example, if a person has a probability of .55 of belonging to Profile 3, he or she will be assigned to that profile in the same way as a person whose probability of belonging to Profile 3 is 1.00. In the subsequent regression, both persons are counted identically as

belonging to profile 3, regardless of what the original assignment probability was (Clark & Muthén, 2009). Second, profile affiliation represents a simplification of a previously more complex response pattern. In the regression, we deliberately left the level of personality variables and only considered profile affiliation to meet our demand for complexity reduction. The pure profile affiliation does not reveal the extent to which the respective personality variables influence the ITU. However, this was not the goal of the study because the associations of the selected personality variables with ITU have already been investigated in previous research. Since the specific associations between the personality variables and ITU can be interesting for the interpretation of the results, we have provided a correlation matrix in Table 3 in the appendix, from which the associations between the examined constructs can be seen. In this context, we would also like to point out that profile affiliation was indeed predictive of ITU in our study. However, as in any regression, these trends are not exempt from variation. Thus, when we assign an individual to the profile to which he or she is most likely to belong based on his or her response pattern, our results allow us to make predictions but not absolute statements about expected ITU. Regarding the model decision, it must be noted that most our information criteria did not reach a low point for any of the model solutions considered and that the likelihood parameters remained significant. This suggests that each additional profile provided insights. According to Nylund-Gibson and Choi (2018), however, the steady decline can also be an indication that the chosen mixture model is not a perfect model for our data. To make a profile decision, we therefore relied on a combination and best possible matching of the fit indices under consideration of the profile size, which best supported the four-profile solution. It must be mentioned that we selected several parameters for the assessment of the fit and brought them into a decision hierarchy. However, there are no uniform rules for this

approach. In this study, we followed current recommendations and best practices from simulation studies. Nevertheless, the profile decision and the interpretation are also subject to a subjective decision-making framework that the LPA entails. The classification of the profiles is also essentially dependent on the separation potential of the used items (Nylund-Gibson & Choi, 2018). With our results, we have now made a first contribution to measuring the separation potential of our items. One task of future studies may be to further refine the findings and the item pool.

Conclusion

Personality plays a significant role in AV acceptance. Our study went beyond the previous findings and integrated them by identifying four profiles based on the most relevant personality traits and related them to the ITU AVs. Our results allow us to draw implications about the characteristics of four profiles of potential users and how to respond to them. These identified profiles differed particularly in variables of self-confidence (i.e., self-efficacy, internal and external control belief), general anxiety (i.e., neuroticism, trait anxiety and technology anxiety), and affinity for technology (i.e., technology acceptance, competence, and control belief): Profiles 1 and 2 were characterized by low technology affinity and ITU, which was accompanied by high general anxiety and uncertainty in profile 1, and high technology anxiety in profile 2. Profile 3 showed average values across all variables, including for the ITU. With high self-confidence and affinity for technology accompanied by low anxiety, profile 4 proved to be particularly promising for the intention to use AVs and thus differed considerably from the other three profiles. Manufacturers and transit agencies should take the differences into account in their AV marketing strategies. In particular, people with a low affinity for technology (mainly represented in profile 2), but also with

general anxiety (mainly represented in profile 1), should be approached with special consideration in order to increase their ITU systematically. Complementary to this, people who are particularly affine to technology and have low levels of anxiety (mainly represented in profile 4) can be deliberately targeted to serve as multipliers for the idea of autonomous driving. An implementation concept tailored to the profiles can help to meet the individual needs of each of the four profile groups. In summary, our study provides important contributions from a psychological perspective to better define potential AV users in terms of their characteristics and potential needs. Our implications provide initial suggestions on how the different profiles and needs of potential users can be addressed by manufacturers and providers. Future research should follow up on this and examine in more detail how potential users can be approached depending on their personality profile.

Study 2: Transportation by the hand of a ghost: The influence of trait anxiety in the context of fear of giving up control on the acceptance of autonomous vehicles

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Study 2 had not yet been accepted for publication by a journal at the time the dissertation was submitted. Please refer to the already available preprint of the paper, https://osf.io/preprints/osf/r2ug5 (Schandl & Hudecek, 2023c).

Abstract

As a new, highly complex, and far-reaching technology, autonomous driving can be associated with various fears and uncertainties. However, recent findings show that high trait anxiety can positively contribute to the intention to use autonomous vehicles. An explanation for this is that the possibility of handing over one's driving control to an AI is even more relieving for more anxious people. Our study aimed to test whether this explanation can be supported by investigating to what extent this relationship can be applied to buses in which control is handed over per se – in the traditional bus to a driver, in the autonomous bus to the AI. We also analyzed how the relationship between trait anxiety and intention to use is mediated by the fear of giving up control. In a quasi-experimental study, 253 subjects were surveyed while riding an autonomous or traditional electric bus. The results confirmed a positive association between trait anxiety and intention to use in the overall sample, but not in the autonomous and traditional subsamples. Contrary to our assumptions, fear of giving up control served as a slightly suppressive, but not significant mediator. The results were independent of whether control was handed over to a human driver in the traditional electric bus or to AI in the autonomous bus. Our study thus provides fundamental new insights into the

acceptance of autonomous vehicles and buses in general and opens the door for subsequent research based on these findings.

Introduction

Autonomous driving has gained increasing attention in recent years and is already beginning to make its first steps into our daily road traffic (Bernhard et al., 2020; Séjournet et al., 2022). Pilot projects are underway worldwide in which artificial intelligence (AI) replaces humans as drivers. In just a few years, autonomous vehicles (AVs) are forecast to represent 50 % of new vehicles sold (Litman, 2022). In this wake, a huge research field has opened around autonomous driving. In recent years, in addition to technical feasibility, the focus has increasingly been on factors that contribute to humans' successful adoption of AVs. The person of the user with his or her individual perception, attitude and personality is a crucial adjusting screw for the successful establishment of AVs (L. Ding & Yang, 2023; T. Huang, 2023). In this context, potential uncertainties, worries, and fears regarding new, largely unknown technologies such as AVs also play an important role (Fraedrich & Lenz, 2016). The degree of anxiety with which a person encounters AVs can be crucial for the ultimate use and success of this development (Hohenberger et al., 2017). Although findings on the positive relationship between anxiety and AV acceptance have been confirmed, results are still inconsistent. Recent findings even suggest that high trait anxiety has a positive effect on AV acceptance (Qu et al., 2021). One possible explanation for this finding is that the more anxious people are, the more they value the possibility of giving up control in AVs. However, this assumption has not yet been examined. To better understand anxiety as an essential factor for the acceptance of autonomous vehicles, we investigate in this study the relationship between trait anxiety and acceptance in the

context of fear of giving up control. We also focus on to whom control is handed over: the driver in the normal bus or the AI in the autonomous bus. With our findings, we aim to contribute to the successful establishment of AVs.

Literature Review and Research Framework

Autonomous driving in general seems to be associated with various fears and anxieties (Fraedrich & Lenz, 2016). Fear of machine movement and concerns about the predictability and reliability of autonomous systems still prevent users from developing trust in autonomous driving technology (J. Lee et al., 2016; Pettigrew et al., 2019). In addition, there are fears regarding data security and driving safety (Fraedrich & Lenz, 2016; Jing et al., 2020). Overall, AVs are still perceived as riskier compared to conventional vehicles, although they even promise to improve road safety (Brell et al., 2019; Yu et al., 2019).

The worries, fears, and perceived risks can unsettle users (Fraedrich & Lenz, 2016; Jing et al., 2020). While perceptions of safety decrease with higher levels of automation, perceived anxiety increases (Hewitt et al., 2019). Access to AVs in public transportation is currently severely limited, so corrective experiences are still rare in this regard (Fraedrich & Lenz, 2016). Prior experience with AVs may favor adoption (Charness et al., 2018). In a simulation study, Park et al. (2019) showed that subjects experienced less anxiety the longer they drove an autonomous vehicle. Regarding autonomous technologies, anxiety lowers the intention to use (ITU) AVs, which in turn prevents positive experiences (Hohenberger et al., 2017). On the other hand, anxiety and concerns are also compensated by positive expectations regarding driving safety and the risk of accidents, which in turn can reduce the anxiety of potential users (Fraedrich & Lenz, 2016). Although the acceptance of AVs is burdened by various

fears, contrary study findings also demonstrate a positive effect of anxiety. Qu et al. (2021) in a study among drivers of self-driving cars in China, found that individuals with higher trait anxiety attributed higher reliability to autonomous driving systems and were more willing to adopt AVs. The authors explained their unexpected positive effect by suggesting that more anxious individuals may be less afraid of the errors of an autonomous driving system than of their own human errors. According to their conjecture, the subjects' anxiety was less about losing control and more about "taking back control from a self-driving car" (Qu et al., 2021, *p*. 2674).

The issue of control has been addressed many times in the AV context. A high need for control has a negative effect on the ITU of AVs (Garidis et al., 2020). In contrast, an external locus of control, i.e., the belief that events are not self-caused but are caused by external factors (Rotter, 1966), leads to higher ITU (Choi & Ji, 2015). It is possible that giving up control is easier for individuals when they see the control in external influences rather than having a higher internal locus of control (Choi & Ji, 2015). Hegner et al. (2019) specially examined the fear of giving up control in the context of AV acceptance and found that low fear of giving up control, along with trust in AVs, positively affects acceptance.

If the possibility to hand over control is indeed decisive for the direction of the correlation between trait anxiety and the acceptance of autonomous cars, as hypothesized by Qu et al. (2021), the question arises as to what extent this effect can also be shown for buses. In contrast to autonomous cars, the main question for autonomous buses is not whether one's control is handed over, but to whom: the human driver or the autonomous technology. Strauch et al. showed that subjects report lower confidence when they are driven in a simulator by an autonomous system instead of a male or female driver (Strauch et al., 2019). Results like this might suggest that people

generally prefer riding a traditional bus to riding an autonomous bus. Therefore, if anxious people generally prefer to use buses because they can hand over driving control, we assume that they nevertheless prefer to hand over control to a human driver rather than to the AI in AVs. According to this reasoning, individuals with high anxiety would prefer riding in traditional buses with human drivers to riding in autonomous buses.

The studies demonstrate the relevance of trait anxiety for the development of AV acceptance. However, it currently remains unanswered how the somewhat contradictory results can be explained. This study aims to understand the role of anxiety and, in this context, the prerequisites for the acceptance and ITU of autonomous shuttle buses in more detail to derive implications for the successful establishment of autonomous buses.

To this end, we examine the relationship between trait anxiety and ITU. Qu et al. (2021) suggested that more anxious individuals are more willing to hand over control. Accordingly, this willingness in turn has a positive effect on the ITU of AVs in which driving control can be surrendered to AV technology. We, therefore, examine the extent to which the relationship between trait anxiety and ITU is mediated by fear of giving up control. Buses present a special case in this context because the passenger on the bus (unlike in a car) cedes control as standard, either to the AI in the AV or to a human driver on the traditional bus. Therefore, we examine to what extent the relationship between fear of giving up control and ITU as well as the relationship between trait anxiety and ITU depend on the so-called bus modality (autonomous vs. traditional). Based on the above considerations, we derive the following hypotheses (Figure 1).

