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How do older passengers of automated vehicles experience comfort on road? An interview study

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ABSTRACT

Understanding older users' comfort needs can inform the inclusive design of automated vehicles (AVs). Real-world experience with automated driving is crucial to elicit meaningful insights for older adults, who are expected to benefit from AVs in terms of enhanced mobility and autonomy. In this study, semi-structured interviews were conducted with 27 participants (aged over 60) who experienced a so-called automated ride, operated by a Wizard-of-Oz driver, in Delft, Netherlands. Following the ride, participants were interviewed about their comfort during the ride. Using thematic analysis, we identified three overarching factors associated with user comfort: (1) **vehicle factors** (including *driving styles, AV capabilities, effect of AV exposure*, and *physical aspects*), (2) **environment factors** (including *effect of external driving environment*), and (3) **human factors** (including *affective experience, attitudes to AV/technology, engagement in non-driving related tasks [NDRTs]*, and *communication with the AV*). Our findings contribute to understanding comfort in automated driving, by offering a comprehensive list of factors associated with comfort, identifying affective reflections of psychological comfort, and discovering the co-existence of psychological comfort and physical discomfort. The study provides implications for designing comfortable AVs, such as the need for smooth, cautious, and anticipatory driving styles, and flexible and early reactions to unexpected events.

1. Introduction

Highly Automated Vehicles (AVs), operating without a human in the driving seat, are currently operational within particular Operational Design Domains (Level 4, SAE, 2021). Becoming increasingly available for use by the general public, examples of these include automated shuttle buses (e.g., Haque and Brakewood, 2020), or passenger vehicles, such as Google's Waymo (e.g., Dai et al., 2021; Waymo, 2023). Providing a comfortable ride for users is one key factor that enhances the acceptance of these vehicles, which will also facilitate their wider uptake (Dichabeng et al., 2021; Nordhoff et al., 2021; Siebert et al., 2013).

Peng (2024, p.191) recently built upon a number of existing definitions of a comfortable ride in AVs (e.g., Bellem et al., 2018; Carsten and Martens, 2018; Hartwich et al., 2018) by integrating multiple physical and psychological concepts to provide an overarching definition. They describe comfort in an AV as a "*state involving subjective feelings of ease and pleasantness…User comfort is a dynamic concept, evolving in response to users' expectations, their communication with automated vehicles, and the varying environmental and traffic conditions.*"

An AV's driving style is considered to be an important contributory factor for users' evaluation of comfort (Elbanhawi et al., 2015; Hartwich et al., 2018). Here, driving style includes vehicle kinematics, such as its speed and acceleration, its proxemics (e.g., distance to roadside objects), and also how the AV negotiates different road geometries (He et al., 2022; Peng et al., 2024; Yusof et al., 2016). The concept of a driving style originated from studies of manual driving styles of drivers who have active control over a vehicle (Elander et al., 1993). These manual driving styles are often categorised along a spectrum from aggressive to defensive, representing the two extremes of the risky–safe range. Such research has been conducted for various purposes, including developing

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interventions to improve road safety (Sagberg et al., 2015; Taubman-Ben-Ari et al., 2004). When transitioning to AVs, the user's loss of control and reduced ability to predict the vehicle's upcoming behaviours have raised concerns about passenger comfort (Elbanhawi et al., 2015; Kaber and Endsley, 2004). Consequently, a range of research has investigated how an AV's driving style affects user evaluations and experiences, such as comfort, trust, feeling safe, and acceptance. Some examples specifically focus on comfort. Hartwich et al. (2018) found that younger drivers (25–35 years) were more comfortable with familiar, automated driving styles, while older drivers (65–84 years) preferred unfamiliar, faster-than-their-own driving styles. Peng et al. (2022) compared user evaluations of three automated driving styles. They found that a defensive and cautious human-like driving style contributed more to user comfort compared with a faster, aggressive human-like driving style or a robot-like style. They also suggested that a natural, familiar driving style is not always the most comfortable, especially for users with a high risk-taking propensity. Carlowitz et al. (2024) assessed three AV deceleration rates at crosswalks and intersection scenarios. They found that AV users' comfort was associated with a lower deceleration rate, but higher rates became acceptable when users understood the AV was yielding to unexpectedly appearing pedestrians. Haselberger et al.(2025) investigated user preference for lateral driving manoeuvres under different weather and traffic conditions. They found that participants expressed greater comfort and trust towards a driving style with reduced curve-cutting gradients, lower accelerations, and more obvious responses to oncoming traffic. These preferences were negatively affected by adverse weather conditions and oncoming traffic.

Most of these studies, while valuable, rely on quantitative approaches that involve statistical comparisons of a limited number of predesigned driving styles. Moreover, because driving styles are characterised and configured differently across studies, direct comparisons are not always feasible, despite the widespread use of similar terminologies, such as "defensive" driving. These approaches limit a comprehensive understanding of factors associated with comfort in automated driving, particularly in relation to the aspects of driving styles that have the most impact. Current knowledge also lacks insights from real-world AVs, as most results are derived from laboratory studies, using driving simulators (e.g., Bellem et al., 2018; Haghzare et al., 2021; Peng et al., 2022) or test tracks (e.g., Carlowitz, Madigan, et al., 2024; Paddeu et al., 2020; Yusof et al., 2016). Although AV prototypes are being tested on public roads during the period of this study (2023), for safety purposes, the speed of these vehicles is usually limited to around 25–30 mph (Nordhoff et al., 2019; Public Utilities Commission of State of California, 2022), which may not reflect a full range of driving scenarios. While such speed limitations have been increased to 65 mph (Au, 2025), the limitation in driving scenarios still exists.

