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Influences of Personal Driving Styles and Experienced System Characteristics on Driving Style Preferences in Automated Driving

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Abstract: As automated driving technology continues to advance, the question of how users prefer to be driven in their new, more passive role is becoming increasingly relevant. In this paper, a real-world study on a German motorway with 42 participants was conducted to analyze driving style preferences for conditional automated driving, taking the participants' personal driving style into account. In the first part, participants' personal driving style (PDS) was recorded during a manual drive in the first half on a given route. For the second half, participants were asked to demonstrate their desired driving style (DDS) for conditional automated driving. In the second part, participants were driven on the same route in a defensive automated vehicle (AV) while rating driving comfort and safety. Subsequently, the relationship between driving style differences and ratings was analyzed. Furthermore, a comparison between PDS and DDS was performed. The results show that very defensive to moderate drivers perceived the AV's driving style, being similar to their own, as equally safe but significantly more comfortable than moderate to very aggressive drivers. No influence of driving style differences was found on the increase in trust. However, a significant increase in trust after experiencing an automated vehicle has been observed. Furthermore, the rated system characteristics of anthropomorphism, safety, and overall driving strategy had a significant influence on driving style preferences for AVs. This study makes an important contribution to answering the question of how users want to be driven in conditional automated driving.

Keywords: autonomous driving; driving style; trust; human-like; driving strategy

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1. Introduction

Automated driving is a rapidly evolving technology with the aim to revolutionize transportation by eliminating the need for human drivers. The predicted potentials of automated driving include increased driving comfort and safety, traffic flow optimization, reduced emissions, and enhanced mobility for people with disabilities or limited access to transportation. A common framework to classify different levels of automation is the SAE standard J3016 [1]. The framework categorizes the degree of automation into six levels, starting with Level 0, representing manual driving with no active assistance systems, up to fully automated driving without the need for a driver in Level 5. The introduction of active driver assistance systems up to Level 2 in the past decades has continuously increased the safety of passengers in critical driving situations [2]. Although Level 2 systems are already actively controlling the longitudinal and lateral vehicle guidance simultaneously, the driver is still obligated to monitor the system. The next step towards fully automated driving is, therefore, Level 3 (L3), also described as conditionally automated driving (CAD). L3 is the first level in which the driver is not required to continuously monitor the automated system under specific conditions, enabling users to spend their time with non-driving-related activities.

With the shift of responsibility to the automated system, the role of the driver also changes to that of a passenger [3,4], raising the question of how users want to be driven when they are no longer in control of the driving task. Do users prefer their own or a different driving style in automated driving? Only a few studies have started to investigate this question in recent years with the majority using driving simulators. A common approach for investigating user preferences is to let users experience different driving styles in comparison. The driving styles are either predefined or a prerecording of the user's own driving style. Refs. [5,6] found that both defensive and aggressive drivers prefer a defensive style. Ref. [7] comes to the same conclusion for defensive drivers, but found no tendency for aggressive drivers. Refs. [8,9] analyzed driving style preferences in relation to participants' prerecorded own driving style without considering driver types. Whereas participants preferred their own driving style in [8], a more defensive style compared to participants' personal driving style was preferred in [9] for all driving situations except for lane change maneuvers, for which a more aggressive style was preferred. Refs. [3,10,11] analyzed driving style preferences for lane changes on motorways. Without considering the driver type or recordings of participants' driving styles, all studies found that participants preferred a defensive driving style.

The presented automated driving styles differ in characteristics of driving dynamics and driving strategies with regard to interaction with other road users and the environment. Under the assumption that drivers will expect their AV to drive like a human, many research papers focus on analyzing [12–14] and learning human-like driving behavior for AVs [15–19]. The goal of human-like driving behavior is to include human driving conventions to increase ride comfort and safety as well as predictability for other road users [20]. Human-like features in AVs, including driving behavior, are also studied in many papers under the term anthropomorphism [21,22].

Whether a driving style is preferred for automated driving is often determined by assessments of comfort, safety, and trust. Although definitions for comfort and safety in the field of automated driving can differ depending on the research question, both can be measured by the absence of discomfort and danger or on one dimension from a negative to positive value range representing different degrees of comfort or discomfort. In [23], trust in automated systems is defined as "an attitude that a user is willing to be vulnerable to an action from an automated system". Trust is seen as a key factor in the acceptance and usage of automated driving technology. Therefore, a considerable amount of literature focuses on understanding trust in the context of automated driving and how it can be increased to meet user expectations [7,24–26].

Due to the small number of studies investigating driving style preferences for automated driving and their varying focus on different driving scenarios and maneuvers, it is not yet possible to derive a clear picture of how users want to be driven in an automated vehicle (AV). Consequently, this study aims to further contribute to answering the question of how users want to be driven by analyzing the influence of personal driving styles on the perception of comfort, safety, and trust in conditional automated driving. In addition, a new approach is introduced to identify user preferences for automated driving by giving participants the opportunity to demonstrate their desired automated driving style through manual showcasing and comparing it to their personal driving style. Furthermore, it is investigated if the perceived anthropomorphism and driving strategy influence whether a presented automated driving style is preferred or not. To complement existing driving simulator studies, a two-part real-world driving study with 42 participants was performed on a German motorway. During the first part of the study, the personal driving style (PDS) and the desired driving style (DDS) for conditional automated driving were recorded on a given route. In the second part, participants experienced a defensive automated driving style (ADS) while seated in the passenger seat of an AV, traveling on the same route as before. Participants were then asked to rate their level of perceived comfort and safety in various driving situations. By comparing PDS with ADS and DDS, it is examined whether a user-like driving style is preferred or rejected for CAD. The ratings for anthropomorphism and driving strategy are collected through a questionnaire. By determining the preferred driving style for CAD and identifying key factors that influence the choice of a presented automated driving style, important implications for the design of future Level 3 driving systems can be derived.

This paper is organized as follows: Section 2 illustrates previous work that serves as the basis for the present study. Section 3 describes the experimental setup and method for analyzing user preferences in automated driving. The results are presented in Section 4, followed by the discussion. The paper ends with a conclusion and an outlook for future research.

2. Literature Review

2.1. Driving Comfort

Driving comfort is an essential component to fulfill customer expectations [27,28]. However, until today, there is no unique definition of comfort [29]. Whereas some studies see comfort and discomfort as two end poles on a single dimension [30,31], others interpret both as independent constructs that can be experienced simultaneously [32,33]. Although no universal definition of comfort exists, Ref. [33] has summarized three aspects of comfort that are commonly shared among a variety of definitions: (1) comfort is subjective and individual; (2) both internal and external factors have an impact on individually experienced comfort; (3) comfort is experienced as a reaction to the environment.

In addition to the absence of a common definition, measuring experienced comfort poses another significant challenge in comfort-related research. In the past, different methods have been introduced to measure comfort. In [34,35], comfort is measured via physiological measures such as heart rate, electrodermal activity, galvanic skin response, and others, whereas [36,37] measures the discomfort via a hand controller. The usage of questionnaires is another approach that is often taken in various studies to measure comfort [38,39].