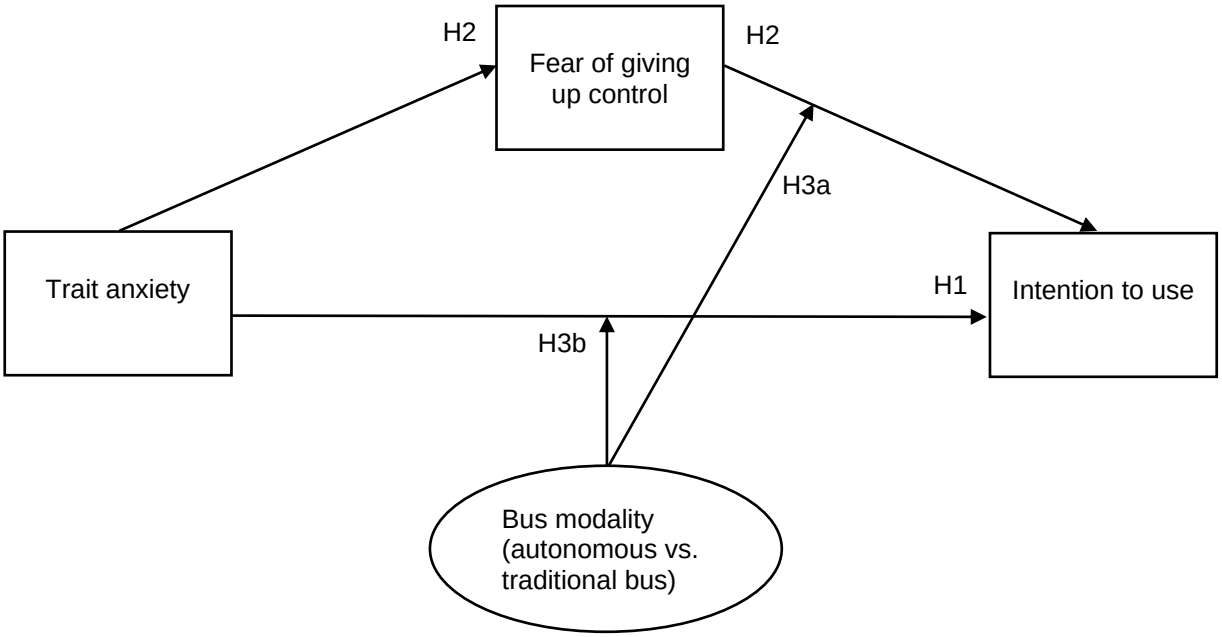
H1. Trait anxiety is positively related to ITU of a) autonomous and b) traditional buses.

H2. The relationship between trait anxiety and ITU of a) autonomous buses and b) traditional buses is mediated by the fear of giving up control.

H3. The mediation models for autonomous buses and traditional buses differ, with a) a stronger relationship between fear of giving up control and ITU (path b) and b) a stronger relationship between trait anxiety and ITU (path c) for AVs.

Figure 1

Hypothesis model



Method

Design and procedure

We conducted a quasi-experimental questionnaire study with two between-subject conditions (autonomous vs. traditional) to investigate the effect of trait anxiety on ITU through fear of giving up control. In the autonomous condition, we collected data from subjects on site while driving an autonomous bus, in the traditional condition,

we collected data from subjects while driving a traditional (electric) bus. We attached importance to the fact that the buses in the traditional condition drove with electric drive to grant a better comparability to the (anyway electrically driving) autonomous buses. The survey was carried out in Regensburg between October 2022 and July 2023. In this period, the use of autonomous buses was being piloted on a ring route in the industrial park. The subjects were surveyed exclusively during their journey with the respective bus to ensure that the sample only included persons who had used the bus. Data was collected via the online service SosciSurvey. Beforehand, the subjects were informed about the study objectives, their rights, and data handling. All participants gave their informed consent digitally by a click in a checkbox. They then answered questions about their sociodemographics, personality, mobility behavior, and their perception and experience with autonomous buses or with traditional buses, depending on which bus they were currently using at the time of the survey. The data were stored anonymously and are available in the OSF repository, (https://osf.io/7e9vc/?view_only=eb332c6d005e41c6aea469d0816b534b) (Schandl & Hudecek, 2023b). The study was approved by the Regensburg Ethics Committee (# 22-3088-101).

Sample

The sample (N = 253, of which 106 were male, 144 were female; age: M = 26.68, SD = 11.18 with a range of 16 to 76 years) was recruited via personal approach in the buses and via student subject platforms. It is composed of 127 subjects (50.20 %) who were surveyed while driving with an autonomous bus and 126 subjects (49.80 %) who were surveyed while driving with a traditional bus. This sample size was determined a-priori using the software G*Power, version 3.1.9.4 to ensure a power of .80 (f^2 = .08, α = .05). Three subjects under 16 years of age were excluded from study

participation beforehand. Participation in the study was voluntary and was not financially remunerated.

Instruments

In our study, we used a set of validated questionnaires to collect information on sociodemographics, personality, mobility behavior, and perceptions and experiences with autonomous or traditional buses. The sociodemographic variables included gender, age, education level, occupation, and income. The mobility behavior scale included two questions on frequently used means of transportation and two items on liking car or public transportation use.

For the survey of trait anxiety, we used the German short form of the trait scale of the *State-Trait Anxiety Inventory* (Grimm, 2009). The eight-point Likert scale (1 = *almost never* to 8 = *almost always*) assessed ten statements about personal indicators (e.g., *I get tired quickly*.) Cronbach's α was high at a = .85 (Blanz, 2015). For fear of giving up control, we developed five items, rated on a five-point Likert scale (1 = *do not agree at all* to 5 = *strongly agree*) following Hegner et al. (2019) (e.g., *I am concerned that I have no control over the [autonomous] bus*.). Cronbach's α reached a = .86, indicating high reliability (Blanz, 2015). We also surveyed the ITU with four items according to Korkmaz et al. (2021) on a five-point Likert scale ranging from *do not agree at all* (1) to *strongly agree* (5, e.g., *I plan to use [autonomous]-electric public buses frequently in the future.*). The reliability of this scale was high (Cronbach's a = .85, Blanz, 2015).

All items related to buses were adapted in their wording to the respective bus modality (autonomous vs. traditional). The study was conducted as part of a large

research project on autonomous driving. Therefore, in addition to the scales relevant to our study, the following were also collected: Technology Readiness Index 2 (Parasuraman & Colby, 2015); perceived safety adapted from Xu et al. (2018); environmental concerns (Wu et al., 2019); perceived sustainability, self-developed; environmental self-efficacy (H. Huang, 2016); knowledge about AVs, self-developed; previous experience with AVs, self-developed, General Self-Efficacy Short Scale (German: Allgemeine Selbstwirksamkeit Kurzskala; Beierlein et al., 2012). These variables are not considered in our study. An overview of all items and scales used is available as a codebook at https://osf.io/7e9vc/?view_only=eb332c6d005e41c6aea469d0816b534b.

Statistical analysis

Data were analyzed using R statistical software (version 2023.12.0) with the *lavaan* and *semtools* package (Jorgensen et al., 2022; Rosseel, 2012). As the examination of the outliers by means of boxplots showed, all of the conspicuous data values were within the plausible range, so we did not exclude them (Leys et al., 2019; Wiggins, 2000). We then reviewed the requirements for the mediation analysis (Hayes, 2018). Our data were collected independently. Therefore, we assume independence of the error terms (no autocorrelation). We confirmed the linearity of the correlations graphically using a scatter plot with a fitting curve. To check for possible multicollinearity, we considered the Pearson correlation coefficient of the predictors, which was not significant and unremarkable at $r = .05$. Furthermore, the requirements of normal distribution and homoscedasticity were not met in our data. We therefore additionally calculated the mediation analyses using bootstrapping with 1000 iterations. This procedure is considered robust to violations of the normal distribution and homoscedasticity (Lancaster, 2007; Preacher et al., 2007). We first examined the

relationship between trait anxiety and ITU in terms of mediation by fear of giving up control. We performed a mediation analysis for the total sample, for the autonomous condition and for the traditional condition (H1, H2). We then compared the mediation models of the two conditions using a multigroup analysis (H3). This procedure is used to uncover possible differences in the mediation models between the autonomous and traditional conditions (Klesel et al., 2019). A significant result indicates significant differences between the groups (Klesel et al., 2019). The used data set and analysis code is available in the OSF repository, https://osf.io/7e9vc/?view_only=eb332c6d005e41c6aea469d0816b534b (Schandl & Hudecek, 2023b).

Results

Descriptive statistical analysis

Table 1 shows the descriptive statistics of the relevant study variables. ITU was left-skewed in both the autonomous and traditional conditions, suggesting that the sample generally showed an open attitude toward bus use. Overall, ITU was lower for AVs than for traditional vehicles. The mean value of trait anxiety was similar to the results of Qu et al. (Qu et al., 2021). On a four-point scale, they found a mean trait anxiety value of $M = 1.94$. This is similar to our value of $M = 3.74$ on the eight-point scale. Noticeably, the autonomous and the traditional sample differed significantly in trait anxiety and fear of giving up control, with lower trait anxiety and higher fear of giving up control in the autonomous condition. To further explore this result pattern, we decided to plot the fear of giving up control as a function of trait anxiety and bus modality using a scatterplot (Figure 2). The graph shows relatively low fear of giving up

control for traditional buses across all trait anxiety values. For autonomous buses, fear of giving up control varied more, with higher values as trait anxiety increases.

Table 1

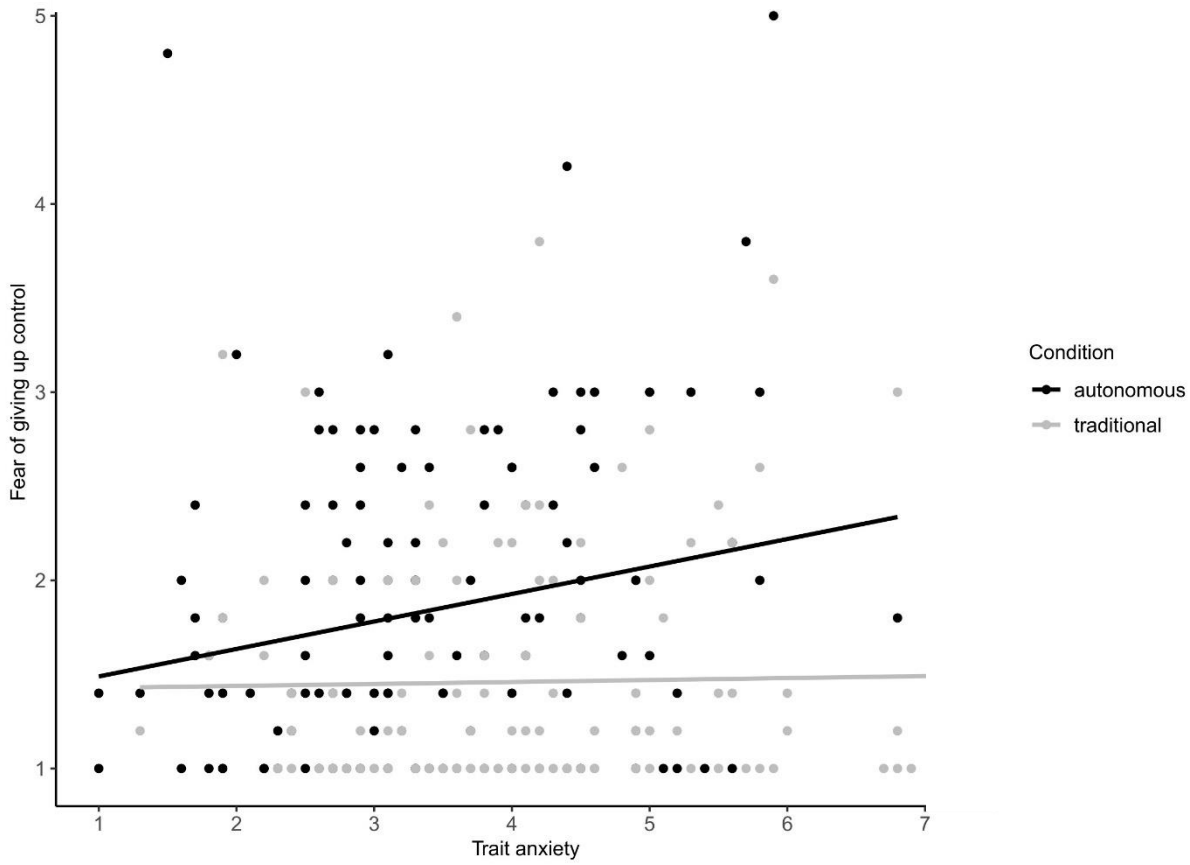
Descriptive statistics: mean values, mean value comparisons and correlations

	M (SD)								
Variable	Total	Autonomous	Traditional	*t*	1.	2.	3.	4.	5.
1. Gender	.59 (.52)	.54 (.50)	.65 (.53)	-1.79	-	-	-	-	-
2. Age	26.68 (11.18)	29.54 (13.00)	23.79 (8.06)	4.24**	-.07	-	-	-	-
3. ITU	4.27 (0.78)	4.10 (0.79)	4.45 (0.73)	-3.60**	.05	-.03	-	-	-
4. Trait Anxiety	3.74 (1.23)	3.41 (1.18)	4.08 (1.20)	-4.47**	.25**	-.12	.14*	-	-
5. FGC	1.65 (0.77)	1.84 (0.82)	1.46 (0.66)	4.08**	-.01	-.03	-.23**	.05	-
6. Bus Modality	0.50 (0.50)	-	-	-	-.10	-.01	.09	-.39**	.00

Note. t = t-Test to compare the two conditions (autonomous vs. traditional).
ITU = Intention to Use. FGC = Fear of giving up Control. Gender: 0 = male, 1 = female.
Bus Modality: 0 = autonomous bus, 1 = traditional bus.
N = 253, autonomous condition: *n* = 127, traditional condition: *n* = 126.
* $p < .05$.
** $p < .01$.