For higher-level AVs (Level 4 AVs, SAE 2021) to be successfully deployed, they must be able to negotiate a variety of road geometries (e.g., of different curvatures, terrains and elevations). They should also be able to seamlessly change lanes and merge into adjacent lanes, negotiating with other road traffic, including vulnerable road users (e.g., pedestrians, mobility-impaired users, and cyclists). However, studies using either driving simulators or AV prototypes are limited in depicting the driving styles of higher-level AVs on public roads. The Wizard-of-Oz method has been used as a suitable alternative to real-world L4 vehicles, providing insights about passengers' responses to the new forms of mobility. These vehicles typically create the perception of automated driving for users, while a driver, hidden from passengers (the "wizard"), controls the vehicle (Figalová et al., 2021; Müller et al., 2019).

1.1. *Theoretical background*

While the relationship between driving styles and subjective user experiences (e.g., comfort, feeling safe, and enjoyment) has been explored quantitatively, a noticeable gap exists in the inconsistent and interchangeable use of these concepts. Definitions are often not provided (e.g., de Winkel et al., 2023; Hajiseyedjavadi et al., 2022; Paddeu et al., 2020), and even when they are, a lack of widely accepted definitions leads to conceptual overlaps (e.g., Hartwich et al., 2018; He et al., 2022). For example, a recent literature review treated a wide range of studies on various subjective experiences as being mostly about comfort (Domova et al., 2024). This mixed usage of different concepts makes it challenging to distinguish subtle differences in user evaluations and presents a challenge for targeted, user-centred designs.

With the aim of conceptualising comfort in AVs from the driving style perspective, Peng et al. (2024) previously investigated factors that affect comfort in automated driving, based on a focus group with experts. They started with a focus on comfort related to driving style, and ended up incorporating both driving-related and non-driving-related factors. A conceptual framework integrating these factors was developed (Fig. 1). This framework divided factors that affect comfort into *physical* and *psychological* layers, where the AV's driving styles, and the external environmental and traffic conditions were always considered relevant. The physical layer includes factors such as G-forces, vibration, temperature, noise, and seating comfort. Psychological comfort is associated with positive feelings, fostered by factors such as *trust, perceived safety, natural perception of driving styles, privacy considerations, engagement in NDRAs, situation awareness*, and *expectation fulfilment*.

However, the findings were solely derived from the perspectives of eleven experts, without considering the insights of the general population, who will be the primary users of AVs. It is important to examine whether the conceptual elements identified through Peng et al.'s (2024) model apply to a wider range of participants, which led to the present study focusing on insights from the general public. Moreover, AVs should be accessible to a wide range of user groups, including those who may not be able to drive due to physical or cognitive impairments, such as older adults (Alessandrini et al., 2015; Faber and van Lierop, 2020; Harper et al., 2016). However, older adults' comfort needs in using AVs remain largely underexplored, which limits the design of accessible and inclusive AVs. Therefore, the present study focuses on older adults to gather their insights.

1.2. *The present study*

In the present study, we further investigated the factors influencing comfort in automated driving using semi-structured interviews following a Wizard-of-Oz ride around the city of Delft. The following research question was addressed.

> What are the factors that are associated with comfort when older passengers experience on-road automated driving?

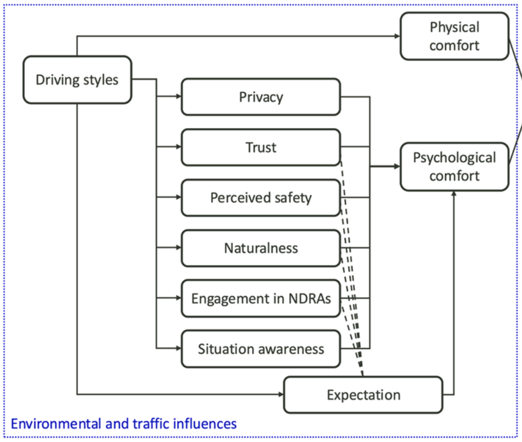

Fig. 1. The conceptual framework of user comfort in automated driving (Peng et al., 2024). Redrawn with permission.

It is worth noting that the present study considers automated driving styles as an essential factor influencing passenger comfort. Therefore, it serves as the primary point of exploration, alongside other non-driving-related factors. Moreover, a particular emphasis was placed on gathering the insights of older passengers, who might have an increased susceptibility to discomfort (Bohman et al., 2019) and motion sickness (Paillard et al., 2013). Insights derived from the study will inform the design of comfortable and inclusive AVs, which is expected to facilitate the public acceptability of AVs.