2.2. Driving Style

In the context of conditional automated driving, the driving style and strategy will become increasingly important for experienced comfort and safety as the driver will have limited predictability of the AV's trajectory and control over the vehicle guidance [10,36,40]. This has also been described as a "loss of controllability" [4]. So far, no universal definition of driving style exists [41]. However, Ref. [41] has summarized three aspects of a driving style that are commonly shared among various definitions: (1) driving styles are relatively stable and habitual; (2) driving styles differ across groups and individuals; (3) driving styles reflect conscious decisions made by the driver.

A common approach to describe a driving style is to use objective parameters such as vehicle kinematics and environment context. In the past, a variety of parameter representations have been introduced, such as time series data [3,42], statistical characteristics [7,43,44], or latent variables, representing a dimensionless combination of different parameter types [9,45,46]. In order to differentiate between various driving styles, classification techniques such as manual or data-driven methods are commonly applied. These techniques typically involve analyzing value ranges or data patterns, which are then followed by subjective categorization using terms such as "defensive", "moderate", or "aggressive" [41].

Driving styles can also be differentiated based on their strategies for direct vehicle control, interaction with other traffic participants, or behavior in specific environments, as discussed in various studies [47]. For instance, different deceleration profiles for approaching a slower lead vehicle have been presented as examples of different strategies used for vehicle control [10,36]. In another study, the behavior of an autonomous vehicle affected whether a cut-in vehicle changed lanes in front of or behind the autonomous vehicle [7] as an example of different strategies for cooperation. In the case of specific environments, Ref. [21] presented different approaches for passing through an intersection. One strategy involves cautious, human-like behavior, whereas the other involves machine-like behavior that conveys a sense of prior knowledge about the environment and other oncoming road users.

Many studies suggest that human-like driving behavior will increase user trust, acceptance, predictability, and ride comfort and safety [18,22,48]. Human-like driving can be learned from large naturalistic data sets [13,49], expert demonstration [14,16], or random subject collectives [50]. A slightly different approach to learning a driving style was taken by [15], specifically asking participants to demonstrate their desired driving style for an automated vehicle through manual driving instead of recording their everyday driving style. The aim of human-like driving styles is to incorporate common driving conventions of human drivers, including in-lane positioning in curves [51], distance regulation for car-following [17], crossing behavior for intersections [52], and others. The use of virtual agents in AVs with human-like features such as voice and appearance [22,53–55] is an additional approach to create an even stronger impression of a human-like automated vehicle, which is also referred to as anthropomorphism in the literature.

Preferences for automated driving have been analyzed for different maneuvers such as lane changes [8,10,11,36,43], car-following [56–59], decelerating to a slower lead vehicle [10,36], or across different maneuvers and scenarios [6,7,25,26]. A common approach by previous studies in this context is to let users experience a predefined driving style in comparison with other driving styles or their own prerecorded driving style, using driving simulators. A Wizard-of-Oz setup was used by [6,36]. The amount of studies investigating driving style preferences for automated driving is considered small. In addition, studies differ in terms of driving environments such as urban, rural, or motorways and whether preferences are evaluated in relation to [5–9] or independently of participants' personal driving style [10,11,36,43], making it yet difficult to derive a clear picture of how users want to be driven in an automated vehicle.

With regard to age-related differences, Refs. [3,60,61] have investigated how age affects the experience of different automated driving styles for various maneuvers on rural and motorway roads. All studies involved participants experiencing their own driving style and up to two predefined automated driving styles. Ref. [3] found that both younger and older participants preferred the driving style of a younger driver, whereas younger drivers in [60] preferred a defensive driving style, showing the greatest rejection of their own driving style in terms of safety and comfort. Results of [61] show that older drivers prefer their own style when compared to a more aggressive automated driving style.

2.3. Trust

Trust has proven to be a critical factor for the acceptance of automated vehicles [24,62,63]. Without appropriate levels of trust, users may not feel comfortable using and relying on driverless technology, preventing them from fully taking advantage of its potential benefits [64–66]. Similar to the terms comfort and driving style, various definitions exist for trust as it is seen as a multidimensional concept. However, Ref. [62] has summarized three aspects that are commonly shared among a variety of definitions: (1) trust is given by a truster to a trustee with something at stake; (2) in order for the trustee to perform the task, an incentive must exist. In the case of technology, the designer's intended use of the system serves as the primary incentive for the trustee; (3) trust involves the possibility of the trustee failing to perform the task, leading to uncertainty and risk. Trust is commonly assessed using questionnaires [7,10,21]. Ref. [26], on the other hand, measured trust via acceleration and brake pedal inputs by the user, expressing their dissatisfaction with the driving style.

Various studies investigated which factors affect users' trust in an automated vehicle and how it can be increased. References [67–69] focused on how information displayed to the driver can help to increase trust, whereas [7,10,21,26,70] analyzed the influence of driving styles on users' trust, all coming to different conclusions. Whereas the simulator study results of [7,26] suggest that automated driving styles that align with the user's personal driving style increase trust, no influence of driving style on trust was found in [10,21]. However, it has been observed that trust can increase over time with repeated experience of an AV [21,62,71,72].

2.4. Research Gap

With the changing role of the driver in conditional automated driving, understanding user preferences becomes an important factor for the acceptance of this new technology. The studies introduced in Section 2, therefore, provide first important insights into the question of how users would like to be driven in their role as a passenger. However, due to the small number of studies and their varying focus on different driving environments and situations, further research is necessary to fully understand how users want to be driven in an AV.

As the majority of existing studies in this context are conducted in driving simulators, it is essential to also conduct studies on public roads to take advantage of the complementary benefits of both methods in analyzing user preferences in automated driving. Particularly, motorways are of special interest as the introduction of further and enhanced automated L3 systems or higher is most likely for this road type. The present study is, therefore, conducted on a German motorway around Stuttgart. Furthermore, a new approach is chosen to analyze user preferences by calculating the difference between the experienced automated driving style and the participants' personal driving style.

As a result of loss of control through possible delayed interventions by the driver due to non-driving-related tasks and limited predictability of the AV's trajectory, we hypothesize that participants prefer a more defensive driving style than their own for automated driving (H1). For the same reasons, we further hypothesize that participants who experience an ADS that is more defensive than their PDS show a higher increase in trust than participants who experience an ADS that is equal or similar to their PDS (H2).

In addition to a large field of studies focusing on extracting and learning human-like driving behavior, the present study analyzes how human-like driving behavior is perceived in an automated vehicle. Under the assumption that human-like driving behavior is preferred for automated driving, we hypothesize that participants who prefer the presented automated driving style also perceive the AV as more human-like (H3) compared to participants who do not prefer the presented automated driving style.

Whereas a variety of studies focus on developing driving strategies for different maneuvers and scenarios, only a few studies focus on the influence of driving strategies on driving style preferences in automated driving. We, therefore, specifically asked participants to rate the overall driving strategy after the experienced automated driving style and analyzed which strategic decisions by the AV were rated during the drive. Under the assumption that the driving strategy influences whether a presented automated driving style is preferred, we hypothesize that participants who prefer the presented automated driving style also perceive the AV's overall driving strategy as more desirable and comprehensible compared to participants who do not prefer the presented automated driving style (H4).