Figure 2

Scatter plot representing the relationship between trait anxiety and fear of giving up control



Inferential statistical analysis

We examined the association between trait anxiety and ITU for mediation by fear of giving up control each for the total sample, for the autonomous and for the traditional condition. The results are shown in Table 2. We found a positive total effect of trait anxiety on ITU for the total sample. This positive relationship was evident in both conditions, being stronger for traditional buses than for autonomous buses, although the association in both conditions did not reach significance (H1 a and b rejected). These results of the total effect were also found using bootstrapping, total sample: $b = 0.09$, $p = .018$; autonomous sample: $b = 0.01$, $p = .890$; traditional sample:

b = 0.10, *p* = .082.Trait anxiety overall contributed to the variance resolution with a small effect of ΔR^2 = .02 (Cohen, 2013). When the mediator was included, this direct effect slightly increased for the total sample as well as for both subsamples, with significant direct effects for the total sample and the traditional subsample. A similar pattern was evident with the use of bootstrapping, total sample: *b* = 0.09, *p* = .008; autonomous sample: *b* = 0.03, *p* = .620; traditional sample: *b* = 0.10, *p*= .050.This phenomenon is known as suppression and indicates that the mediator damps down, rather than strengthens, the positive association between trait anxiety and ITU (Hayes, 2018). This was confirmed when analyzing each mediation pathway in more detail. Contrary to our prior hypotheses, trait anxiety positively predicted fear of giving up control in the total sample, but also in both subsamples. However, the relationship only reached significance in the autonomous condition. Fear of giving up control had a negative effect on ITU, which was significant for the total sample and the traditional subsample, but not for the autonomous subsample. Overall, the indirect effect on ITU was negative. Nevertheless, the indirect effect of fear of giving up control did not reach significance, neither for the total sample, nor for autonomous buses and traditional buses. This result for the indirect effect was also found using bootstrapping, total sample: *ab* = -0.01, *p* = .506; autonomous sample: *ab* = -0.02, *p* = .130; traditional sample: *ab* = -0.00, *p* = .859. Therefore, we reject H2 a and b.

The multigroup analysis revealed no significant difference in the models between the autonomous and the traditional condition. This implies that the proposed mediation model was independent of bus modality, *t*(3) = 4.96, *p* = .175. H3 is therefore not confirmed.

Table 2

Mediation analysis: coefficients of the investigated paths and correlations

		Criterion									
		FGC					ITU				
Sample	Predictor	*B*	*SE*	*p*	95 %-CI		*b*	*SE*	*p*	95 %-CI	
					UL	LL				UL	LL
total	TA (Total effect)	-	-	-	-	-	0.09	0.04	.026	0.01	0.17
	TA (Direct effect)	0.03	0.04	.444	-0.05	0.11	0.10	0.04	.013	0.02	0.17
	Indirect effect	-	-	-	-	-	-0.01	0.01	.452	-0.03	0.01
	FGC	-	-	-	-	-	-0.24	0.06	< .001	-0.36	-0.13
		R^2 = .07, F(2,250) = 10.13, p < .001									
autonomous	TA (Total effect)						0.01	0.06	.905	-0.11	0.12
	TA (Direct effect)	0.15	0.06	.015	0.03	0.26	0.03	0.06	.649	-0.09	0.15
	Indirect effect						-0.02	0.02	.183	-0.05	0.01
	FGC						-0.14	0.09	.112	-0.31	0.03
		R^2 = .02, F(2,124) = 1.24, p = .29									
traditional	TA (Total effect)						0.10	0.05	.066	-0.01	0.20
	TA (Direct effect)	0.01	0.05	.831	-0.09	0.10	0.10	0.05	.050	0.00	0.20
	Indirect effect						-0.00	0.01	.831	-0.03	0.02
	FGC						-0.28	0.09	.003	-0.47	-0.10
		R^2 = .09, F(2,123) = 6.18, p = .003									

Note. CI = Confidence Interval. LL = Lower Limit; UL = Upper Limit; ITU = Intention to use; TA = Trait Anxiety; FGC = Fear of giving up Control.
N = 253, autonomous sample: n = 127, traditional sample: n = 126.

Discussion

Summary and practical implications

This study aimed to investigate whether trait anxiety is associated with the ITU of autonomous buses and to what extent this relationship is mediated by fear of giving up control as well as and dependent on the bus modality. Three main findings emerge from our study:

First, we found a positive influence of trait anxiety on the ITU across both conditions. This result was also evident for the subsamples, although not significantly, but on a descriptive level. These findings are of special interest. They show that although autonomous driving may be associated with various fears according to some studies, e.g., Keszey, 2020; Kyriakidis et al., 2015, this does not mean that more anxious individuals are in general more skeptical about AVs. The contrary is observed here. We can conclude from the above results that AVs and traditional buses seem to be particularly attractive to more anxious individuals. Our study thus extends the results of Qu et al. (2021) first, by the perspective of real AV users and, second, by the context of autonomous and traditional buses. This shows that the positive association is not only evident in autonomous cars, but also in autonomous buses, as well as in traditional buses. In practical terms, this means that anxious people are not the more critical target group at all when it comes to AVs. Rather, this target group seems to see an advantage in AVs. The results also suggest that more anxious individuals may even see an advantage in both autonomous cars, autonomous buses, and traditional buses (Qu et al., 2021).

Although the correlation was significant for the overall sample, this effect did not reach significance for the subsamples (autonomous and traditional, H1 not supported). Our results are therefore not fully consistent with the findings of Qu et al.

(2021) One reason for this could be the reduced sample size and thus reduced power in the subsamples (Kadam & Bhalerao, 2010). Qu et al. (2021) collected their data among the general population, regardless of their previous AV use. The authors thus achieved a sample size of $N = 527$. However, no experience with autonomous driving technology can currently be expected. To ensure the validity of the results, we therefore decided to conduct an on-site survey among users of autonomous and traditional buses. Within the research project, we only had access to autonomous buses for a defined period in which the data could be collected. A further increase in the sample size was therefore not possible in this time span, particularly for the autonomous bus. It is possible that (unlike in the study by Qu et al., 2021) existing smaller effects were therefore not revealed. Another reason for the non-significant effect could be that Qu et al. focused on autonomous cars, not autonomous buses. It is possible that the use of a car is more attractive to anxious people than the use of a bus, e.g., because the person is not sitting in a car with strangers, unlike on a bus. This might increase the influence of trait anxiety on the ITU of private vehicles and thus make it more evident. However, the positive, although not significant, relationship between trait anxiety and ITU AVs in our study already indicates that trait anxiety may also have an affirmative role in the use of autonomous buses.

Second, we found that the opportunity to hand over driving control is not the crucial factor/aspect that promotes the ITU of anxious people. We investigated the relevance of fear of giving up control as a potential underlying mechanism of this relationship. Here, we were able to show that, contrary to our assumptions, fear of giving up control is not accounting for the positive relationship between trait anxiety and ITU (H2 not supported). Based on the assumption made by Qu et al. (2021) discussing their results, we supposed that more anxious individuals would prefer to

hand over control to other entities (in our study, the AI vs. the human driver) rather than taking driving control themselves. Accordingly, a high fear of giving up control would in turn have a negative effect on the ITU of AVs or buses. However, our results do not support this assumption. In our study, there was no significant mediation by fear of giving up control.

In this context, it is noteworthy that trait anxiety and fear of giving up control showed significant differences between the subsamples. In particular, the fear of giving up control showed little variance in the traditional condition, with lower values (see Fig 2). This is surprising because we expected the two variables and their association to be independent of bus modality. It is possible that the fear of giving up control is particularly stimulated when control is handed over to an abstract autonomous technology. Previous research has already shown that people have greater trust in a human driver than an autonomous driving technology (Strauch et al., 2019). The fear of giving up control would therefore also be dependent on bus modality. Nevertheless, our results also show that trait anxiety has a significant influence on the fear of giving up control, however only among users of autonomous buses. Some studies suggest that anxiety is particularly strong in situations that are associated with uncertainty or threat (Qiao et al., 2022; Reuman et al., 2015). Possibly the use of autonomous driving technology represents a comparable situation because the technology is still difficult to grasp and hardly accessible (Brell et al., 2019; Fraedrich & Lenz, 2016; Schandl et al., 2022). This could explain why the influence of trait anxiety on fear of giving up control is only evident in the autonomous condition. To validate this assumption with our data, we subsequently decided to examine how bus modality affects the relationship between trait anxiety and fear of giving up control. For transparency of the calculation and results of this subsequent analysis, the corresponding R code is available in the OSF

repository: https://osf.io/7e9vc/?view_only=eb332c6d005e41c6aea469d0816b534b (Schandl & Hudecek, 2023b). The results of the moderation analysis confirmed the previously revealed significant positive influence of trait anxiety, but not bus modality, $b = 0.07$, $p = .808$, on fear of giving up control. Moderation by the bus modality narrowly missed significance, $ab = 0.052$, $p = .083$, possibly due to the previously discussed sample size. Future studies can take this finding as a starting point to investigate these relationships in more detail and in larger samples. This may help to understand whether trait anxiety exerts a greater influence on fear of giving up control in autonomous buses than in traditional buses. However, it remains open why the trait anxiety in the autonomous condition does not also have a stronger effect on the ITU.

Furthermore, contrary to our expectations, more anxious individuals descriptively also showed a higher fear of giving up control to buses, which had a negative effect on ITU. Thus, our model includes a positive direct effect and a (non-significant) negative indirect effect in both conditions (autonomous vs. traditional). Accordingly, although trait anxiety has a positive direct effect on ITU in the total sample, it has a non-significant negative indirect effect on ITU via the mediator. This seemingly contradictory phenomenon is known in the mediation analysis literature as the "suppression effect" (Hayes, 2018). The actual effect of trait anxiety on ITU is thus underestimated because it is dampened by the fear of giving up control (Hayes, 2018). In our study, however, the effect of this suppression is negligible because it only has a slight effect on the relationships. The opportunity to give up control by Qu et al. (2021) is thus not an explanation for the positive association between trait anxiety and ITU, neither for autonomous nor for traditional vehicles.

Nevertheless, it remains open why more anxious individuals reported a higher ITU for buses. A possible explanation for this is that concerns about autonomous

driving have meanwhile been reduced by the higher availability, e.g., of autonomous assistance systems, and AVs may even be perceived as safer than, e.g., driving a car oneself. Cunningham et al. (2020) showed that autonomous driving is associated with higher road safety by more than one-third of people. It may be that anxious people in particular value the new technology, e.g., because of the higher safety. It might also be possible that the positive association is due to another common feature of the buses that has nothing to do with either autonomous technology or control delivery. The buses in which we surveyed ran on electric propulsion in both conditions. We made a conscious decision to have electric buses in the traditional comparison group to ensure comparability with electric-driving autonomous buses. Some studies provide evidence that higher trait anxiety is associated with higher concern about climate change (Searle & Gow, 2010). It is possible that therefore more anxious individuals are more likely to prefer public transit, which is inherently more environmentally friendly than private driving (Byrne et al., 2021). The electric drive of our buses may also be perceived more positively in this regard, conditioning the positive relationship between trait anxiety and ITU. Future work can address our findings and further examine these and other possible explanations for the positive association between trait anxiety and ITU. According to our results, fear of giving up control is not an explanation for the positive association. However, it decreased ITU for traditional buses in a direct way. Manufacturers and providers of buses can use this as an opportunity to specifically strengthen the perceived control while riding the bus, e.g., by installing emergency buttons that are highly visible and that passengers can use to intervene if necessary (Dong et al., 2019). In the buses, posters could provide information about the training path to becoming a bus driver or about the functioning of the AI to strengthen trust in its reliability and take away users' fear of giving up driving control. Another approach may be to give people the feeling

that they have control over the bus route, e.g., by requesting a bus via app. These on-demand services are currently being simulated and tested for several cities, e.g., Hamburg, Germany (Neidhardt, 2022) or Fuyang, China, (Zhai et al., 2020), and might have a positive impact on the perceived control. Providers should also emphasize the benefits of buses and inform passengers specifically, e.g., opportunities related to driving safety or optimizing traffic flow (Maurer et al., 2016; Yu et al., 2019). It may be the task of future work to find out which measures are best suited to counteract the fear of giving up control in buses.