2. Method

2.1. Participants

Participants were recruited through an advertisement for the members of the Delft panel and were asked to book their slots on Calendly, where the expected duration, location, and research aim were stated. Participants were required to be proficient in English. A driving license was not required. It was stated that participants aged 60 years or older were particularly encouraged to participate. After participants booked a timeslot on Calendly, confirmation emails, including detailed time and location information, were sent out to participants. After the study, participants were entered into a draw to win one of five €25 vouchers. The study was approved by the Human Research Ethics Committee of Delft University of Technology.

Twenty-night participants (aged over 60) were recruited for this study. One participant's interview data was not usable as the recording was not suitable for transcription, and another participant used a walking frame and could not take the ride. This led to 27 complete interviews for transcription (n = 27; mean age = 69.4, SD = 6.20, min = 61, max = 88) (see Table 1 for more details). In addition, while we recruited a group of younger participants (n = 10), we excluded them from the manuscript due to imbalances in sample size.

2.2. Study set-up and apparatus

2.2.1. The Wizard-of-Oz approach

The automated ride was conducted using a Wizard-of-Oz vehicle. The vehicle was a Nissan e-NV200 electric bus provided by Leaseplan and owned by the Department of Civil Engineering at Delft University of Technology (TU Delft).

To prevent the participant from seeing the driver or looking out through the windows, a shield was placed between the driver's seat and the backseat, along with two shields on the side windows (also to prevent seeing these through window reflections). The shields were made of wood and covered with dark fabric. A large screen was mounted on the front shield, and two smaller screens were attached to the side windows. These three screens displayed the external view (Fig. 2), which was captured by three cameras mounted on the vehicle (Fig. 3). A small monitor below the front screen indicated whether the vehicle was in manual or automated driving mode.

All four drivers (males) were trained and instructed to drive in a similar manner during the "automated driving mode" to ensure consistency across participant experiences. This involved driving as smoothly as possible, avoiding abrupt manoeuvres, accelerating smoothly, braking gently, and maintaining large distances from other road users. The driver controlled the display, indicating whether the vehicle was in automated or manual mode using a laptop connected to the screens. The drivers were introduced to participants as "safety drivers", responsible for any emergencies. The ride always began in "manual mode", and at specific points along the route (near the starting point; see "mode switch" in Fig. 4), the driver changed the mode display to simulate a "switch" between manual and automated driving. This switch was accompanied by an auditory notification. Participants heard "Switch to Autopilot. Autopilot is on" when the automation mode was activated, and "Return to manual mode. Back to manual mode" when switching back to manual control. This mode switch pattern was introduced in the information sheet for participants and was consistent across all participants.

Table 1
A summary of the characteristics of the sample.

	n	Percent
Gender		
Female	10	37%
Male	17	63%
Education		
University or HBO	25	93%
Other	2	7%
Frequency of driving		
Less often or never	6	22%
At least monthly	1	4%
1–2 days/week	7	26%
3–5 days/week	7	26%
(Nearly) Every day	6	22%
Frequency of using public transport		
Less often or never	8	30%
At least monthly	10	37%
1–2 days/week	6	22%
3–5 days/week	3	11%
(Nearly) Every day	0	
Frequency of using active travel modes		
Less often or never	0	0%
At least monthly	1	4%
1–2 days/week	1	4%
3–5 days/week	7	26%
(Nearly) Every day	18	67%

Note. Data is from the post-ride questionnaire.

2.2.2. Route

The vehicle followed a looped route (7 km), beginning and ending at the same location on the TU Delft campus (Fig. 4). The route featured a variety of road environments, including rural areas with traffic, as well as urban areas characterised by dense roadside buildings, pedestrians, and cyclists (Fig. 5). The entire ride lasted approximately 20 min. Approximately 75% of the route had a speed limit of 50 km/h, while the remaining motorway section (approx. 25%) had a limit of 100 km/h. The vehicle always obeyed these speed limits.

As the vehicle approached a canal bridge, there was a possibility that the bridge could be raised to allow a ship to pass through. Although this situation was rare, when it occurred, the driver switched the mode display to inform the participant that the vehicle was under manual control for that specific section.

2.3. Procedure

Upon arrival at the starting point, the experimenter provided the information sheet, explained the procedures, and asked the participant to sign the consent form. The participant was then asked to answer three questions about previous comfortable and uncomfortable riding experiences, and their expectations about riding in the automated vehicle. This pre-ride interview took about 10 min. Then the participant was taken to the vehicle and completed the ride. They were instructed to

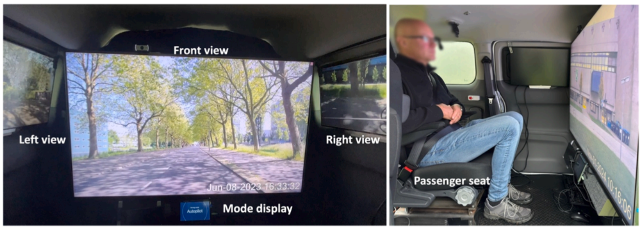

Fig. 2. The participants' view (left) from their seat (right) in the vehicle.

Fig. 3. The live-streamed footage was captured by one camera mounted behind the windshield (1) and two cameras attached to the side windows (2 and 3).