The methodology for determining preferred driving styles in automated driving also shows potential for new approaches. In previous studies, participants were only able to choose from their own or predefined automated driving styles. Although participants were asked in [15] to demonstrate their desired driving style, the primary objective of the paper was to utilize reinforcement learning to acquire driving styles for acceleration and lane change maneuvers within a specific velocity range. However, the analysis of the learned driving policies and their presentation to the participants is left open for future work. Therefore, we also asked participants in this study to demonstrate their desired driving style for automated driving and analyzed their demonstrated driving style to investigate if there are any differences compared to their personal driving style.

3. Method

3.1. Participants

A total of 59 participants took part in this study. All participants are employees of Mercedes-Benz AG who do not work in the field of advanced driver assistance systems (ADAS). The sample was reduced by n = 17 participants, due to the occurrence of long traffic jams and measurement equipment failures. The final sample, therefore, consists of 42 participants, with 27 males and 15 females. The participants range between 23 and 65 years (M = 40.19, SD = 11.29) and hold a driver's license for an average of 22.76 years (SD = 11.19). The participants travel an average of M = 16345.24 km (SD = 6747.56 km) per year with 39% on motorways, 31% on country roads, and 30% in urban areas. Furthermore, the participants spend 6.93 h (SD = 3.28) per week as a driver and 2.57 h (SD = 2.90) as a passenger. The attitude towards automated systems is rather positive for all three scales: Concern (M = 3.49, SD = 0.74); Eagerness to Adopt (M = 3.55, SD = 0.91); Willingness to Relinquish (M = 3.93, SD = 0.72). Whereas the participants show a high affinity for technology (M = 4.81, SD = 0.73), the experience with ADAS can be regarded as neutral (M = 2.92, SD = 0.50) and the usage of these systems as rather low (M = 2.28, SD = 0.77).

3.2. Experimental Setup

The study was conducted on the motorway sections A81 and A8 between Sindelfingen-East and Kirchheim unter Teck-East with a length of 71 km (see Figure 1) and consisted of a manual and a conditional automated drive. Two vehicles of the same model with different equipment lines were used. The suspension settings were set to comfort in both vehicles. Before the start of the first drive, the participants were instructed with the study procedure, the test route was explained, and a preliminary questionnaire was completed.

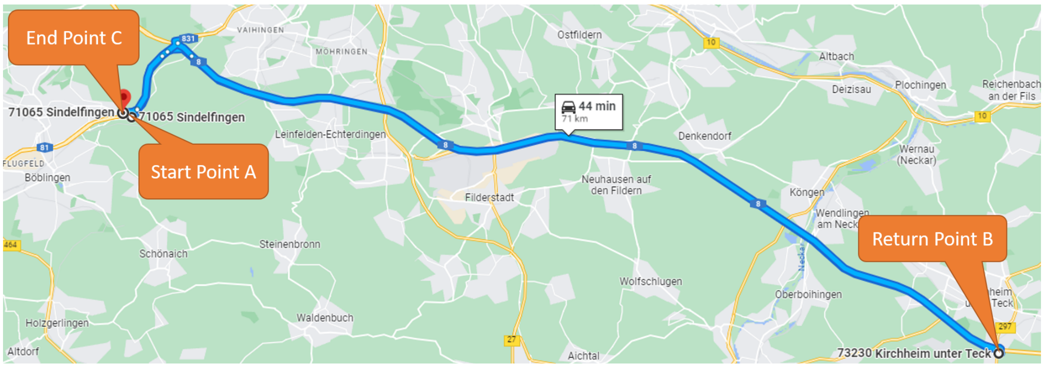

Figure 1. Test route on German motorway A8/A81 between Sindelfingen East and Kirchheim unter Teck East. Section A-B: Recording of personal driving style (PDS). Section B-C: Recording of demonstrated desired driving style (DDS). Section A-C: Recording of automated driving style (ADS). Maps Data: Google, © 2023 GeoBasis-DE/BKG (©2009) [73].

In the first part of the study, participants drove completely manually without the use of active assistance systems on the specified test route, using a navigation system. For the manual drive, an S-Class (W223) with a steering wheel that has no activation buttons for CAD and monochrome paint was used. During the first half of the route from Point A to Point B, the participants' personal driving style (PDS) was measured. In order to keep the influence of the study setting on the personal driving style as low as possible, the participants did not receive any instructions from the experiment leader for their driving behavior and were not informed about the measurement equipment installed in the trunk. Instead, the participants' focus was directed towards familiarizing themselves with the route, which has no effect on personal driving behavior, but plays an important role in the evaluation during the conditional automated drive. Driving the route beforehand prevents evaluation influences caused by unfamiliarity with the route. The first half of the route ends at a parking lot, which is located directly at the exit Kirchheim unter Teck-East (return Point

B). For the way back (B-C), participants are asked to demonstrate their desired driving style (DDS) for an automated L3 system through manual showcasing. After the first drive, participants were asked to fill out a second questionnaire.

For the second drive, the participants changed to a different S-Class (W223). Due to a lack of approval for an L3 system with functional availability at speeds above 60 km/h, the participants sat in the passenger seat and were driven on the same route with a simulated L3 functionality from A to B and back to C. For this purpose, the L2 assistance systems were presented as an L3 system, which was activated and monitored by a safety driver in the driver's seat. In order to further increase the credibility of the L3 functionality for the participants, an S-Class with a steering wheel with two activation buttons for CAD and special external foiling was used for the automated drive. This emphasized the contrast of functionality of the two vehicles for the participants. The safety driver had his hands near the steering wheel while driving but only touched it when the L2 assistance systems reached their limits or to generate variance in the maneuvers. The driving style guideline of the automated test vehicle is characterized as follows:

1. Compliance with traffic regulations such as strict adherence to speed limits.
2. The AV's maximum speed was set to 130 km/h and was based on the recommended speed for motorways of the German Road Traffic Act.
3. The time gap to the lead vehicle was varied in four settings between one and two seconds to analyze user preferences. For each route quarter, one of the four time gaps was set randomly.
4. The in-lane driving path in curves on motorway feeder roads, on- and off-ramps is varied between driving in the lane center and driving closer to the inside of the curve to analyze user preferences. Fifty percent of participants experience one variation in section A-B and the respective other variation in section B-C, whereas the other 50% of participants experience the reverse order of variations.

The participants were informed that lane changes are automatically executed by the test vehicle, but are manually initiated by the safety driver who mimics the logic of the automated L3 system. The former does not apply if the safety driver varies the lane change maneuver manually. Common Wizard-of-Oz setup elements such as curtains that hide the safety driver from the participant were deliberately omitted in order not to raise any doubts about the functionality of the L3 system among the participants.