Third, according to the multigroup analysis results, the effects of our mediation model appeared to be independent of whether control was handed over to a human bus driver or the AI (H3 not supported). Contrary to earlier assumptions, AV technology did not further increase the impact of fear of giving up control significantly. This bodes well for the widespread adoption of autonomous buses, as in our study it seemed irrelevant for ITU whether control was handed over to the AI or a human bus driver. Overall, however, the willingness to use autonomous buses was still lower than for traditional buses. This result may be due to disadvantages of AVs that were not considered in this study but have a negative impact on ITU, e.g., the unfamiliar driving situation or possibly higher infrastructure costs (Dudziak et al., 2021; Litman, 2022).

Limitations and future work

To evaluate the results of our study in a well-founded manner, we would like to point out some limitations. First, the limited generalizability of our study results based on the selected sample should be noted. Due to the limited availability of autonomous buses, we were only able to collect test subjects for the autonomous bus condition on one autonomous bus route in the city Regensburg. However, we would not have been able to meet our pre-specified sample size if we had recruited only natural users of the

autonomous bus in Regensburg because the driving schedule and passenger numbers of the Regensburg bus were very limited. Therefore, the sample of the autonomous condition consisted mainly of students from the University of Regensburg, who were specifically recruited through a university platform. This made the sample less variant and limited representativeness in terms of age and education level but also achieved a larger size. In addition, the sample was not balanced with respect to gender, resulting in a higher proportion of women in our study. There were significant differences in trait anxiety and fear of giving up control that could possibly be related to gender or age effects (Abdel-Khalek, 2021; Chaudhary, Hu, et al., 2023; Chaudhary, Zhang, et al., 2023). This made it difficult for us to compare the two conditions with regard to the influence of trait anxiety. Furthermore, sociodemographic factors, e.g., gender, age, education, or socioeconomic status, may directly influence the ITU of AVs (Y. Ding et al., 2022; Dong et al., 2019; Yuen et al., 2022). In our study, ITU was largely independent of gender and age. Nevertheless, we recommend that the sociodemographic generalizability of our findings be tested at a later point in time when AVs are widely available and that the study also be replicated with a focus on other (e.g., older) populations. Under these conditions, the results should also be examined within a larger sample. Within the project period, it was not possible to expand the sample due to the limited availability of autonomous buses. Future studies may address our findings to replicate them in larger samples once autonomous buses are widely implemented. This could reveal effects that may not have been evident in our study due to the limited sample size (Kadam & Bhalerao, 2010).

Furthermore, we need to consider the limitation of our survey situation. The autonomous buses in which the study data of the autonomous condition were collected are currently driving in the industrial park of Regensburg on a ring-shaped route. The

autonomous bus reaches a maximum speed of 18 km/h and is thus slower than the traditional buses in the comparison condition. This could potentially lead to a perception of the trip being less time efficient, which could negatively affect ITU.

Another limitation is the inconsistent reference framework of different anxiety questionnaires. For better comparability, we surveyed trait anxiety with the same inventory already used by Qu et al. (2021): the State-Trait Anxiety Inventory (Spielberger et al., 1983). The inventory is established worldwide, and its psychometric quality and validity were confirmed many times (e.g., Metzger, 1976; Quek et al., 2004). However, as already noted by Qu et al., (2021) the results are dependent on what the anxiety refers to in the wording of the items. Qu et al. (2021) cite as an example a study by Hohenberger et al. (2017), in which anxiety negatively affected the ITU of AVs. In this study, the anxiety items primarily related to anxiety about making mistakes when interacting with AVs (e.g., *I would be afraid that I could cause (e.g., by pushing a button) a malfunction (e.g., emergency brake) by using an [semi-] automated car.*, Hohenberger et al., 2017, *p*. 10). In contrast, the items of the State-Trait Anxiety Inventory used by Qu et al. (2021) refer more to general inadequacies of oneself in the context of trait anxiety (e.g., *I don't have self-confidence*., translated from german, Grimm, 2009, *p*. 2). Thus, while the items of Hohenberger (2017) directed the focus to anxiety in dealing with AVs, we possibly addressed general self-related anxiety in our study (Qu et al., 2021). According to Qu et al. (2021), this may be one reason why anxiety (focusing on AVs) negatively affected ITU in the study of Hohenberger et al. (2017). In contrast, in the study of Qu et al. (2021) as well as in our study, individuals with high (self-focused) anxiety were more open to AVs. Among other reasons, this may be because potential risks and dangers related to AVs (unlike in the study of

Hohenberger et al., 2017) were not explicitly addressed and thus less anxiety was raised among the subjects.

Furthermore, the general characteristics of mediation analysis must be considered. We found in our study that the effect of trait anxiety on ITU was slightly partially suppressed by fear of giving up control. The actual magnitude of the influence was revealed only when the mediator variable was included. However, it is unlikely that the fear of giving up control is the only mediator of this relationship. Thus, other mediators may exist that mediate the association between trait anxiety and ITU, both reinforcing and suppressing (Hayes, 2018). For example, as discussed in the section above, higher trait anxiety could lead to higher climate change anxiety, thereby increasing the propensity to use public, electric, and efficient vehicles. Therefore, it cannot be ruled out that the actual association is even stronger than we currently found (Hayes, 2018). This is a well-known general limitation of mediation analysis (Hayes, 2018). We can only progressively confirm the true role of our mediator by further understanding the relationship between trait anxiety and ITU, thereby ruling out the influence of possible confounding mediators. This may be the task of future research in this field.

Conclusion

The present study on the acceptance of AVs aimed to understand the influence of trait anxiety on ITU in greater detail by focusing on the fear of giving up control. Trait anxiety positively affected ITU in general, but the association only reached significance when the total sample was considered. The mediation by fear of giving up control was in our study not the positive direction of the relationship. Surprisingly, these results appeared independent of whether control was given to an AI in the autonomous

bus or a human driver in the traditional bus in a direct statistical model comparison. The finding that AVs and public transport in general, are attractive transport concepts, particularly for anxious people, suggests that there may already be widespread awareness in the population of the benefits of autonomous, sustainable, and efficient transport concepts. It may be the task of future research to further investigate the underlying mechanisms of action that condition the relationship between trait anxiety and ITU.

Study 3 If it concerns me: An experimental investigation of the influence of psychological distance on the acceptance of autonomous shuttle buses

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Abstract

Autonomous vehicles (AVs) will revolutionize our everyday mobility in the future. However, the prerequisite for this is that the technology is accepted by the population. Currently, AVs are still difficult to grasp for many people, i.e., the topic of autonomous driving is psychologically distant. In other contexts, it has been shown that this psychological distance or proximity can be used to influence product perception. However, the influence of psychological distance has never been investigated in the AV context. To address this research gap, we investigated the impact of psychological distance on the intention to use (ITU) AVs. We manipulated psychological distance in a 2x2x2 scenario-based experiment (N = 2114) on two different dimensions and additionally varied driving modality for comparison purposes: subjects either imagined themselves or an average person (social distance) using either a traditional or autonomous bus (driving modality) either today or in ten years (temporal distance). Our results showed a main effect of driving modality and social distance, with higher ITU

for AVs and the average person. Temporal distance interacted with social distance to affect ITU. Interestingly, psychological distance also affected ITU for traditional buses with a similar interaction pattern. Thus, our study suggests that psychological distance affects the ITU of buses in general rather than AV technology. Providers can benefit from framing AVs as temporally close and providing as concrete, detailed information as possible. Future research should examine the underlying mechanisms (e.g., a shift in bus use priorities) that can explain why social distance plays an important role, particularly in future scenarios.

Introduction

Our mobility is about to face a fundamental change: autonomous driving. In about 20 years, autonomous vehicles (AVs) are expected to account for 50 % of new vehicles (Litman, 2022). To successfully integrate AVs into road traffic, acceptance by potential users is essential. To date, however, this technology remains hard to grasp for the general public, in large part because AVs have very limited availability and the underlying artificial intelligence (AI) technology is complex (Brell et al., 2019; Litman, 2022; Wiegand et al., 2020). In this context, autonomous driving is still very abstract on two levels in particular: first, it is a future, rather than an immediate development on a temporal level (Litman, 2022). Second, to date, autonomous driving is not yet personally relevant to most individuals due to its limited availability. Trope and Liberman (2010) refer to circumstances such as these as psychological distance. Numerous studies from a variety of fields show that this psychological distance is a key factor in shaping our judgments of situations and objects (e.g., Lermer et al., 2015, 2016a, 2016b; Pronin et al., 2008; So et al., 2021). Psychological distance is emerging in current research as a factor that significantly affects the perception and acceptance of

new technologies (e.g., Bitcoin: Abraham et al., 2019; robots: Akdim et al., 2021; AI: Hudecek et al., 2024). New technologies can be perceived as distant to potential users at a temporal level when they are currently hardly available (Fraedrich & Lenz, 2016; Trope & Liberman, 2010). Similarly, developments that do not affect ourselves are distant at the social level (Trope & Liberman, 2010). In turn, these dimensions of psychological distance can significantly shape technology acceptance and intention to use (ITU). In this course, we aimed to focus on autonomous driving, which is currently hardly available and thus very abstract but could revolutionize everyday life for many people soon (Gavanas, 2019; Litman, 2022). Especially autonomous public or shared vehicles have great potential. As a comparatively resource-saving and efficient mobility solution, they can help to reduce the use of private cars and contribute to protecting the environment (e.g., through intelligent route planning, Chan & Shaheen, 2012; Gurumurthy et al., 2019). Therefore, it is important to identify the factors that contribute to the successful implementation of autonomous public vehicles (Schandl et al., 2023). To the best of our knowledge, we are the first study to use a large-scale experimental design to investigate the influence that psychological distance at the social and temporal level has on the acceptance of autonomous buses compared to traditional buses. We aim to draw practical implications for the current situation, in which autonomous driving is still hardly relevant in society, but society is slowly being familiarized with the new technology.

Literature Review and Research Framework

Psychological Distance and Construal Level Theory

Innovative technologies such as autonomous driving may be difficult for individuals to grasp due to their novelty and can cause uncertainty and skepticism (Jing

et al., 2020; Zmud et al., 2016). An essential prerequisite and option for concretizing abstract representations such as those of AVs is to reduce the psychological distance. Psychological distance describes the extent to which a circumstance is "not part of one's direct experience" (Trope et al., 2007, p. 84). Trope and Liberman (2010) distinguish four different types of psychological distance: temporal distance (e.g., now vs. 10 years from now), spatial distance (e.g., here vs. on another continent), social distance (e.g., me vs. a stranger), and hypothetical distance (e.g., real vs. imagined). The classification of an object within these distances occurs automatically and on a continuum, and the different types of psychological distance can interact with each other (Trope & Liberman, 2010; Williams & Bargh, 2008). Psychological distance, in its total constellation, affects the perception and internal representation of objects. Trope and Liberman (2010) describe this cognitive-social psychological phenomenon using Construal Level Theory (CLT). According to the authors, objects that are psychologically distant from the subject are represented abstractly and theoretically. Due to their abstraction, these representations are usually poor in detail. To nevertheless develop an internal concept of the object, the missing details and information have to be compensated by one's own mental imagination, i.e., they are mentally constructed. Psychological distal objects, therefore, have a high construal level according to CLT. In contrast, objects that are close to the subject require a low construal level and allow for a more concrete, detailed mental representation (Trope & Liberman, 2010). Peng et al. (2013) figuratively compare a high construal level to the perspective of a bird viewing a sprawling forest from above. In contrast, they analogize a low construal level to an animal that closely sees single trees at the bottom of the forest.