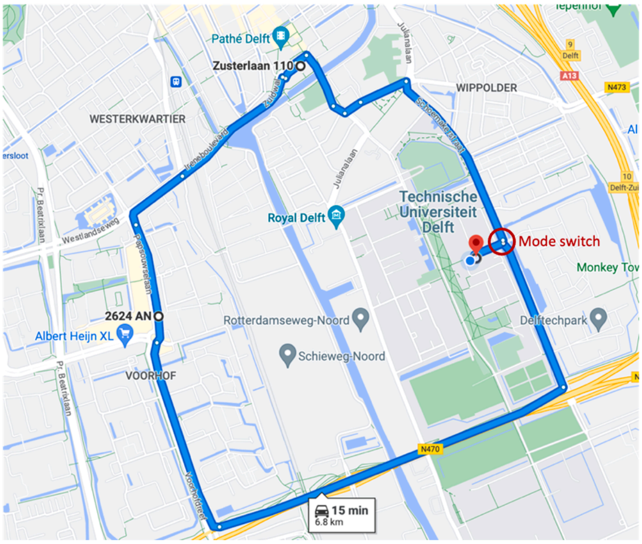

Fig. 4. An overview of the driving route. Between the starting/ending point and the "mode switch" point (inside the university campus), the mode was displayed in manual mode. The rest of the route was displayed in automated mode. The mode switch point was used for both "manual to automated" and "automated to manual" mode transitions.

Fig. 5. Examples of different road environments.

observe the driving style and any other factors that affected their comfort during the ride. After the ride, the participant took part in a 30-minute post-ride interview, where they were asked about their experiences in the vehicle. They then completed a demographic questionnaire, and the experimenter debriefed participants by explaining how the Wizard-of-Oz vehicle worked (Fig. 6). The method and procedure are described in further detail in previous work, which also includes a video demonstration (see Peng et al., 2023).

2.4. *The interviews*

We conducted semi-structured interviews before and after the ride. The pre- and post-ride interviews, conducted in English by the first author, took place at the start/finish point of the ride, between June and July 2023. The Voice Memo application on an iPhone was used to record interviews. The pre-ride interviews are not reported in this manuscript (see Peng, Öztürk, et al., 2025), and any further reference to *interviews* in this manuscript relates to post-ride interviews.

The post-ride interviews consisted of 12 key questions (Table 2). These interview questions were designed based on the conceptual framework of Peng et al. (2024) (see also Fig. 1), exploring participants' *experiences of comfort* during the ride. Prior to the interview, participants were instructed to reflect on their perceptions of the AV's driving styles and other factors that affected their comfort or discomfort.

Due to the semi-structured nature of the interviews, the sequence of questions was occasionally adjusted to facilitate a more natural and engaging conversation with participants. Probing questions were also used to encourage a more in-depth exploration of participants' experiences.

2.5. *Data analysis*

Audio recordings of the interviews were first transcribed using the automatic transcription software by Happy Scribe (https://www.happyscribe.com). Then the lead author checked the transcription verbatim, by comparing it with the audio recordings, removing repetitions and correcting wrongly transcribed words.

We adopted a thematic analysis technique to explore patterns in the interview data. Thematic analysis is an approach used for identifying, analysing, and reporting patterns, or themes, in qualitative data (Braun and Clarke, 2006). It has been widely used in qualitative studies to generate valuable insights, including in transport-related research (Berge et al., 2022; Coyne et al., 2024; McIlroy et al., 2021). We used an inductive, or bottom-up, approach to code the data and to capture emerging patterns, which combined both semantic and latent coding. Following the guidelines in Braun & Clarke (2006), the thematic analysis included six phases: 1) familiarisation with data, 2) generation of initial codes, 3) generation of potential themes from codes, 4) development of review themes, 5) refining, defining and naming themes, and 6) production of the report. The coding process was iterative, involving repeated cycles of analysis, and recursive, involving going back and forth between data and codes.

Interpreting qualitative data is always subjective and affected by individual researchers' prior experiences and knowledge (Braun and

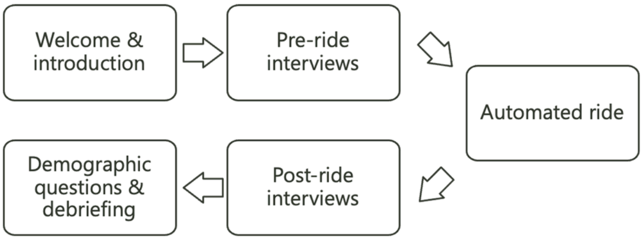

Fig. 6. The procedure of the study.

Table 2
Interview questions and rationales. Probes for each question can be found in Appendix 2.