During the automated drive, the participants verbally rated their perception of comfort and safety for different situations and gave reasons for their decision. The participants were free to choose which situations they wanted to rate. Lane changes and previously defined curves, however, were always rated and queried by the experiment leader. The participants were encouraged to mentally place themselves in the driver's seat during the evaluation and to consider the entire drive as conditionally automated. The safety driver was not to be considered for any rating. The participants were free to rate both positively and negatively perceived comfort and safety experiences. The experiment leader sat in the back seat and documented the participants' ratings. In this way, participants could concentrate exclusively on observing the traffic and maneuvers. The experiment ended with a final questionnaire after the second drive.

3.3. Material

In total, participants were asked to fill in three questionnaires. In the preliminary questionnaire, data on demographics, attitudes towards automated driving [74], experience with assistance systems up to L3, vehicle usage behavior, Affinity for Technology Interaction [75], Trust in an Automated System [76], and assessment of personal driving style were collected. The personal driving style was surveyed via two single-item questions that capture how the participants describe their own driving style on a 5-point scale from (1) calm/balanced to (5) sporty/dynamic and how their own driving style would be described by a co-driver using the same scale. The experience and usage of assistance systems was queried for five different systems on a 5-point scale from (1) no experience to (5) a lot of experience and from (1) never to (5) multiple times per week, respectively. The Trust in Automated Systems questionnaire consists of six items and was asked on a 5-point Likert scale with the end poles (1) strongly disagree and (5) strongly agree.

During the automated drive, participants could rate both comfort and safety in different driving situations on a 7-point Likert scale with a value range from -3 (very uncomfortable/unsafe) to 3 (very comfortable/safe). In the second questionnaire, participants were asked if their demonstrated DDS is equal to their PDS. If the answer was no, the participants were asked to describe the difference between their two driving styles.

In the final questionnaire after the automated drive, data on Trust in an Automated System were collected again. Furthermore, data on the ADS evaluation were collected. The perceived human-likeness of the ADS was rated via the Anthropomorphism subscale of the UX questionnaire [77]. The questionnaire also contains three further subscales: Intelligence, Likeability, and Safety. Each subscale was rated on a semantic differential scale with five gradations. The overall driving strategy was rated with two items on a 5-point scale from (1) very bad to (5) very good and (1) never comprehensible to (5) always comprehensible, respectively. In a multiple-selection question, the participants stated which driving style they would prefer for an automated L3 system: (a) PDS, (b) DDS, (c) ADS, or (d) different with the opportunity to describe with their own words. To investigate how the Wizard-of-Oz setup was perceived, the participants rated which percentage of the automated drive was driven by the system and the safety driver.

3.4. Data Preprocessing

In order to compare the personal and automated driving style for H1 on the basis of comfort and safety, firstly, the driving style had to be quantified by objective parameters. As data for ADS were collected between Section A-C and data for PDS only between Section A-B, the parameters were chosen in a way that minimized the influence of the test route environment. In this paper, the driving style is described by the following four parameters:

1. Maximum longitudinal velocity;
2. Median of time gap;
3. Percentage of time in which the time gap is below 1 s;
4. Percentage of time in which the longitudinal velocity is above the speed limit.

The longitudinal speed is a characteristic parameter often used to describe the driving style of a person. Whereas high maximum speeds are characteristics of a more dynamic driving style, lower values are characteristics of a less dynamic driving style. The time gap measures the time intervall between the test and lead vehicle and is is used to represent the distancing behavior. It divides the distance between the test vehicle's front bumper and the lead vehicle's rear bumper by the test vehicle's velocity. The advantage of the time gap over the distance headway (dhw), measuring only the distance, is the incorporation of the dependency on speed. Therefore, distances at different speeds are better comparable. As the AV's maximum driving speed was 130 km/h, time gaps above 140 km/h for PDS and DDS were not considered for better comparability. The willingness to take risks was measured by the percentage of time in which the time gap is less than one second. For this parameter, no upper-velocity limit was set. For both time-gap-related parameters, the following condition applies. Time gaps at which the longitudinal distance to the lead vehicle is greater than the test vehicle's stopping distance were not considered. They are regarded as a random result of the traffic situation and not as a consciously chosen distance. For the stopping distance, a constant deceleration of $a = 5\,\mathrm{m/s^2}$ and reaction time of $t_r = 1\,\mathrm{s}$ was assumed. Furthermore, the stopping distance included a safety buffer of $s_{sb} = 2\,\mathrm{m}$ in standstill to an object ahead. With the vehicle velocity v, the stopping distance was calculated as follows:

$$s_{stop} = \frac{1}{2}\frac{v^2}{a} + t_r v + s_{sb}. \tag{1}$$

Compliance with traffic speed regulations was taken as a further parameter to describe the driving style of a person. The higher the percentage of time above the speed limit v_{lim}, the more aggressive the driving style is considered. To prevent traffic jams from falsifying the parameter values, values were only considered at speeds greater than 60 km/h. Exceeding the speed limit was, therefore, only taken into account for limits of 80 km/h or higher. The parameter values were normalized across all participants for each parameter. For normalization, time gap values were negated. With this, high and low time gap values have the same meaning with regard to aggressiveness as the other parameters. The average of all four normalized parameters describes the resulting driving style DS. In order to create a reference for the normalized values, an artificial very aggressive (VA) and very defensive (VD) reference driver was defined and added for normalization (see Table 1). The parameter values of the reference drivers were determined on the basis of the test route conditions such as speed limits, average traffic conditions, and collected driving data outside this user study.

Table 1. Parameter values for an artificial very defensive (VD) and very aggressive (VA) driver.

Parameter	Unit	Artificial VD Driver	Artificial VA Driver	Condition
Maximum Velocity	km/h	115	180	No Speed Limit
Median Time gap	s	−2.50	−1.00	60 km/h < $v \leq$ 140 km/h $dhw \leq s_{stop}$
Time gaps below 1 s	%	5	40	$v >$ 60 km/h $dhw \leq s_{stop}$
Time above Speed Limit	%	0	80	$v >$ 60 km/h 80 km/h $\leq v_{lim} \leq$ 120 km/h
Resulting Driving Style DS	-	**0.02**	**0.87**	

DS between 0 and 0.2 was considered as very defensive (VD), DS greater than 0.2 and below or equal to 0.4 as defensive (D), DS greater than 0.4 and below or equal to 0.6 as moderate (M), DS greater than 0.6 and below or equal to 0.8 as aggressive (A), and DS greater than 0.8 and below or equal to 1 as very aggressive (VA).