With regard to the perception of new technologies, psychological distance seems to play a crucial role. New technologies such as AVs require a high construal effort at

the cognitive level (Förster, 2009; Trope & Liberman, 2010). In parallel, several studies on CLT suggest that the extent of social and temporal psychological distance in particular has an impact on the acceptance of innovations. For example, Abraham et al. (2019) found in the context of cryptocurrencies that the lower the perceived spatial, social, and hypothetical distance, the higher was the ITU for Bitcoin and its blockchain. According to the author, potential users need to see the technology as concrete, relevant, and feasible for successful establishment (Abraham et al., 2019). This contrasts with findings on decision-making behavior, which show that risk perception (e.g., of new technologies) decreases under higher psychological distance (Lermer et al., 2015, 2016a, 2016b). A possible explanation for the divergent results is provided by Fujita et al. (2006). Thus, rational decision behavior is associated with an abstract mindset and affective decision behavior is associated with a concrete mindset. Following this reasoning, a low psychological distance could lead to higher risk perception via affect (e.g., fear). On the other hand, an affective component (e.g., fascination, curiosity) also might have a favorable effect on the acceptance of new technologies (e.g., Bitcoin, Abraham et al., 2019; autonomous driving, Brell et al., 2019). These findings are also found in the reverse way. In a letter recognition task, Förster (2009) showed that new subliminally presented stimuli are associated with global perception, and familiar stimuli are associated with detailed perception. He, therefore, hypothesized that people automatically encounter new events with more abstract perception at a high construal level, possibly to first roughly semantically categorize the new impression and thus classify the relevance and valence of the stimulus (Förster, 2009). Thus, the construal level and human perception seem to be in a reciprocal relationship.

Temporal psychological distance

Based on CLT, numerous studies demonstrate that temporally distant objects and events (i.e., located in the past or future) are represented more abstractly (Trope et al., 2007). This is in line with several findings that expand our understanding of the effects of temporal distance. Depending on the construal level, the acceptance of new technologies may depend on different factors. Bagratuni (2021) examined the relationship between affective and cognitive factors and the acceptance of air cabs on moderation by temporal distance. Consistent with the findings of Fujita et al. (2006), he found that at a low temporal distance, affective factors, such as hedonic motivation, are primary determinants of acceptance. In contrast, when the temporal distance to air cabs was high, cognitive factors such as utility and safety concerns were primary. The hedonic motivation had no influence in this condition (Bagratuni, 2021). This finding is in line with Sagristano et al. (2002), who found that for temporally distant events, the focus was on the desirability, and for temporally proximal events, the focus was on the feasibility of the event. Possibly, high temporal distance favors the acceptance of new technologies because, although new technologies are often desirable per se (distal level), practical feasibility (proximal level) is often still difficult to imagine (Peng et al., 2013).

Social psychological distance

Another influential effect of psychological distance on cognition may be observed at the social level. We see and evaluate other people differently from ourselves, presumably because we can better comprehend our own cognitive processes, affective states, or the variability of our behavior (Trope & Liberman, 2010). Thus, social distance affects our perceptions and influences which aspects we consider in evaluation processes. J.-Z. Xu and Xie (2012) examined social distance by comparing

the decision-making behavior of directly affected individuals (socially proximal) with that of advisors (socially distant). Low social distance showed a stronger focus on feasibility, while high social distance showed a stronger focus on desirability of an alternative. The authors also found that advisors' decision-making behavior was more similar to that for themselves when they perceived a similarity to the people involved. An interesting research area on social distance opened up in recent years around the acceptance of new technologies: According to Abraham et al. (2019), an abstract mindset positively affects the perceived social relevance of Bitcoin. This perceived relevance was in turn positively associated with ITU in their study. The authors reasoned that abstract technologies like Blockchain, require an abstract, open mindset to grasp the complexity of the technology. Consistent with this, Hudecek et al. (4 2024) found in their study of online medical advice that subjects preferred the advice of a human doctor to the advice of an AI. However, this difference could only be shown if the medical judgment concerned the subject's own person. For other, unknown persons (i.e., socially distant), the subjects showed no preference for a certain source of advice (Hudecek et al., 2024).

Findings on the interaction of different levels of psychological distance

The findings by Hudecek et al. (2024) provide evidence that psychological distance at one level (e.g., me vs. another person) influences the effects of psychological distance at another level (e.g., doctor vs. AI). Similar findings were found in a study by Peng et al. (2013): In cancer treatment imagining scenarios, subjects who opted for themselves preferred radiotherapy with a high treatment survival rate but a low five-year survival rate over surgery with a low treatment survival rate and high five-year survival rate. Subjects who judged for others showed an inverse pattern. According to the authors, individuals at low social distance may be more likely to focus on the

present, and those at high social distance may be more likely to focus on the future. Thus, the level of social distance affected treatment decisions through the evaluation of temporal distance. An alternative explanation provided by the authors lies in the focus on feasibility vs. desirability described earlier. Thus, under social proximity, individuals may prefer radiation treatment with a higher chance of feasibility. Under social distance, on the other hand, the preference for surgical intervention predominates, which is more difficult to perform but more desirable in the long term (Peng et al., 2013). Pronin et al. (2008) also showed in their study that a higher hypothetical distance modulates the influence of temporal and social distance on decision behavior. In imagination scenarios, subjects were rather willing to drink the amount of an unenjoyable beverage that they would also ask a stranger or their future self to drink. Under real-life conditions, however, subjects chose smaller amounts for themselves (Pronin et al., 2008). These results are consistent with the assumptions of CLT that the psychological distance on one dimension influences the perceived psychological distance on another dimension (Trope & Liberman, 2010).

AV acceptance

Studies such as Hudecek et al.'s (2024), but also e.g. by Larkin et al. (2022) or Luo et al. (2019) illustrate that people are currently still measurably more skeptical of AI-based technologies than of human performance. As AI progressively spreads into more areas of everyday life and promises far-reaching applications in the future (e.g., in the form of AVs, Jiang et al., 2022), a key goal is to prepare the general population for the implementation of artificially intelligent and autonomous technologies. The primary focus here is on the acceptance of the technologies, which is expressed in the ITU (Davis, 1985). In recent years, research on the acceptance of new technologies has opened a wide area of interest in the field of autonomous driving technology. In

addition to extrapersonal factors (e.g. service and vehicle characteristics), studies are increasingly focusing on the influence of intrapersonal characteristics (e.g. socio-demographics, personality, perception) on ITU (Nordhoff et al., 2019). For example, it has already been observed that younger, male people with a higher level of education are more willing to accept AVs (Y. Ding et al., 2022; Dong et al., 2019). Possible reasons for this are discussed by Schandl et al. (2023). In addition, it has been shown that personality has an influence on AV acceptance. People with high extraversion and openness, for example, have a higher ITU (Qu et al., 2021). In contrast, a low ITU is associated with increased neuroticism and general anxiety (Qu et al., 2021; Schandl et al., 2023). A significant role is also attributed to the individual need for control (Garidis et al., 2020). People with a high fear of giving up control show lower AV acceptance (Schandl & Hudecek, 2023c), possibly because AVs are associated with safety concerns (Zmud et al., 2016). Consistent with this, in the study of Detjen et al. (2020), perceived safety was the most frequently cited requirement for feelings of well-being and comfort during an AV ride.

A special focus of research on AV acceptance are autonomous public and shared vehicles. The implementation of autonomous driving technology in public transportation is considered as promising (Pakusch & Bossauer, 2017). For example, it allows intelligent route planning for users at low costs (Litman, 2022; Pakusch & Bossauer, 2017). This can help to reduce the traffic volume caused by private vehicles and thus have a positive impact on traffic flow and the reduction of greenhouse gas emissions (Litman, 2022; Pakusch & Bossauer, 2017). In addition, driverless buses allow to counter the shortage of bus drivers that has been observed in public transportation worldwide in recent years due to insufficient working conditions and structures (Aluwi et al.; H.-K. Chen et al., 2019). With mainly fixed routes, public and

commercial transport is particularly suitable for the deployment of autonomous driving technology (Litman, 2022). According to Litman (2022), it will therefore be implemented in public transport as early as the 2030s and thus precede the establishment of autonomous private cars.

At present, AVs are hardly common and are therefore still abstract (i.e., psychologically distal) for society (Fraedrich & Lenz, 2016). As they become more established, AVs will become a current technology that will impact an increasing number of people. The psychological distance will therefore be reduced. From research on the acceptance of new technologies, we can assume that psychological distance may have a significant influence on the AV acceptance. To what extent psychological distance or a shift in psychological distance can affect the acceptance of AVs and autonomous buses, is still unclear.

Research Goal

The generation of psychological proximity or distance (e.g., through framing in advertising slogans) can influence object perception and acceptance (Reczek et al., 2018). So far, these phenomena have not been studied in an AV context. We aim to fill this research gap and investigate the role of psychological distance in the context of the acceptance for autonomous buses. To distinguish the effects due to autonomous technology from those shown for buses in general, we comparatively contrast autonomous buses and traditional buses in our study. We take up previous results and investigate 1. to what extent AV acceptance is influenced by temporal and social distance, and 2. if the results can be found exclusively for autonomous buses or also for traditional buses in general.

We assume that the temporal distance influences AV acceptance. The widespread availability of this technology is still in the future. Information about the

timely implementation of AVs on the road could make the abstract notion of this technology more concrete and tangible. Moreover, examining the effect of temporal distance allows us to draw initial conclusions about the extent to which AV acceptance might change when AVs are a present, rather than a future, technology. In this study, we, therefore, manipulate temporal distance to AVs and examine the extent to which it affects ITU. AI technology and AVs may still be associated with reservations or uncertainty (Jing et al., 2020; Zmud et al., 2016), so we hypothesize that temporally distal, abstract framing will be less threatening to subjects and therefore result in an increased ITU (Lermer et al., 2016b):

H1. Temporal distance (now vs. 10 years from now) has a positive effect on ITU.

Hudecek et al. (2024) showed that social distance also has a significant influence on the acceptance of AI systems. When people themselves were affected by an AI-based advice, they were more skeptical than they were when others were affected by it. We would like to take up this finding and investigate to what extent social distance plays a role in the ITU of AVs. This may help to understand how AV acceptance may be influenced by the purposeful framing of social distance, e.g., for marketing purposes. Based on the findings of Hudecek et al. (2024), who showed that AI technology is more likely to be accepted when it does not affect oneself, we hypothesize H2:

H2. Social distance (self vs. others) has a positive influence on ITU.

To interpret the results, we need to understand to what extent the influences of psychological distance are specific to autonomous AI technology, which is still abstract, or to traditional buses, which are already available and relevant to individuals. As shown, people prefer decisions by a human source instead of an AI (Hudecek et al., 2024). We, therefore, hypothesize the following regarding the driving modality.

H3. The bus modality has an influence on ITU, with lower ITU for autonomous buses compared to traditional buses.

According to CLT, the distance on one dimension can influence the perceived distance on another dimension (Trope & Liberman, 2010). The authors describe social distance as a "core psychological distance" (Trope & Liberman, 2010, p. 444). According to this theory, we therefore assume in our theoretical model that temporal distance affects the impact of social distance. Thus, high temporal distance in our study can diminish the effect of social distance and vice versa. Accordingly, the closer in time to the introduction of AV, the more relevant is the extent to which it affects a person himself (Trope & Liberman, 2010). Similarly, temporal distance should also play a smaller role for ITU when subjects evaluate for an unknown person (social distance). In this context, it is logical to assume that the role of driving modality is reduced when temporal or social distance is high. We also hypothesize, in reverse, that when temporal or social proximity is present, driving modality has a greater impact on ITU because consequences become more tangible when temporal and social distance effects are more direct. From these considerations, we derive hypothesis H4 to H6:

H4. The influence of social distance on the ITU is smaller under temporal distance.

H5. The influence of the bus modality (autonomous vs. traditional) is smaller under temporal distance.

H6. The influence of the bus modality (autonomous vs. traditional) is smaller under social distance.

Method

Sample

To ensure a strong power and informative value with the eight planned conditions of our experiment, we set the sample size in advance to at least 700 participants using the software G*Power, version 3.1.9.4, for a power of .95 (f = .20, α = .05; Kadam & Bhalerao, 2010).The final sample comprised 2,114 participants (n = 1,437 female, 664 male, 13 divers), who were between 16 and 77 years old (M = 26.20, SD = 8.61). They were recruited via social media and online platforms of the University of Regensburg, the University of Munich, and the FOM University. For study participation, participants had to be at least 16 years old. Three subjects who were younger were excluded in advance. In addition, 38 persons who had not completed the questionnaire completely were excluded prior to the analysis. Students received course credit for participation; apart from that, study participation was without further compensation or reward.