	Interview question	Rationale
1	Generally speaking, how was your ride experience?	Asking about overall experience, setting the scene specifically about comfort for the participants.
2	What do you think of the self-driving vehicle's driving style?	Probing aspects of the driving styles that were noticed and assessed
3	You mentioned … when we talked about your expectations before the ride. After your experience with the self-driving vehicle, have your expectations about self-driving vehicles changed in any way?	Understanding the link between expectation fulfilment and comfort.
4	During the ride, did you notice anything physically or psychologically impacting your comfort level?	Addressing both physical and psychological factors that affected participants' comfort
5	How natural/familiar was the vehicle's driving style? Here, a natural driving style means how closely it matches what you would expect to experience in a manually driven vehicle?	Tapping into the relationship between naturalness of the driving styles and comfort.
6	Throughout the ride, did you notice any changes in your comfort (either positive or negative)?	Encouraging a more detailed response rather than general impressions.
7	During the ride, how did what was happening around you affect your comfort? Such as the road environment, and pedestrians, cyclists and so on.	Exploring the influence of environmental factors, traffic conditions, and the presence of vulnerable road users.
8	How safe did you feel about the self-driving ride?	Addressing feelings of safety and its relationship with comfort.
9	Did you trust the self-driving vehicle during the ride?	Addressing trust and its relationship with comfort.
10	Did you notice any changes between the manual and self-driving modes?	Examining if any difference between the manual and automated driving modes was perceived.
11	Imagine you use such an slef-driving vehicle in the future, how comfortable would you feel when engaging in other activities?	Exploring how comfortable the participants would be to engage in NDRTs in future AVs based on their current experience.
12	Is there anything else you would like to share about your experiences with the slef-driving vehicle?	Offering the opportunity to share any additional comments.

Clarke, 2013; Smith and McGannon, 2018). Therefore, three coders (CP, IO, and RM) were involved in the initial coding process of the first seven participants. This multiple-coder approach was used to ensure a shared understanding of the coding process and achieve agreement on the coding protocol, such as selecting larger segments to preserve context, allowing multiple codes to be assigned for the same data segment, and reaching a consensus on how to define, interpret, and categorise codes. The three coders worked both independently and collaboratively (see similar approaches by Campbell et al., 2013; Jiang et al., 2018; McDonald et al., 2019). The involvement of multiple coders and intercoder agreement was a way to provoke reflexivity and discussions within the researcher team, instead of justifying the strength of codes (McDonald et al., 2019; O'Connor and Joffe, 2020).

For the first three participants (10% of the data), this process started with the lead author (CP) coding the transcript using Microsoft Word, which was then reviewed by the other two coders (IO and RM) independently. The three coders discussed any disagreements on code definitions in meetings until a consensus was reached. After this discussion, the three coders categorised the initial transcript codes independently for seven participants, which was followed by discussions to achieve a consensus on how the codes should be interpreted and categorised. Intercoder agreement was calculated using the simple percentage of agreement among coders, following the suggested approach for in-depth semi-structured interviews by Campbell et al. (2013). Once a satisfactory intercoder agreement (75 – 82 percent) was achieved, the rest of the participants were coded and categorised by the lead author independently (CP). A spot check was performed by the other two coders (IO and RM) for codes, coded data segments, and categorisation of codes, which was discussed in a meeting with the lead author (CP). Coauthors were given the chance to comment on themes, sub-themes, and codes. After the initial process involving multiple coders, MAXQDA (https://www.maxqda.com) was used to code and categorise the rest of the data. The codebook can be found at https://github.com/pchencecilia/interview_woz.

3. Results

In this section, we present the list of factors associated with user comfort in automated driving, as indicated by the themes and categories derived from the thematic analysis. We identified a wide range of factors, including 9 themes and 32 sub-themes (Table 3). These themes were related to three overarching factors: *vehicle, human,* and *environment.*

The following sections provide detailed descriptions for each theme, together with a selection of quotes from participants, for each aspect. The presentation of these factors and more detailed information about them follows the sequence presented in Table 3.

3.1. Vehicle factors

3.1.1. Driving styles

The theme, *driving styles,* characterises aspects of the AV's driving styles that participants perceived and evaluated in relation to their comfort levels during the ride. Example quotes are presented in Table 4.

3.1.1.1. Overall driving style. When discussing comfort, participants identified several distinct elements pertaining to the overall driving style exhibited by the AV. The AV's driving style was mostly perceived as smooth, human-like, cautious, and anticipatory, while one interviewee considered it was over-cautious, and another interviewee stated that the driving was not anticipatory enough.

Participants used their own driving style as a reference point for evaluating the automated vehicle's driving style and determining its relation to their comfort. In terms of speed, braking, and cautiousness, the AV's driving style was considered human-like, i.e., similar to their own or other drivers' driving styles.

3.1.1.2. Interaction with ORUs and OREs. How the AV interacted with other road users and infrastructure elements was considered when evaluating comfort with respect to the AV's driving styles. Maintaining a perceived sufficient distance to other road users, such as other vehicles, cyclists, and pedestrians, appeared to be the primary factor associated with comfort and perceived safety.

With regards to other road elements (i.e., road surface, lanes, traffic lights, speed limit, and road geometries), the majority of interviewees showed a desire for early reactions, adjusted speed for speed bumps, along with gradual and smooth lane changes, and smooth and slower turning when the AV negotiated curves.

3.1.1.3. Kinematics. Participants evaluated the kinematics of the AV, with a focus on two elements: speed and acceleration/deceleration. High speed was perceived as unexpected and uncomfortable, and participants expressed a desire to see speed information to eliminate their concerns. It was also mentioned that minor deviations from the expected speed were acceptable. Participants also noted that they preferred early and smooth braking, as well as smooth acceleration, over abrupt, quick, and late movements, because the latter was associated with uncomfortable experiences.