3.5. Statistical Analysis

The resulting *DS* values of all participants were correlated with their self-reported driving style of the pre-questionnaire using Kendall's tau correlation to compare the perception of driving dynamics across participants. The difference between driving styles was calculated between the *PDS* and *ADS* according to the following formula:

$$\Delta DS = ADS - PDS, \tag{2}$$

The resulting differences were divided into three groups. Positive differences represent a more aggressive (DS_{magg}) and negative differences a more defensive (DS_{mdef}) driving style of the AV compared to the participant's PDS. Differences close to zero represent a driving style that is similar or equal to the PDS (DS_{eq}). The similarity threshold *ST* for differences defining a similar to equal driving style was calculated by Equation (3) and based on two factors.

$$ST = \pm(2\sigma_{ADS} + \Delta DB). \tag{3}$$

Although the AV and safety driver followed a strict driving style guideline, the AV's driving style varied within a certain value range due to different traffic conditions. The first factor, therefore, considers the influence of traffic on the driving style by taking twice the variance of the AV's driving style. The influence of the driver was considered negligible as the driver was trained in replicating the same driving style. In addition, the L2 function was active for more than 75% of the drive on average, which further reduced any potential influence of the driver. The second factor ΔDB represents the difference between two driving styles due to differences in driving behavior and was set to 0.1.

For H1, a Mann–Whitney U-test was used to compare the participants' comfort and safety ratings between the groups' DS_{mdef} and DS_{eq}, as well as DS_{eq} and DS_{magg}. A prerequisite for a group comparison was a minimum number of five participants and ten ratings in each group. Furthermore, the differences and ratings needed to show a significant correlation before a group comparison was performed in order to check if a general relationship between the two parameters could be observed without group classification. For the calculation of the correlation, Kendall's tau was used. For all group comparisons, a Bonferroni–Holm correction was applied. In addition to H1, the PDS and DDS were compared using a paired *t*-test to evaluate if the participants' DDS was more defensive than their PDS. To analyze the increase in trust before and after the AV drive in dependency on the different group classifications of the experienced automated driving style, a mixed ANOVA for H2 was performed.

For H3 and H4, an unpaired *t*-test was used to compare the experienced anthropomorphism and driving strategy that were asked in the post-questionnaire between participants who selected the experienced ADS as their exclusive or one of several preferred driving styles for CAD (Selected ADS) and those who selected among other driving styles for CAD (Unselected ADS). For further analysis of the driving strategy, the comfort and safety ratings for the AV's driving behavior in each rated driving situation were compared between the two groups, using a Mann–Whitney U-test. The driving situation categories were derived based on the participants' verbal feedback about the reasons for their ratings.

To assess a possible influence of the Wizard-of-Oz setup on the perceived anthropomorphism of the automated system, the participants' rated anthropomorphism and the estimated percentage of being driven by the automated system were correlated. For the calculation of the correlation, Pearson was used. Furthermore, a group comparison with regard to the estimated percentage of being driven by the automated system was performed between the groups' Selected ADS and Unselected ADS to examine a possible influence on the preferred DS.

4. Results

4.1. Comfort and Safety Perception of Experienced Automated Driving Style

A total of 2.544 situations were rated during the automated drive. The vast majority of situations were rated positively with values greater than zero. Specifically, 83.73% regarding comfort and 91.75% regarding safety. Ratings with a scale value of 3 represent the highest proportion of all ratings with 55.19% for comfort and 68.32% for safety. Of all situations, 7.11% were rated neutral in terms of comfort and 3.58% in terms of safety. Negative ratings account for a total of 9.16% for comfort and 4.68% for safety.

The participants' PDS includes all types of DS from very defensive to very aggressive. In total, there are 4 participants with a very defensive, 21 with a defensive and 14 participants with a moderate DS. Two participants show an aggressive and one participant a very aggressive DS. Figure 2b shows the resulting DS values for PDS, DDS, and ASD of each participant. The participants are listed in ascending order based on their PDS. The artificial very defensive driver has ID 0, and the artificial very aggressive driver has ID 43.

For the self-reported driving style from the driver's perspective, the values tend to be closer to the rating pole calm/balanced (M = 2.62, SD = 1.02). The values for the self-reported DS from a co-pilot's perspective are significantly higher (M = 2.90, SD = 1.09, $t = -2.75$, $p = 0.009$). For comparison of both self-reported DS, a paired *t*-test was used. The DS values show a high correlation with both the self-reported DS from the driver's perspective ($t = 0.49$, $p < 0.001$) and from a co-driver's perspective ($t = 0.45$, $p < 0.001$). Figure 2a shows the resulting PDS over both self-reported DS.

The ADS ranges between 0.13 and 0.23 with a mean value of M = 0.18 (SD = 0.03). Hence, the similarity threshold defining a similar to equal DS results in $ST = \pm 0.16$ by using Equation (3). Based on this threshold and the driving style differences from Equation (2), 23 participants with a DS ranging from 0.09 to 0.38 experienced an ADS similar or equal to their PDS. A total of 19 participants with a DS ranging from 0.30 to 0.89 experienced an ADS that is more defensive than their PDS. Due to the defensive to very defensive DS of the AV, no participant experienced an ADS that was more aggressive than their PDS. Prior to performing a group comparison for comfort and safety, the data were checked for a correlation to see if a general relationship between the DS differences and ratings existed. The DS differences show a significant correlation with comfort ($\tau = 0.09$, $p < 0.001$) but no significant correlation with safety ($\tau = 0.00$, $p = 0.982$). Therefore, a group comparison was performed between the groups DS_{mdef} and DS_{eq} with regard to comfort, as shown in Figure 3a. Since only two groups result from categorization, no Bonferroni–Holm correction is applied. Participants in group DS_{eq} show a higher comfort rating (M = 2.26, SD = 1.17) than participants of group DS_{mdef} (M = 1.83, SD = 1.57, $U = 892226.5$, $p < 0.001$). The participants' PDS (M = 0.38, SD = 0.16) and DDS (M = 0.36, SD = 0.15) show no significant difference ($t = 1.11$, $p = 0.272$). Figure 3b shows the value range of both driving styles.

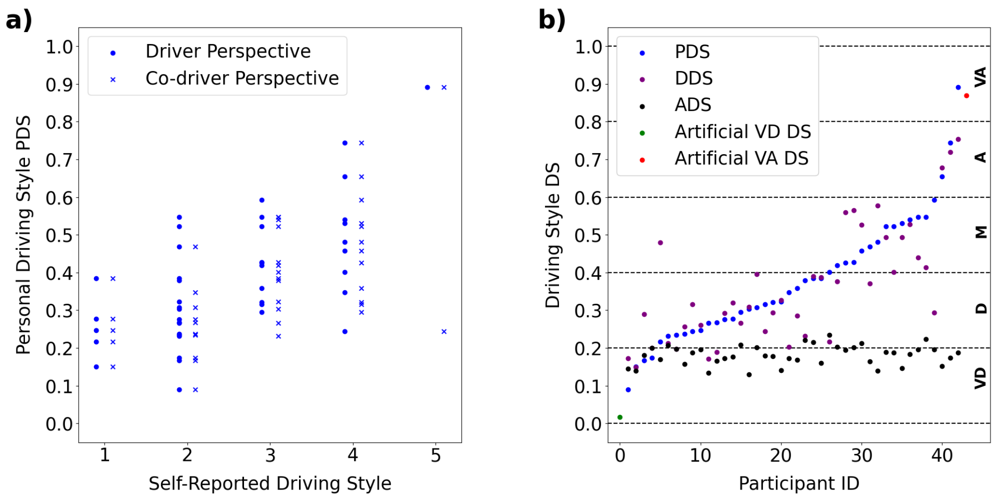

Figure 2. (**a**) Comparison of self-reported DS from the driver's perspective and from a co-driver's perspective with the calculated personal driving style (PDS) values. The endpoles 1 and 5 on the x-axis represent a calm/balanced and sporty/dynamic driving style, respectively. (**b**) Calculated DS values for personal driving style (PDS), desired driving style (DDS) and automated driving style (ADS). The artificial drivers are marked with green (very defensive) and red (very aggressive). The driving style categorization VD, D, M, A, and VA is described at the end of Section 3.4.