Design

The study was part of a large-scale research project that explored the acceptance of autonomous shuttle buses on a public test route in the city of Regensburg (Germany). In this context we conducted a preregistered (https://osf.io/pbwrc/?view_only=9bb26b253fb2452b84c97b3af09c9c08) 2x2x2 scenario-based experiment. We initially started the data collection with four conditions manipulating social distance and bus modality using the present tense (temporal proximal). After the first 400 surveys, we extended the design to include the temporal distance condition. In other words, we added four more conditions in the future tense (“in 2033“, temporal distal). We continued the further surveys with randomized

assignment to one of the eight conditions with the aim of balancing the group sizes as far as possible. All conditions surveyed were included in the present study. Temporal distance was manipulated by temporal reference (today vs. 10 years from now), and social distance via the user's affectedness by the technology (me vs. another average person). In addition, we differentiated the bus modality (autonomous vs. traditional). For this purpose, we asked the participants to imagine themselves (socially proximal) using or an average person (socially distal) using an autonomous shuttle bus or a traditional bus today (temporally proximal) or in ten years (temporally distal). Assignment to each condition was randomized. This resulted in eight possible combinations:

- I use a traditional bus today. (temporally proximal, socially proximal, traditional)
- I use an autonomous bus today. (temporally proximal, socially proximal, autonomous)
- An average person uses a traditional bus today. (temporally proximal, socially distal, traditional)
- An average person uses an autonomous bus today. (temporal proximal, social distal, autonomous)
- I will use a traditional bus in 10 years. (temporal distal, social proximal, traditional)
- I will use an autonomous bus in 10 years. (temporal distal, social proximal, autonomous)

- An average person will use a traditional bus in 10 years. (temporal distal, social distal, traditional)

- An average person will use an autonomous bus in 10 years. (temporal distal, social distal, autonomous)

Instruments

We measured ITU using behavioral intention scale developed by Venkatesh et al. (2012) on a seven-point Likert scale ranging from "Strongly disagree" (1) to "Strongly agree" (7). The items were adopted by the authors and adapted in wording to the (autonomous or traditional) bus context as well as the distance condition (temporal and social). Internal consistency was excellent with McDonald's ω = .91 (Blanz, 2015; McDonald, 2013; Zinbarg et al., 2005).

The study was part of a larger study project on autonomous shuttle buses. Therefore, we also collected the variables of the extended Unified Theory of Acceptance and Use of Technology (performance expectancy effort expectancy social influence facilitating circumstances hedonic motivation price and habit, Venkatesh et al., 2012) as well as disposition to trust (Gefen & Straub, 2004), perceived safety (Z. Xu et al., 2018), travel behavior and the price subjects would be willing to pay for a day ticket. To avoid impairing the clarity and interpretability of the results, we decided against including these variables in our analysis after we had extended the study design to eight conditions. An overview of all items used in the study is available in the OSF repository, https://osf.io/ayq9p/?view_only=81b4885f3a394872901134ce4703f456.

Statistical analysis

Statistical analysis was performed using the statistical program R (Version: 2023.12.0) with the car-package (Fox & Weisberg, 2019). In advance, we ensured that

the data set did not have extreme outliers that were more than three times the interquartile range from the mean (Balducci et al., 2019). We conducted a three-factor ANOVA without repeated measures to test the influence of social and temporal distance and bus modality on ITU. The conditions for conducting ANOVA are independence of measurements, interval scaling, and normal distribution of the criterion, as well as variance homogeneity within factor groups (Rasch et al., 2021). We considered the first two conditions to be met in our experimental design. A significant Shapiro-Wilk test revealed the non-normal distribution of the data (Shapiro & Wilk, 1965). However, in analyses with sufficiently large samples, ANOVA is considered robust to the violation of this assumption, so we decided to neglect this aspect in our study (Blanca et al., 2017). Levene's test for variance homogeneity proved significant, indicating variance heterogeneity, possibly due to the sensitivity of the test to large samples (Field, 2013). Violation of this last assumption may lead to a bias in the Type I error rate (Delacre et al., 2019). To control for this, we performed an analysis with bootstrapping (1000 repetitions), which is robust to variance heterogeneity, in addition to the *F* statistic of the classic ANOVA (Krishnamoorthy et al., 2007). The dataset of the current study is available in the OSF repository, https://osf.io/ayq9p/?view_only=81b4885f3a394872901134ce4703f456.

Results

Table 1 displays the correlations of the considered variables and conditions. We calculated a 2x2x2 ANOVA to investigate the influence of temporal distance (proximal vs. distal), social distance (proximal vs. distal), and driving modality (autonomous vs. traditional) on ITU. The overall model contributed moderately (*adjusted* R^2 = .04) to the variance explanation of ITU (Cohen, 2013). The results are presented in Table 2. For temporal distance, contrary to our assumption, there was no significant main effect (H1

not confirmed). At the social distance level, ITU proved to be significantly higher in pairwise comparisons when rated for others than for oneself (H2 supported). Overall, ITU was higher for autonomous buses than for traditional buses, with a significant main effect of driving modality. Therefore, H3, in which we expected a significant main effect of driving modality but with a higher ITU in the traditional conditions, is not confirmed. Despite the significant results, the effect sizes for the main effects were marginal with $\eta^2 \leq .01$ (Cohen, 2013; Sauer, 2019).

Table 1

Correlations of ITU with independent variables

Variable	1. ITU	2. Temporal Distance	3. Social Distance
1. ITU			
2. Temporal Distance	.04		
3. Social Distance	.09**	.00	
4. Bus Modality	.10**	.01	.00

Note. ITU = Intention to Use.
$N = 2114$.
*: $p < .05$
**: $p < .01$

Temporal distance interacted significantly with social distance. Figure 1 shows the interaction pattern for both the autonomous and traditional conditions. In the temporally proximal conditions, subjects rated ITU similarly high for themselves and for others, with a (nonsignificant) slightly higher ITU when judging for themselves. However, this pattern reversed in the temporally distal conditions. For future scenarios, subjects estimated their ITU to be lower than for present scenarios. In contrast, the ITU that participants attributed to others in the future was significantly higher than the present ITU. Thus, while social distance in the temporally proximal conditions caused

little difference in ITU, in the temporally distant condition ITU attributed to others was substantially higher than ITU attributed by subjects to themselves. Contrary to H4, temporal distance increased the influence of social distance instead of reducing it. Interestingly, this interaction appeared largely independent of driving modality; thus, the interaction of all three factors was not significant. Driving modality also did not interact significantly with either level of psychological distance (H5 and H6 not confirmed). The effect sizes of the interactions were marginal with partial $\eta^2 \leq .01$ (Cohen, 2013). At a significance level of $\alpha = .05$, our study showed a statistical power of .99. As our data did not meet the assumptions of normal distribution, we also carried out the analysis using bootstrapping with 5000 iterations. The results pattern of the ANOVA with bootstrapping was identical to the ANOVA without distribution assumption und therefore fully supports the previous findings (see Table 2).

Table 2

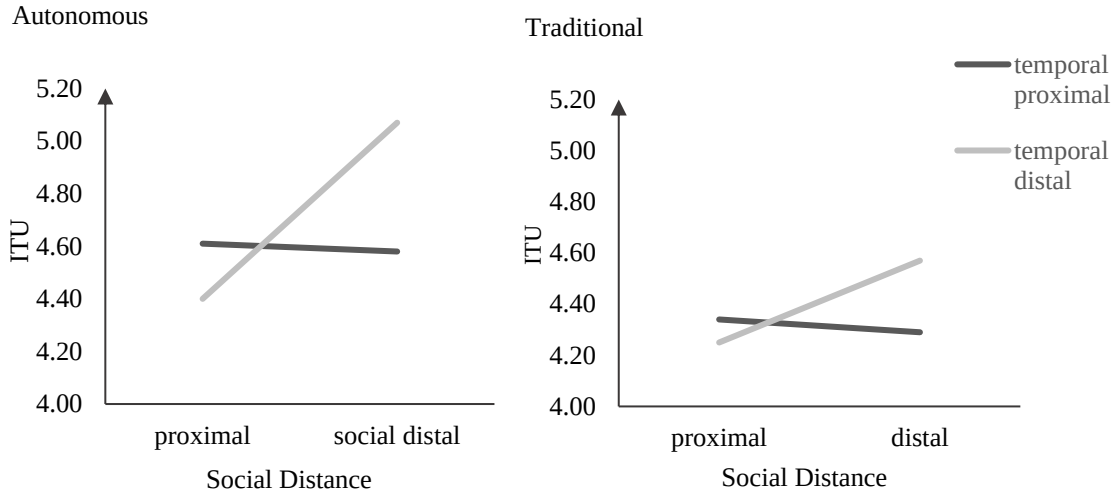
ANOVA results with criterion ITU

Factors	Classic ANOVA					Bootstrapping ANOVA
	F	*df*	*P*	*Partial* η^2	*95 % CI*	*p*
Temporal Distance	3.21	1	.073	.002	[0.000, 0.005]	.066
Social Distance	15.92	1	< .001	.008	[0.002, 0.015]	< .001
Bus Modality	23.23	1	< .001	.010	[0.003, 0.018]	< .001
Temporal Distance x Social Distance	16.90	1	< .001	.008	[0.002, 0.015]	< .001
Temporal Distance x Driving Modality	0.11	1	.746	.000	[0.000, 0.001]	.740
Social Distance x Driving Modality	2.48	1	.116	.001	[0.000, 0.000]	.111

Note. ITU = Intention to Use; CI = Confidence Interval.
N = 2114.

Figure 1

Graphical visualization of the interaction effects per driving modality



Discussion

Summary and Practical Implications

The aim of our study was to investigate the influence of different dimensions of psychological distance on AV acceptance to make predictions and suggestions for successful AV implementation. To this end, we manipulated temporal and social distance as well as driving modality in a large-scale experiment using a scenario-based approach and examined ITU as the relevant outcome variable.

We were able to document substantial influences of psychological distance at the temporal and social level. This emphasizes the importance of temporal and social tangibility in successful AV adoption. Our study was, to the best of our knowledge, the first to date devoted to psychological distance in the AV context. A major strength of the study is the large-scale experimental design, which allowed us to uncover causal influences of psychological distance on ITU. Thus, we were able to draw direct conclusions about the direction of effects. In addition, the design of our study allowed

us to observe not only the individual dimensions of psychological distance but also their multidimensional interaction. To investigate which effects of psychological distance are actually specific to autonomous driving technology, we compared the autonomous conditions to traditional buses. The large sample is another important advantage of our study as it strengthens the validity of the current results. In total, we obtained three main findings:

First, regardless of temporal and social distance, the autonomous bus was better accepted. This contradicts our initial expectation and also previous studies that showed that AVs tend to be met with even more criticism than traditional vehicles (e.g., Clayton et al., 2020; Hewitt et al., 2019. Indeed, autonomous buses were even encountered with considerably more openness. Schandl and Hudecek (2023) were able to identify this phenomenon in a real-life-condition study in which passengers of autonomous and traditional buses were interviewed while driving. Perhaps one reason for this is that AV technology and its advantages over traditional vehicles are now more recognized (e.g., with regard to driving safety or traffic flow, Litman, 2022). Especially in large cities (e.g., Munich or Regensburg), where a significant part of the sample was recruited, there are pilot projects on autonomous buses through which the population might be better familiarized with AVs (Bundesministerium für Digitales und Verkehr, 2021; Hartl, 2021). In addition, autonomous driving assistance systems (e.g., parking or lane-keeping assistants) are meanwhile widely used and allow drivers first contact with autonomous driving technology. Maybe this removes skepticism (N. Sharma & Garg, 2022). For the successful adoption of autonomous buses, the results of our study are a positive outlook because they show that people are open to this new technology. This suggests that autonomous buses might be welcomed even when widely introduced on

the roads and could be a remarkable alternative to traditional buses. This is a promising prognosis for the AV future.