Table 3
Themes, sub-themes, and categories within sub-themes, derived from the thematic analysis, with the number of participants mentioning each category/theme presented in parentheses. The table follows a bottom-up approach from right to left, with “category within sub-theme” including basic codes.

Overarching factor	Theme	Sub-theme	Category within sub-theme
Vehicle	Driving styles (27)	Overall driving style (27)	Perception of driving styles (20) Comparison with human driving (23) Expectations and preferences (8) Age related preference (1)
		Interaction with OREs and ORUs* (23)	Distance with ORUs (16) Road infrastructure elements (16)
		Kinematics (15)	Speed perception (10) Acceleration and deceleration (10)
		Specific contexts (2)	
	AV capabilities (26)	Ability to handle various driving scenarios and unexpected situations (23)	Effective reaction and interaction (14) Complicated situations and environments (12) Unexpected situations and crash prevention (10)
		AV competence and the role of the safety driver (15)	Belief about role of a safety driver (10) AV competence (7)
		Ability to perceive and understand external situations (11)	
		Reliability and safety (11)	Reliability (4) Safety and cybersecurity (3) Rule compliance (3) Consistent performance (3)
	Effect of AV exposure (23)	Changes in user experience and attitudes (12)	
		Changes in perceptions of AV’s capabilities (12)	
		Expectations and reality alignment (12)	
		Adaptation to AV (11)	
		Monitoring and control preferences (7)	
	Physical aspects inside the vehicle (25)	Air quality and temperature (6)	
		Suspension (2)	
		Experimental setup and vehicle design (25)	Screen-related aspects (20) Seat position and visibility (12) Overall interior and experimental setup (5) Front and rear information (5) Space-related aspects (4)
Environment	Effect of external driving environment (16)	Sensory perception of environment (subjective) (11)	
		Road type (urban vs rural) (5)	
		Traffic and road conditions (dynamic) (3)	
		Cultural and regional factors (2)	
Human	Affective experience (24)	Positive states (23)	Presence of ease (23) Absence of negative states (relief) (5)
		Negative states (9)	Safety concerns and trust issues (8) Vigilance and uncertainty (cognitive) (4)
		Coexistence of comfort and discomfort (9)	
		Interplay between comfort, trust, and perceived safety (8)	
	Attitudes to AV/technology (21)	Trust and mistrust (16)	Trust and preference for technology/AV (8) Conditional trust (8) Trust and preference for humans (4)
		Future outlook (15)	Future use cases (13) Development expectations (6) Age-related considerations (1)
	Engagement in NDRT (26)	Attitudes towards NDRT engagement (16)	Positive attitudes (10) Hesitation and reluctance (8)
		Prerequisites for NDRT engagement (15)	Trust and reliability (13) Acceptance of passive role (4) Situational comfort (1) Environmental factors (1)
		Vigilance and monitoring (12)	Perceived necessity of monitoring (8) Need for vigilance (5)
	Communication with AV (21)	Understanding AV systems (14)	Decision making processes and actions (14)
		Desire for control and influence (8)	Intervention (5) Choices (4)
		Information needs (5)	Current status information (5)

Note. *ORE: Other road elements (non-human); ORU: Other road users; NDRT: Non-driving related tasks. The order in which the themes are presented aligns with the order in which the results are reported. For sub-themes without categories, we consider the sub-themes sufficient to describe the contained codes.

Table 4

Example quotes for the theme *driving styles*.

Sub-theme	Example quotes
Overall driving style	*“It was relaxed. It was not aggressive or not very slow.” (P32, F) (Perception of driving styles)* *“Overall, I think the driving style is quite similar to mine. I'm also driving quite defensive.” (P23, M) (Comparison with human driving)* *“I would have driven a little bit more slowly and a little bit more anticipating.” (P40, M) (Expectations and preferences)* *“It drives more riskily than I'm used to, but that's perhaps my age.” (P34, M) (Age related preference)*
Interaction with OREs and ORUs	*“It keeps quite a lot of distance from cars in front, which I like a lot. That makes me trust it more than I would if it was a driver.” (P33, M) (Distance with ORUs)* *“The only thing that the bumps in the road, it's not used to that, I guess. It's the slowing down and especially the slowing down, I guess was not that good.” (P17, M) (Road infrastructure elements)*
Kinematics	*“He was doing all the things what I expected, only a little bit faster or slower than others. But that's no problem for me.” (P12, M) (Speed perception)* *“I had once or twice that when I would have been driving an ordinary car, I would have braked earlier.” (P20, F) (Acceleration and deceleration)*
Specific contexts	*“You don't have to hurry or just like a vacation.... You drive very easily and smoothly and look around and gets out.... But when you have an appointment and you are a little bit late, then it's a different story because then you want to hurry and then you do some things driving through the orange light or something like that.” (P18, F)*

Note. The “example quotes” column includes Quotes (ID, Female or Male) (Category when applicable).