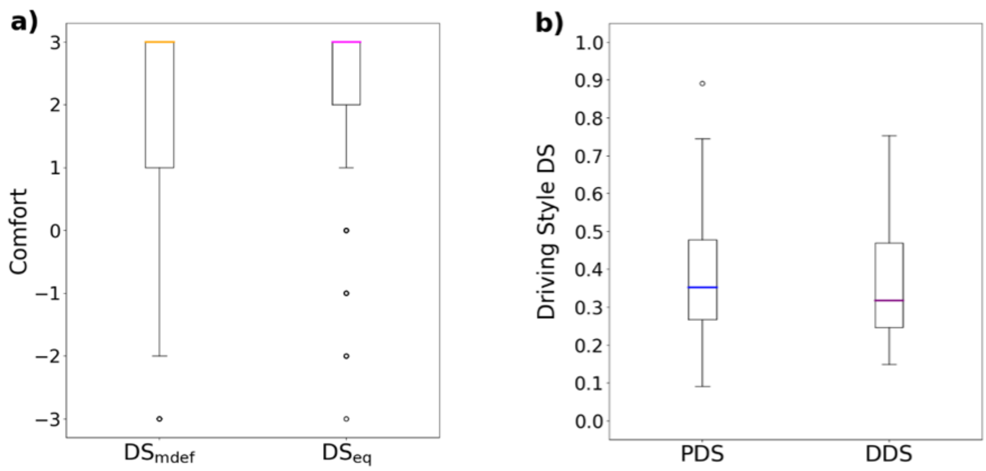

Figure 3. (**a**) Comparison of comfort ratings between participants who experienced a more defensive ADS compared to their PDS (DS_{mdef}) and participants who experienced an ADS similar or equal to their PDS (DS_{eq}). (**b**) Comparison between participants' personal (PDS) and desired (DDS) driving style.

4.2. Drivers' Trust and Experienced Automated Driving Style

As shown in Figure 4, no significant interaction effects on trust between the experienced ADS relative to participants' PDS and time of survey before and after the AV drive was found ($F(1, 40) = 2.00$, $p = 0.165$). Also, no main effect was found for the experienced ADS ($F(1, 40) = 0.09$, $p = 0.764$). However, a significant main effect was found for the time of survey before (M = 3.47, SD = 0.43) and after the AV drive (M = 3.64, SD = 0.43, $F(1, 40) = 8.22$, $p = 0.006$), showing an overall increase in trust after the AV drive.

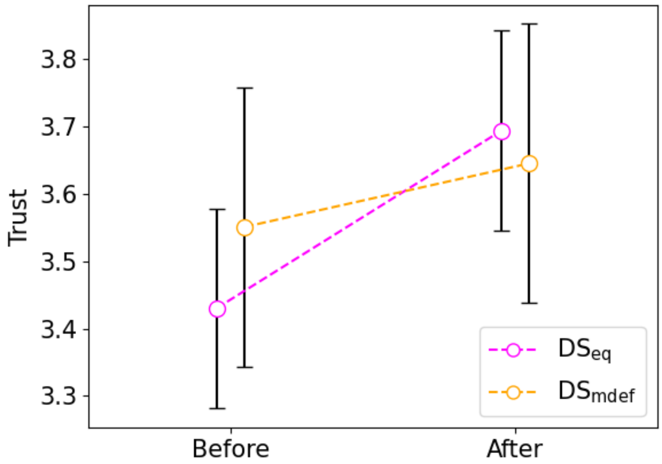

Figure 4. Effects of experienced automated driving style (ADS) relative to participants' personal driving style (PDS) and time of survey before and after the AV drive on trust (confidence intervals: 95%).

4.3. Experienced System Characteristics and Automated Driving Style Preference

When reporting the preferred driving style, 26 participants selected ADS as their exclusive or one of several preferred driving styles for conditionally automated driving (Selected ADS), whereas 16 participants selected among the options personal, demonstrated, or other driving style (Unselected ADS). The mean rating of Anthropomorphism, Likeability, Intelligence, Safety, and Overall Driving Strategy within the group Selected ADS is above four and, therefore, considered high on all scales (see Table 2). Similar results can be seen for the group Unselected ADS.

Participants of the group Selected ADS perceived the experienced automated driving style as significantly more anthropomorphic and safer than participants of the group Unselected ADS. No correlation was found between the rated anthropomorphism and the estimated percentage of being driven by the automated system ($r = -0.024$, $p = 0.879$). Furthermore, the overall driving strategy is rated significantly better and perceived as more comprehensible in group Selected ADS. No difference was found for Likeability and Intelligence (see Table 2).

Table 2. Comparison of perceived system characteristics between group Selected ADS and group Unselected ADS.

Scales	Selected ADS M (SD)	Unselected ADS M (SD)	*t*	*p*
Anthropomorphism	4.35 (0.40)	3.80 (0.74)	2.71	0.013 *
Likability	4.44 (0.46)	4.20 (0.61)	1.34	0.191
Intelligence	4.33 (0.46)	4.09 (0.56)	1.46	0.156
Safety	4.56 (0.46)	4.25 (0.45)	2.19	0.036 *
Overall Driving Strategy				
Assessment	4.54 (0.51)	3.94 (0.86)	2.55	0.018 *
Comprehensibility	4.31 (0.47)	4.00 (0.37)	2.37	0.023 *

Note: * $p < 0.05$.

For further analysis of the overall driving strategy, the rated driving situations are taken into account. Based on the participants' verbal feedback about the reason for their rating, 99 different categories were derived that describe the respective driving situations. Out of 43 rated driving situation categories that have been mentioned at least ten times, 7 have been identified showing a significant difference in comfort and/or safety ratings between the groups Selected ADS and Unselected ADS (see Table 3). The meaning of each category is explained in Table 4. Interestingly, the majority of participants did not know about the correct rules for when it is allowed to overtake on the right side. A common assumption was that thicker lane markings would always allow overtaking on the right side without any further conditions.

Table 3. Comparison of comfort and safety ratings between group Selected ADS and group Unselected ADS in different driving situation categories.