Second, ITU in our study was influenced by social distance, which in turn additionally interacted with temporal distance. The results are consistent with the study by Hudecek et al. (2024), in which subjects accepted AI as an alternative to human medical opinion for others but preferred human judgment for themselves. In the AV context subjects attributed a higher ITU to others than to themselves. However, this effect of social distance in our study is almost entirely due to the results of the temporally distal conditions. For temporally proximal manipulations, this effect was not evident. Rather, subjects actually rated their own ITU higher than the ITU of others in immediate situations, although not significantly. Thus, the two dimensions of psychological distance interacted. The direction of the interaction, however, is surprising. We expected the influence of social distance to be especially crucial in temporally proximate scenarios because the idea of driverless driving should seem more threatening and risky, especially to oneself and again especially under temporal relevance (Lermer et al., 2016a, 2016b). At the same time, we hypothesized that social distance would be less influential in future conditions because temporal distance would make the scenario seem less relevant to the person. This assumption was consistent with CLT, according to which high psychological distance at one level diminishes the influence of psychological distance at another level (Trope & Liberman, 2010). However, our results showed an opposite pattern: especially in future scenarios, social distance was determinant, with a higher attributed ITU for others. One explanation for the discrepancy between the results and the assumptions could be that, according to the authors of the CLT, temporally distal framing favors the clarity of preferences, even if temporally distal events are less tangible (Liberman & Trope, 2003; Trope & Liberman,

2003a, 2003b). Accordingly, the results would be due to clearer decision behavior in the temporally distal condition, which may in turn have made social distance more influential. Another explanation is that the manipulation of psychological distance caused a shift in bus use priorities. As presented earlier, several studies suggest that temporal proximity directs cognitive focus to feasibility, whereas psychological distance favors focus on aspects of desirability (Kim et al., 2009; Sagristano et al., 2002). It is possible that the manipulation of temporal distance resulted in ITU being evaluated once with respect to feasibility and once with respect to desirability, depending on the condition. Thus, with this interpretation, psychological distance would not directly affect ITU. Rather, the distance manipulation would cause a shift in priorities (feasibility vs. desirability) that would result in different ITU ratings. Assuming this shift in priorities, in our study context, this would mean that the autonomous bus would be willingly used if feasibility (i.e., proximal temporal distance), the "how?" is the primary concern (Kim et al., 2009). In terms of feasibility, the autonomous bus seems to be appealing to oneself and also to strangers. If the focus is on desirability (i.e., distal temporal distance), the "why?", we are personally less likely to use the autonomous bus (Kim et al., 2009). In contrast, for other individuals, we suspect a high ITU in this context. The clearer decision behavior or priority shift are possible reasons for the effects of temporal distance on ITU.

Third, the main effect of social distance and the interaction pattern of social and temporal distance emerged not only for autonomous but also for traditional buses, with a higher ITU for autonomous buses across all conditions. This finding is key to the interpretation of our previous results. Indeed, the similarity of the pattern for both driving modalities indicates that our results are less due to the autonomous technology and perhaps more due to the general context of a bus driving experience. If we assume

that decision behavior was clearer in the temporally distal condition, this is also applicable to traditional buses. Also, the priority shift to feasibility (temporally proximal condition) or desirability (temporally distal condition) would thus show up in a similar way for autonomous as well as traditional buses. The suggestion, therefore, is that these findings relate less to autonomous technology and more to the characteristic that underlies both driving modalities, i.e., bus driving.

These results at the same time illustrate that the focus of research on AV adoption should not lie on the acceptance of autonomous buses but on the acceptance of buses in general. In our study, the manipulation of psychological distance affected ITU almost independently of bus modality: The interaction pattern we found for autonomous buses was similarly evident for traditional buses. Therefore, the practical implications apply equally to both autonomous and traditional buses. Buses are accepted and recognized as a viable transportation alternative. Our study provides evidence that buses are accepted primarily when it comes to pragmatic feasibility and less when it comes to desirability. Accordingly, bus providers should, on the one hand, focus their marketing efforts on emphasizing the pragmatic utility aspects of buses (e.g., cost advantage over car use or parking independence). At the same time, the second goal should be to increase desirability, which may be less convincing so far. To make bus riding desirable away from instrumental benefits, the focus should be on hedonic affective factors (Redman et al., 2013). For example, the opportunity for social interaction or productive activities could be more emphasized, or bus travel could be specifically marketed as a relaxing period (Vos et al., 2020). Another key finding is that subjects in the temporally concrete conditions rated their ITU higher. From this, we infer that concrete information on the timely introduction of AVs can favor adoption (Reczek et al., 2018). AV marketing should rely as much as possible on detailed, vivid information that makes

AVs more tangible to potential users. The focus should be more on emotional visual language (e.g., photos of the buses), rather than cognitive verbal language (e.g., slogans), to make mental representations more concrete (Amit et al., 2013; Septianto & Pratiwi, 2016).

Limitations

As with all such studies, some limitations offer opportunities for further research. First, we had to use scenario-based instructions to manipulate the experimental conditions to induce social and temporal distance. For example, subjects were asked to imagine themselves in the perspective of another person using an autonomous bus ten years from now. This allowed us to examine psychological distance from multiple dimensions. Several studies from different fields have shown that scenario-based experiments in particular have a high external validity and produce comparable results to field experiments (e.g. G. Chen et al., 2019; Weyrich et al., 2020; R. Zhang et al., 2023). However, impressions are based on one's own imagination. Therefore, we cannot eliminate the possibility that another dimension of psychological distance was involved in our study: hypothetical distance. Hypothetical distance refers to the extent to which a perception is real (proximal) or imagined (distal). Thus, the scenario-based instruction might have induced hypothetical distance, which in turn acted on or interacted with other levels of psychological distance (Trope & Liberman, 2010). It is possible, for example, that personal involvement or temporal immediacy were perceived as less relevant because subjects knew that the situation was not real (Pronin et al., 2008). It remains unanswered to what extent hypothetical distance had an effect in our study.

Another limitation is the generalizability of our results. Even though our sample was very large, it was not balanced with respect to sociodemographic variables. As a result, it has a higher proportion of female, younger, and academic individuals than the

average population. In particular, gender and age may influence the ITU of AVs (Y. Ding et al., 2022; Dong et al., 2019). The extent to which the results are representative of different populations remains to be verified.

Future Research

The findings and limitations presented above provide a starting point for further examination. Our study yielded surprising findings that open up promising research opportunities. We were able to show that temporal and social distance, especially in their interaction, influence ITU. However, the pattern of interaction was found to be opposite to what was expected: Especially in conditions with high temporal distance, social distance was more influential, with a higher ITU attributed to other persons than to the self. These results highlight the relevance of psychological distance to bus acceptance. A first goal of future studies may be to replicate these results in different contexts (e.g., age groups, cultures, etc.). Furthermore, our study focused specifically on public transport as part of a research project on autonomous shuttle buses. We were able to show that the interaction patterns can be found equally for autonomous and traditional buses. It is therefore conceivable that the interaction pattern is determined by the framework of public transport, instead of the bus modality (autonomous vs. traditional). This raises the question of the extent to which the findings from our study focusing on public transport can be transferred to other vehicles (e.g., autonomous and traditional cars). For example, it is conceivable that people under socially distal conditions generally consider public transport use to be reasonable for environmental reasons, but reject it if they were directly affected, e.g., for reasons of convenience (Eriksson et al., 2013; Stojic et al., 2020). This main effect of social distance could therefore be reversed for private vehicles. These are possibly more convenient for the individual to use, but less sustainable and therefore generally to be less advocated

(Eriksson et al., 2013; Stojic et al., 2020). It remains the task of future research to investigate these questions and assumptions regarding transferability to other means of transportation.

In parallel, further research is needed to clarify the expectation-contradictory results. We derived from the results the assumption that psychological distance could possibly not have a direct effect on ITU but conditioned a change in priorities (feasibility in proximal conditions vs. desirability in distal conditions). This assumption should be investigated in follow-up research, e.g., by additionally assessing the perceived feasibility and desirability of AVs and buses, respectively. This should include an investigation of the extent to which their influence on ITU changes as a function of psychological distance. If the assumption of priority shifting cannot be substantiated, further explanations for the interaction patterns have to be derived and verified. A further logical step is to replicate the results under real conditions. As described earlier, our study was scenario-based. This procedure was necessary to ensure the experimental manipulation of temporal distance and to induce future imagination. Once AVs become widely available, studies should at least manipulate social distance under real-world conditions, e.g., by allowing subjects to decide whether they themselves or other people prefer to use a real (autonomous) bus or car to drive a certain distance. In this way, possible influences discussed in the limitations could be controlled, e.g., by the hypothetical distance, and results could be validated.

Conclusion

Our study represents an initial attempt to investigate the influence of psychological distance on AV acceptance. Our aim was to investigate how psychological distance affects ITU of autonomous vs. traditional buses. Our extensive 2x2x2 experimental study yielded surprising findings. It showed that psychological

distance has a significant effect on the acceptance of both autonomous and traditional buses. According to these findings, we were able to derive practical implications for ITU and the acceptance of buses. Future studies can address these findings and develop them further.

General Discussion

This dissertation followed the overarching goal of examining previously largely unexplored aspects of psychological acceptance research on autonomous driving to derive practical recommendations for the successful implementation of AVs in street traffic.

Specifically, the goal of study 1 was to identify AV user groups based on key personality characteristics. Four distinct personality patterns were identified that are predictive of ITU. Personality traits around self-confidence, general anxiety and affinity for technology proved to be particularly relevant. The study integrates the existing research on the key personality traits associated with AV acceptance into an overall framework and thus fills an important research gap. To the research team´s best knowledge, this study is the first to analyze user groups regarding AVs based on personality using latent profile analysis. These user groups enable AV developers and providers to address user needs in a more differentiated way and to promote AV acceptance purposefully and as a function of the user's personality.

Study 2 builds on the user group analysis (study 1), in which general anxiety was found to be a relevant indicator of user group membership. The evidence of studies in this regard is inconsistent, with recent findings surprisingly suggesting that more anxious people are more open to AVs (Qu et al., 2021). However, it is currently unclear to what extent this initially surprising positive association is mediated by third variables. Therefore, the aim was to re-examine this relationship as a function of fear of giving up control and bus modality. A quasi-experimental data collection with passengers of autonomous and traditional buses revealed that people with higher trait anxiety were indeed more likely to use buses, independent of fear of giving up control and bus modality. Study 2 thus extends the existing findings on trait anxiety and AV acceptance

and shows that the possibility of giving up control is not a sufficient explanation for this association, contrary to the assumption of Qu et al. (2021).

In study 3, we investigated the extent to which ITU depends on being personally affected, in terms of psychological distance at the social level (relevance to me vs. to another person) and temporal level (relevance today vs. in 10 years). The social dimension was found to be most relevant in terms of psychological distance, with subjects attributing a lower ITU to themselves than to strangers. Temporal distance interacted with social distance, with the effect of social distance being most evident for future scenarios. Under high temporal distance, respondents attributed a higher ITU of AVs to strangers than to themselves. The same interaction pattern was also shown for traditional buses, whereby the ITU of AVs was significantly higher. These results indicate that psychological distance, among other technologies (e.g., Abraham et al., 2019; Bagratuni, 2021; Hudecek et al., 2024), also plays a significant role in the acceptance of AVs. To the research team´s knowledge, this study is the first to date to consider AV acceptance from the perspective of psychological distance. It highlighted an important approach to foster AV acceptance and allowed us to derive concrete practical interventions for AV implementation, e.g., with regard to marketing communication. Psychological distance should be urgently addressed as an influencing factor in understanding AV acceptance as a holistic concept.

Across all studies, a positive picture emerged regarding AV acceptance. Even though concerns may still play a role in this regard and part of the population still seems to be skeptical about AVs (see study 1), the subjects nevertheless proved to be open to AVs. In study 3, the willingness to use autonomous shuttle buses was even greater than the willingness to use traditional buses. These findings suggest a positive prognosis for the successful widespread adoption of AVs.

Limitations

For a reflected interpretation of the study results, possible limitations are to be discussed. Since the limitations of the individual study projects were already addressed in the study papers, central and cross-study limitations will be discussed in this section.