3.1.1.4. Specific contexts. Two participants acknowledged that their preferences for driving styles would depend on the context, such as their trip purpose and specific situation. For example, a relaxed driving style would be favoured on vacation trips, while a faster speed would be desired when being late for an appointment.

3.1.2. AV capabilities

Overall, participants’ comfort was found to be associated with their perception of the AV’s capabilities during the ride. Example quotes are provided in Table 5, with more details outlined below.

3.1.2.1. Ability to handle various driving scenarios and unexpected situations. Participants expressed appreciation for the vehicle’s ability to make early and effective responses to other road users and objects, such as its early deceleration and lane changes in response to larger vehicles ahead, its flexible lane changes around road obstacles, and its anticipation of pedestrians’ crossing intentions, based on participants’ perception. Participants mentioned these perceived capabilities along with their comfort, perceived safety, and trust in the AV. However, some participants reported confusion when the vehicle yielded for pedestrians who did not have the right of way, as well as in occasional instances where the vehicle exhibited delayed responses to traffic lights, which led to the vehicle being perceived as a distracted human driver.

Participants generally considered the vehicle capable in normal traffic situations, and praised its cautious behaviour in potentially riskier environments, such as roundabouts. They also expressed a desire to see the AV’s performance in more complex, challenging, or even extreme scenarios, such as parking and navigating roads without clear markings. Participants believed that witnessing such performance would enhance their confidence and trust in AVs. Regardless of these perceived capabilities in normal traffic, concerns were raised about the AV’s ability to manage more challenging environments in the future. For example, the presence of many bicycles, particularly in Dutch cities, was seen as potentially difficult for AVs to handle. Moreover, they expressed a desire to see more unpredictable or emergent situations to showcase the vehicle’s crash-prevention capabilities.

Table 5

Example quotes for the theme *AV capabilities*.

Sub-theme	Example quotes
Ability to handle various driving scenarios and unexpected situations	*“He also interacts very well with what you experience on the road. If there is a bump for making the traffic a bit slower, he sees that from a distance and decelerates already. If you have a pedestrian crossing, a zebra, he sees already when there is a pedestrian coming. Yeah, very good. And he sees from a distance all the traffic lights, also a small sign, go left, for instance, he can see that and he interacts exactly with that. Yeah, It think he's a perfect driver.” (P27, M) (Effective reaction and interaction)* *“When you are around the roundabout, you have always to take care of people who use the roundabout. All the people use the roundabout, sometimes less careful. So, we have always to look around and I have no experience with this car … And I don't know how he reacts on such situation, because the situation didn't happen.” (P2, M) (Complicated situations and environments)* *“Maybe just when somebody is jumping before the car.” (P17, M) (Unexpected situations and crash prevention)*
AV competence and the role of safety driver	*“But I once thought that I was happy that there was a driver there, because eventually self-driving cars will be without a driver, I presume. And I thought, oh, when I was in this car without him, then I would be … I will not feel relaxed then, because then you have to trust that the car will do everything okay. … Probably that will also be in ten years’ time, people will feel more relaxed when everything is going okay.” (P32, F) (Belief about role of a safety driver)*
Ability to perceive and understand external situations	*“I think this car is safer than when you drive yourself because I can't see. Sometimes I can't see something, but the camera sees, I think, everything.” (P14, M)*
Reliability and safety	*“When there is the technology, other people also can take over that technology. They can know everything where you went, perhaps, so they can track and trace your whole life in the end.” (P38, O, F) (Safety and cybersecurity)* *“I guess that everything is according to the law. That's where you're allowed to drive 50 and you drive 50.” (P17, M) (Rule compliance)*

Note. The “example quotes” column includes Quotes (ID, Female or Male) (Category when applicable).

3.1.2.2. AV competence and the role of the safety driver. Several participants perceived and mentioned the AV’s ability for independent control, based on its supposed preprogrammed routes and perceived anticipation. In contrast, one participant considered that the vehicle’s anticipation was less developed than that of experienced human drivers, while another participant expressed concerns over the vehicle’s control capabilities due to its high speed. Despite positive feedback on the vehicle’s control, more participants highlighted the importance of the safety driver. They believed that having a driver actively monitoring the AV contributed to their trust, sense of safety, comfort, and confidence, as they were assured by the driver’s ability to intervene if needed.

3.1.2.3. Ability to perceive and understand external situations. The vehicle’s ability to detect dynamic road users (i.e., understand traffic conditions and interact with infrastructure) was linked to participants’ comfort/discomfort. One participant reflected on their increased comfort provided by the assumed vehicle's ability to monitor beyond human limits. However, many participants expressed concerns about the vehicle’s ability to detect certain elements, such as speed bumps, other road users, and road conditions.

3.1.2.4. Reliability and safety. Participants' expectations and concerns regarding the reliability and safety of automated vehicles were closely associated with their overall sense of comfort. Participants expressed worries about potential system failures. Two participants acknowledged their safe feelings in the vehicle, whereas another one showed their uncertainties about cybersecurity and privacy. Participants expected AVs to follow traffic rules more reliably than human drivers, such as adhering to speed limits and not passing amber lights. Moreover, some participants observed and evaluated the consistency of the vehicle's performance, linking it to the predictability of the system.