Rating Criteria	Driving Situation Category	Selected ADS M (SD)	Unselected ADS M (SD)	U	p
Comfort	Reaction to Speed Limit	2.36 (0.97)	1.36 (1.87)	1512	0.013 *
	Deceleration to Lead Vehicle: Intensity	2.26 (1.01)	0.79 (1.93)	228	0.027 *
	Driving Path in Curve	2.46 (0.71)	1.71 (1.47)	1937	0.012 *
	Deceleration in Curve	1.88 (0.93)	0.75 (1.54)	147	0.037 *
	Lane Selection	0.21 (1.22)	−1.21 (1.28)	453.5	<0.001 ***
Safety	Reaction to Speed Limit	2.68 (0.77)	2.06 (1.48)	1502.5	0.006 **
	Deceleration to Lead Vehicle: Intensity	2.70 (0.70)	2.07 (1.14)	221	0.027 *
	Driving Path in Curve	2.33 (0.80)	1.67 (1.46)	1882	0.033 *
	Overtaking on the Right	2.60 (0.97)	0.45 (2.21)	84.5	0.023 *
	Lane Change Right: Decision	2.76 (0.60)	1.95 (1.73)	661	0.038 *

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4. Explanation of the Rated Driving Situation Categories.

Nr.	Rated Driving Situation Categories	Meaning
1.	Reaction to Speed Limit	Timing and intensity of deceleration in front of a speed reducing speed limit sign and acceleration behind an increasing speed limit sign.
2.	Deceleration to Lead Vehicle: Intensity	Deceleration intensity when approaching a slower lead vehicle.
3.	Driving Path in Curve	Driving paths taken in curves on motorway feeder roads, on- and off-ramps. The driving paths varied between driving in the lane center and driving closer to the inside of the curve.
4.	Deceleration in Curve	Timing and intensity of deceleration in front or while driving through curves on motorway feeder roads, on- and off-ramps.
5.	Lane Selection	Appropriateness of lane selection decision. In this category, no lane change was performed. Participants were expressing either their satisfaction with the choice of lane or dissatisfaction when they wished to switch lanes to the left for the purpose of driving faster or responding to a potential cut-in vehicle, or to the right in order to comply with the rule of driving on the right-hand side.
6.	Overtaking on the Right	Appropriateness or correctness of overtaking on the right side. Note: The AV always complied with traffic regulations and only overtook on the right if conditions to legally do so were fulfilled.
7.	Lane Change Right: Decision	Appropriateness of the decision to change to the right lane.

4.4. Wizard-of-Oz Evaluation

The automated system was active for 76.19% (SD = 4.85) of time without any driver intervention. For the estimated percentage of being driven by the automated system, 73.80% of participants reported a proportion of 70% or greater, 83.33% reported a proportion of 60% or greater, and 16.67% estimated a proportion between 30 and 40%. No significant difference was found in the estimated percentage between the group Selected ADS and the group Unselected ADS ($U = 221.00$, $p = 0.959$).

5. Discussion

This study was conducted to analyze how an automated driving style that differs from a participant's own driving style influences the perception of trust, comfort, and safety in conditional automated driving on a motorway. In addition, it was examined how anthropomorphism and driving strategy influence whether a presented automated driving style is preferred.

The correlation between the calculated and self-reported DS shows a comparable perception of driving dynamics across all participants. Interestingly, the participants' self-reported DS from a co-pilot's perspective is rated as significantly more dynamic compared to their self-reported DS from the driver's perspective. This could indicate that participants are aware that the passive experience of the same situation is generally perceived as more dynamic compared to when participants are actively driving by themselves. As a result, it is conceivable that the same driving dynamics experienced during conditional automated driving are also perceived to be higher than during active manual driving. Assuming that participants perceive their own driving style as appropriate when driving actively, an improved comfort and safety experience could be achieved if the automated driving style does not correspond to the actual, but to the participants' perceived personal driving style. This thesis is supported by previous findings of [9], showing that participants want to be driven the way they think they drive, regardless of how they actually drive. Consequently, in order to develop an automated DS that participants perceive as positive, a comparatively more defensive DS would have to be selected in order to be perceived as similar to their PDS.

This is in contrast with the results for H1 where participants preferred their PDS compared to an ADS that is more defensive than their own with regard to comfort. The dependency of comfort or safety on the driving style differences between PDS and ADS was set as a precondition for further analysis in H1. As it is not fulfilled for safety, only a group comparison for comfort was performed. For interpretation of the results, however, it has to be considered that only participants with a very defensive to moderate DS, with DS values ranging from 0.09 to 0.38, experienced an ADS that was equal to their PDS. Defensive drivers preferring their own DS has also been seen in [5–7]. It is, therefore, possible that the comfort level of a defensive driver is already at saturation and cannot be further increased by an even more defensive driving style. The magnitude of DS difference, on the other hand, may explain why participants who experienced a more defensive DS than their own gave lower comfort ratings. Although it has been observed in previous studies that aggressive drivers can also prefer a more defensive DS [5,6], it might be that a too-defensive DS compared to the PDS of an aggressive driver leads to a rejection of the automated system. However, this raises the question of how an automated L3 system could adapt its driving style to the preferences of an aggressive driver while still complying with traffic regulations.

As it was assumed in H1 that participants prefer a more defensive DS than their PDS, the increase in trust after the automated drive was also assumed to be higher for participants who experienced a more defensive ADS than their PDS compared to participants who experienced an ADS similar to their PDS. As the opposite was found for H1, it was assumed that participants who experienced an ADS similar to their PDS would show a higher increase in trust, contrary to the previous assumption of H2. However, no interaction effect between the experienced ADS relative to PDS and time before and after the AV drive was found, although participants experiencing a PDS-like ADS showed a higher increase in trust compared to participants who experienced a more defensive ADS. H2 can, therefore, either way not be confirmed. In accordance with previous findings [21,62,71,72], however, our results show that participants generally report a significantly higher level of trust in automated systems after the automated drive than before. As both the safety driver as well as the automated system avoided safety-critical driving behavior, it is possible that the experienced ADS increased trust regardless of the participants' PDS. The predominantly positive ratings of individual driving situations during the automated drive are in line with this finding.

The increase in trust after the automated drive is assessed as low, which may be related to the fact that the questionnaire did not ask about trust in the specific automated driving system, but in automated systems in general. However, Ref. [78] assumes that general trust in a technology correlates with trust in a specific system. It can, therefore, be assumed that the increase in trust is based on the experience with the automated L3 system. Another possible explanation for the low increase in trust might be the generally high affinity for technology and the high trust of participants in automated systems due to their professional proximity to the product. For a different group of participants outside the field of automotive engineering, however, a lower range of values of both characteristics before the automated drive is expected, and thus a higher increase in trust might be seen.

The third hypothesis assumed that participants who selected the experienced ADS as their exclusive or one of several preferred driving styles for conditionally automated driving also perceive the experienced ADS as more anthropomorphic compared to participants who selected among the other driving style options. As we found a significantly higher perceived anthropomorphism for participants who selected ADS, H3 could be confirmed. An influence of the estimated percentage of being driven by the automated system on the assessment of anthropomorphism could be rejected as no significant correlation between the two parameters was found. Previous studies have already shown that human-like features can have a positive influence on the perception of automated systems [22,53,54]. A higher perceived anthropomorphism can, therefore, also be associated with a more confident driving style and thus increases the tendency of participants to select a presented automated driving style as their preferred driving style for conditionally automated driving. Future studies could further analyze what passengers perceive as human-like driving behavior in an AV and in which situations and scenarios it is especially preferred.