Generalizability to AVs

First, attention must be drawn to the still pending evidence on the generalizability of the findings in this research project. The generalizability is still preliminary and needs to be investigated in further research in several respects. One important aspect is, besides others, the generalizability of the study findings to other AVs, which cannot be conclusively evaluated yet. All studies were conducted in the context of the Autonomous People Mover Regensburg project and accordingly dealt with the acceptance of autonomous driving technology, especially of level 3 shuttle buses. Especially for public transport, autonomous driving technology offers enormous potential for establishing alternative transport concepts, e.g., ridesharing or driving on demand (Gurumurthy et al., 2019; Jones & Leibowicz, 2019). This makes it even more important to develop an in-depth understanding of potential factors influencing ITU, especially for shared autonomous mobility. Consequently, the results are predominantly interpretable in relation to autonomous shuttle buses. Previous research has already shown that acceptance for autonomous shuttle buses is higher compared to other shared autonomous transport modes, possibly because autonomous shuttle buses are more widespread and low-threshold to use than other autonomous transport concepts, such as autonomous ridesharing (Chng et al., 2022). Thus, it will be necessary to expand the studies to a wide variety of application contexts and modes of transportation to determine the extent to which the findings can be generalized. According to the current state of the law, fully autonomous driving vehicles have not yet been approved for public transport in Germany

to date (Gesetz zur Änderung des Straßenverkehrsgesetzes und des Pflichtversicherungsgesetzes – Gesetz zum autonomen Fahren, 2021). In the video presentation of study 1 and with the survey of real bus passengers in study 2, level 3 autonomous buses were addressed (Komarnicki et al., 2020). The buses thus drove on circumscribed routes and were accompanied by a human operator who took over driving control when needed. As development progresses, fully autonomous driving will be approved for road use in the future (Altenburg et al., 2018). In this process, it will be necessary to verify the results from studies 1 and 2 for fully autonomous driving as well.

Sociodemographic generalizability

Complementary to this, the second limitation relates to the sociodemographic generalizability of the presented studies. To ensure the highest possible statistical power, large sample sizes were determined a priori for each study. Thus, the recruitment of students, especially those majoring in psychology, was decisive to recruit enough subjects for participation. The samples had therefore an above-average proportion of women and students below the German population-representative age average (study 1: 26.19 years, study 2: 26.68 years, study 3: 26.20 years), which was 44.6 years in 2022 (Statistisches Bundesamt Deutschland, 2023). Gender, age, and education level may have an influence on the AV acceptance (Y. Ding et al., 2022; Dong et al., 2019). Therefore, replicating the studies in further, however smaller, sample compositions, e.g., for older or less-educated demographic groups, is recommended to achieve a more comprehensive understanding of AV acceptance in the population.

Impact of pandemic-related social distancing regulations

Another limitation is the data collection period of the studies that were conducted during and after the Covid 19 pandemic. Due to the risk of infection, the population was

encouraged to engage in social distancing; in some cases, public transportation was therefore stopped completely or was only accessible under strict regulations (e.g., existing Corona vaccine protection, N95 masks). There is already evidence that willingness and well-being to use public transport was reduced by Covid measures (Kopsidas et al., 2021). It might be that, especially during this time, public transportation was associated with fears or skepticism related to the risk of infection rather than related to autonomous driving technology. This may have had a diminishing effect on the general ITU. Future studies should examine this by controlling for fears related to social contact and infection.

Practical Implications

A central goal of the abovementioned studies was to derive practical implications that favor the successful introduction and adoption of AVs. In addition to the study-specific conclusions, which are already discussed in the respective papers, the practical findings will be placed in relation to another and considered from an overarching perspective.

Overall, all studies showed a predominantly positive attitude towards AVs. This indicates that potential users are already open to the new technology even before its widespread implementation. Since all three studies focused primarily on public autonomous shuttle buses, it can be assumed that shared mobility concepts, in which the passengers are unfamiliar with each other, are also accepted and interesting for potential users. Moreover, in study 3, the ITU of autonomous buses was even higher than for traditional buses. It is possible that the advantages AVs have over human-driven vehicles (e.g., reduced accident risk, more efficient driving behavior, Litman, 2022) are already well known. Overall, therefore, a positive picture of AV acceptance is emerging.

Together, studies 1-3 show that the person plays a significant, barely ignorable role when considering the factors for successful AV adoption. The user's perspective and

associated needs in relation to AVs can differ significantly. The four user groups that were identified in study 1 each represent a significant proportion of the sample and therefore probably also of the population. This makes it even more important that providers and developers of AVs are familiar with these groups and respond to their characteristics and needs by introducing targeted measures. For insecure people, it is important that fears and concerns about AVs are addressed. There is another group alongside the generally anxious group whose anxiety is predominantly related to technology. Recognizing that, AV providers should ensure that their measures cover the needs of both groups. In addition to general anxiety-reducing measures (e.g., a pleasant driving atmosphere with quiet music or a conservative driving style, Bellier et al., 2020; Dillen et al., 2020; van der Weijden et al., 2022), technology-related concerns should therefore also be addressed, e.g., through information campaigns on the technical function and road safety of AVs. The different measures are not mutually exclusive but can complement each other to meet the demands and needs of each user group.

The user group analysis also showed that there are groups of the population that are more tech-savvy and are therefore possibly closer to AVs than others. Conversely, it is also reasonable to assume that technology-averse groups without in-depth knowledge of autonomous technology view AVs even more abstractly or have a greater psychological distance to this technology. As described in study 3, aspects of desirability are primarily considered in the case of greater psychological distance, while aspects of utility are primarily considered in the case of psychological proximity. To address the technology-averse user group in particular (high psychological distance), AV providers should therefore focus on desirable aspects of AVs, e.g., the sustainability of electrically powered AVs or the increase in general road safety through AVs (Litman, 2022). People with an affinity for technology, on the other hand, can be attracted to AVs primarily

through pragmatic arguments of usefulness, e.g., reaching their destination as quickly and efficiently as possible (Litman, 2022).

An important factor that influences AV acceptance according to the findings in studies 1 and 2 is giving the control to an external system. This proved to be an inhibiting factor for ITU in both studies. Interestingly, this association was found not only for autonomous technology, but for buses in general (study 2). This suggests that control is not handed over willingly both to an AI and to a human driver. It can therefore be advisable for developers and providers to create perceived control opportunities for users through system transparency, e.g., using displays with current driving parameters (speed, braking behavior, etc.) or targeted intervention options (e.g., emergency button for emergency braking, Nordhoff et al., 2020). This can reduce the feeling of handing over total control to an external entity and thus contribute to adoption.

The challenge of autonomous shuttle buses is to integrate the different demands and needs of the various user groups in a way that the buses meet the needs of all groups simultaneously. It will be necessary not to consider the derivations and measures as separate directions, but to implement them in parallel and not to neglect any of the user groups. Another perspective opens when considering the presented findings from a wider point of view and applying them to privately used AVs. Unlike in shuttle buses, the user in private vehicles is not anonymous and the vehicle does not have to satisfy several interests at the same time, but those of the vehicle owner. This allows private AVs to be adapted even more closely to the user's needs if these are known. With the help of AI, user data could be systematically analyzed and classified to adapt the private AV to the personality pattern and user characteristics of the vehicle owner, e.g., in terms of provision of information, design or driving behavior (L. Chen et al., 2023). This could make the interaction between humans and AVs even more effective and enable AVs to

meet the users' needs more precisely (L. Chen et al., 2023). The identification of user groups creates an important initial prerequisite for this use case. Based on the personal data, AI could assign the user to the appropriate user group and derive needs and acceptance-promoting measures from the user group membership. This ensures that the individual needs of the user groups within the population are met in a targeted manner.

Research Implications

In the publications of the separate studies, a specific outlook for future research was already provided. In this section, these implications will be expanded with some general and overarching perspectives for upcoming research on AVs.

The first research perspective is the consideration of further informative outcome variables. In the presented research, the focus was primarily on ITU as a key outcome variable. ITU is a well-established construct in technology acceptance research that has been shown to predict actual use of a technology and is part of central models (e.g., MAVA, Nordhoff et al., 2019; UTAUT 2, Venkatesh et al., 2012). In the AV context, ITU has also been taken up as an indicator of adoption or use in numerous studies (e.g., Kaye et al., 2021; Keszey, 2020; Séjournet et al., 2022). Compared to technologies that did not exist before and were newly developed (e.g., ChatGPT), autonomous driving technology is an evolution of traditional vehicles. The latter are thus always available to the user as a traditional alternative, so that the user not only decides whether to use the technology in general, but also whether to choose to use the new one over the existing, familiar driving technology. Therefore, for further research, in addition to ITU, intended or actual behavior change may also be a relevant outcome variable, indicating whether a person actively chooses to use AVs despite having previously used traditional vehicles. Behavioral change should therefore be given greater consideration in future research on AVs as it is already done in other areas which demand an active commitment to change

in behavior., e.g., in relation to climate change mitigation (van de Ven et al., 2018) or health promotion (Laverack, 2017).

Second, autonomous driving technology is currently hardly widespread. Autonomous cars or buses operate at the moment mainly for testing purposes and with appropriate safety measures (e.g., with a human operator present to intervene in case of emergency, Ainsalu et al., 2018). It is possible that "preferences toward AVs may change with market penetration, technological developments, government policies, pricing, and so forth" (Jing et al., 2020, p. 15). Accordingly, it is currently still open to what extent the perception and assessment of AVs in the population will develop when AVs are available broadly. Therefore, one of the most significant tasks of future AV research will be to revisit the findings in 20 to 35 years, when AVs are a reliable part of everyday traffic (Litman, 2022).

Third, a major research priority is to examine practical implications. In this research project, great emphasis was placed on generating valuable insights for AV implementation. The core of each study was therefore to derive practical implications that AV developers and providers can use to address user needs in a more targeted way and thus establish AVs even more successfully. The next logical step will be to further investigate the assumptions and implications that were derived. For example, future research can analyze how the four different user groups react to user group-specific measures to increase AV acceptance (e.g., AV information campaigns for the technology-anxious user group 2 or targeted marketing measures for the technology-enthusiastic user group 4) or how different user groups interact and influence each other when they use AVs together. Another interesting practical question is which measures, for example, prove effective in creating the right degree of psychological distance in the AV context.

The studies of this dissertation project provide an initial empirical basis to further explore these approaches and successfully apply the findings to AV practice.

Fourth, according to current knowledge, in addition to psychological factors, vehicle characteristics, the social environment, or various sociodemographic variables also influence the adoption of AVs (Nordhoff et al., 2019). Even if the results prove to be individually valid and replicable, it is to be expected that multiple impact factors on AV adoption interact with each other. Therefore, another goal is to further examine the findings in terms of their interactions. This step-by-step approach will gradually allow us to understand the previous findings in more depth and, at the same time, to develop an even more holistic picture of the effect factors on AV acceptance.

Conclusion

The findings of this dissertation highlight the relevance of psychological factors to AV adoption research. They also shed new light on the potential of personalized solutions for successful AV adoption. In the progress of the dissertation project, the understanding of how to meet the person of the user as accurately as possible was steadily deepened and important research gaps were addressed. To the best knowledge of the research team, study 1 was the first to uncover patterns in personality traits from which needs-oriented measures to increase AV acceptance can be derived. Trait anxiety proved to be particularly influential for general bus evaluation in study 2. Complementary to these findings study 3 shows- to the research team´s best knowledge for the first time - that individual perception in the form of psychological distance also plays an important role in AV acceptance.

The studies emphasize that users need to be approached with differentiation for successful AV adoption. The user’s personality can be decisive for the perception and evaluation of AVs. This research also provides valuable insights to better understand the

acceptance of new technological developments in general, which are proceeding rapidly in various areas of life. The findings provide new approaches for future research in this field. They can complement and expand the current state of research on AVs with this new perspective that puts the individual person in the spotlight (e.g., by examining previous findings separately for each user group or taking into account different psychological distance dimensions). In addition, the findings allow direct conclusions for the development and marketing of AVs (e.g., for the targeted addressing of user groups or the relevance of measures to enhance perceived control). Findings on the characteristics of user groups, the influence of trait anxiety, and the role of psychological distance can support developers and providers in making AV marketing more human-centric and more targeted to the needs of potential users. The autonomous driving technology is calculable and programmable in its entirety. It is the human user that we must meet with his or her individual perception of his or her needs to successfully integrate AVs into our everyday traffic.

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