Participants who selected ADS also perceived the ADS as significantly safer compared to participants who selected the other driving style options. This result is in line with the findings of previous studies, which have already identified the relevance of safety for trust and acceptance of automated driving systems [24,25,79–81]. No differences were found for Likeability. It is possible that participants found it difficult to transfer the items from human-robot interaction to an automated vehicle. With regard to Intelligence, participants who selected ADS and those selecting the other driving style options showed no difference in the perceived capability of the AV to interact with the environment. However, both groups differed in their evaluation in terms of how the AV interacted in seven specific driving situation categories.

The hypothesis that the general assessment of the AV's overall driving strategy and its comprehensibility is rated higher among participants who selected ADS as their preferred driving style could be confirmed. This indicates that driving strategies could be used to align with user preferences. However, it is possible that different driving strategies might not make a difference for users in every scenario or situation, as seen in [21]. It is, therefore, also important to identify situations in which driving strategies have a bigger impact on whether an automated driving style is preferred. These strategies could be adapted depending on the driver's personal driving style as suggested in [5–7]. In the present study, several categories of driving situations have been identified that had a significant impact on the choice of participants' preferred automated driving style. The only exception is seen for the category Deceleration to a Lead Vehicle (intensity), as the pure deceleration intensity is not considered as strategy related. Besides the identified categories, an additional observation has been made with regard to the category Overtaking on the Right. The majority of participants did not know about the correct rules for when it is allowed to overtake on the right side. It might, therefore, be interesting to investigate if the displayed information in AVs on off-ramps and motorway feeder roads could help to increase the user's comprehensibility in these situations.

For the interpretation of the results, several aspects of the experimental setup have to be considered. Due to the experimental setup in a real traffic environment, the study has high external and, at the same time, limited internal validity due to the different traffic conditions for each participant. The influence of the safety driver, however, is considered low, as the automated system was active for more than 75% of the time on average, with no intervention by the driver. Another factor that must be taken into account is the collective of participants. Since all participants share a high level of technology affinity, the findings may only apply to a subset of the actual user population. Individuals with lower levels of technology affinity might show a more critical assessment of the presented automated driving style. On the other hand, the limited or non-existent experience or knowledge about the capabilities of L2 or L3 functions are seen as representative characteristics of a broader spectrum of potential users.

Based on the feedback after the automated drive, it is assumed that the deliberate omission of typical Wizard-of-Oz covers has increased the credibility of the presented L3 functionality. Despite the efforts taken for an authentic presentation of the test vehicle as an automated L3 system, it was taken into account that some interventions of the safety driver would not stay undetected by the participants and may influence the evaluation. Therefore, the instruction highlighted that the study solely focused on evaluating the resulting driving behavior, regardless of whether it was a result of the safety driver's or the system's actions. Since the estimated proportion of automated driving during the automated drive has no significant influence on driving style preference, it can be assumed that the instruction worked. Furthermore, the estimated proportion of automated driving is considered high, taking into account that the question was already implying the existence of manual driving sections. Participants were, therefore, also assuming a certain percentage of manual driving even when they reported that they did not notice any manual intervention by the safety driver.

The survey methodology also plays a decisive role in the quality of the collected comfort and safety ratings. For this, three aspects have to be considered. Firstly, rated situations need to be marked shortly after the experienced situation to enable an automated and correct allocation of ratings and rated situations during data preprocessing. Secondly, the different amount of time participants can take for the assessment of a situation needs to be considered. Thirdly, for the operationalization of comfort and safety ratings, it must be determined whether they are measured by the absence of discomfort and danger or whether they are measured on one dimension between two end poles. Under the assumption that humans find it easier to describe discomfort, Ref. [36] used a hand controller. Here, comfort is set as a default as long as the controller trigger is not pressed, whereas any discomfort can be expressed through the magnitude of how much the controller trigger is pressed. With this method, participants are required to press the controller trigger to mark a situation and to specify the rating for the driving behavior at the same time. This could lead to the following problems. If participants take more time to think about the situation and their rating, the time mark moves away from the respective situation. If participants press immediately to mark the corresponding situation, but want to adjust their rating, it complicates the interpretation of the data or makes it even impossible in extreme cases. Considering these aspects could also explain the binary usage of the controller trigger in [36]. Here, it was observed that the value range of the hand controller was not fully utilized. The participants either did not press at all or pressed the trigger to the full extent. The hand controller may, therefore, have been used to mark existing discomfort rather than to express its magnitude.

On the basis of the three aspects mentioned above and the experiences in [36], a marker was set when participants begin to give their verbal evaluation, marking the evaluated situation in the data, but giving unlimited time for evaluation and reasoning. A preliminary test study had already shown that participants also needed up to a minute to evaluate a situation and occasionally corrected them while talking about their reasoning. The verbal feedback also makes it easier to collect different evaluation criteria for the same situation, as in this case comfort and safety. Due to the free choice and weighting of the evaluation criteria, participants were enabled to evaluate not only discomfort but also comfort. The utilization of the entire scale shows that participants were able to not only distinguish between comfort and discomfort in a binary way, but also perceive and evaluate gradations of both characteristics. However, most of the ratings are above zero, which might be explained by the cautious driving style of both the automated system and the safety driver, who generally avoided safety-critical driving behavior.

In addition to the aspects of the data collection methodology, the presence of a safety driver must also be taken into account. Although the participants were instructed to evaluate each situation as if they are in the driver's seat and alone in the test vehicle, it cannot be ruled out that the presence of a safety driver has nevertheless contributed to a subconscious increase in the feeling of security. Furthermore, it must be taken into account that the seating position of the test person on the passenger side can also have an impact on the evaluation in some situations. Examples include the lateral positioning within the lane and lateral distances to surrounding vehicles or static environmental objects. For the majority of rated situations, however, the seating position is considered as neglectable.

6. Conclusions

In this paper, a real-world study was conducted to analyze how an automated driving style that differs from a participant's own driving style influences the perception of trust, comfort, and safety in conditional automated driving on a motorway. In addition, it was examined how anthropomorphism and driving strategy influence whether a presented automated driving style is preferred.

The results show that the personal driving style can be used for the design of a conditional automated driving system to achieve a higher comfort experience for the users. Regardless of the user's personal driving style, enhancing trust in automated systems can be achieved by allowing users to experience a defensive conditional automated driving style. The identified reasons for driving situation evaluations that had a stronger influence on the preference for a particular driving style in conditional automated driving indicate that driving styles should not only be adopted to user preferences at the level of driving dynamics but also at the level of driving strategies. The identified reasons for driving situation evaluations can further be used to set the focus for the design of a conditional automated system accordingly. Although the driving style is a critical factor for the acceptance of automated vehicles, other factors such as usability, cost, and availability have to be considered as well for a successful introduction of future automated driving systems.

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