3.1.3. Effect of AV exposure

This theme summarises participants' impressions of the brief AV ride. It provides insights into changes in their attitudes, adjustments in their perception of AV capabilities, alignment of expectations with reality, adaptation to the AV's driving styles, and their preferred role in monitoring and control. Example quotes are presented in Table 6.

3.1.3.1. Changes in user experience and attitudes. Participants initially reported feelings of discomfort due to the novelty of the experience. As the ride progressed, many participants expressed a generally positive impression, noting increased comfort, a sense of safety, confidence in AVs, trust, and relaxation.

Table 6
Example quotes for the theme *Effect of AV exposure* and *Physical aspects inside the vehicle*.

Sub-theme	Example quotes
Effect of AV exposure	
Changes in user experience and attitudes	*"When I get used to it, it gets more comfortable. Because I think that everything is new and there's strange screens and there's flickering and this light is getting look near and this is getting to look there, that is exciting, uncomfortable, because it's new. But after you get used to it, it's very easy, and then it gets more comfortable." (P36, M)*
Changes in perceptions of AV's capabilities	*"Because I thought sometimes like oh, is he going now? Is he stopping for the red light? Or is he going to the right or to the left? But everything was okay. I thought, yes, I trust that the technique will be so good that I don't have to doubt it." (P32, F)*
Expectations and reality alignment	*"It was better than my expectations. It was really very smooth and very… I didn't expect it would go beside the terrain of the university. It surpassed my expectations." (P23, M)*
Adaptation to AV	*"There is a driving style. Everyone has his driving style. And also, this car has his driving style. And many driving style is safe. Then I accommodate immediately to the driving style of the technical car. No problem." (P2, M)*
Monitoring and control preferences	*"I'm a person who always wants to be a bit in control. So yeah. I will look around and see what happens and perhaps, when necessary, interfere at the moment. I don't think, let's say, when you're in an airplane, you think the pilot will do anything okay, but I don't trust a car for 100%. I always want to see and to have the feeling that I can control when necessary, something myself." (P38, F)*
Physical aspects inside the vehicle	
Air quality and temperature	*"It was not comfortable because of the fact there was no ventilation. That's the only thing that made it really uncomfortable." (P30, M)*
Suspension	*"There was one factor that you need to take account of, and that was the suspension of the vehicle is not that good. Not that I expected it's going to be like an Audi or something, but that made it somewhat less comfortable through the bends. It was harder to judge what the behaviour of the vehicle was through the bends because the suspension isn't very good." (P37, F)*
Experimental setup and vehicle design	*"It's difficult to say because it did affect my comfort level, but it's because of the heat and screen was not very clear." (P35, F)*

Note. The "example quotes" column includes Quotes (ID, Female or Male) (Category when applicable).

3.1.3.2. Changes in perceptions of AV's capabilities. As also noted in Section 3.1.2, exposure to the ride allowed participants to observe and develop an understanding of the AV's capabilities. By observing the vehicle's behaviours, some participants reported gaining a better appreciation of the AV's ability to interact with other road users.

3.1.3.3. Expectations and reality alignment. Many participants reported that the AV ride exceeded their expectations, in terms of comfort and smoothness of the ride. In particular, while some participants found the vehicle's speed normal, some perceived it as higher than expected.

3.1.3.4. Adaptation to AV. Participants expressed changes in their adjustment to the AV and its driving styles during the short ride, with some comparing it to adapting to the driving styles of other human drivers.

3.1.3.5. Monitoring and control preferences. Participants reflected on their vigilance levels during the ride and their willingness to monitor the vehicle. Some reported a gradual decrease in vigilance as they became more familiar with the AV. They expressed an increased willingness to relinquish control to the AV and shift attention from constant monitoring to observing their surroundings. In contrast, some others indicated a preference for maintaining a certain degree of vigilance and control, even as their confidence grew.

3.1.4. Physical aspects inside the vehicle

This theme summarises physical aspects of the vehicle that affected participants' comfort during the ride. As these factors are considered as the more traditional comfort-related factors, which have been thoroughly investigated, the results are reported briefly. However, this does not mean these factors are not important. Fulfilling these physical comfort requirements should be seen as a basis for further comfort research in automated driving. Moreover, physical aspects include a subtheme summarising the factors that are specific to the experimental setup and vehicle design. Example quotes are presented in Table 6.

3.1.4.1. Air quality and temperature, and suspension. A high temperature in the vehicle was frequently mentioned as uncomfortable. The lack of fresh air led to discomfort as well. This was due to the experiment taking place in the summer, and the lack of air conditioning in the vehicle. Discomfort was also associated with the vehicle's suspension, which made the vehicle bounce over speed bumps.

3.1.4.2. Experimental setup and vehicle design. This subtheme captures participants' reflections on how interior-related factors, such as screens, seat position, space, information, and overall experimental setup, affected their comfort. While the setup may not be fully generalisable, the fact that these reflections emerged highlights the importance of testing the interior set-up of any new vehicles prior to their rollout. More detailed descriptions for this section can be found in Appendix 2, which provides insights for future studies to enhance their experimental designs.

3.2. Environmental factors

3.2.1. Effect of external driving environment

This theme characterises how participants perceived the environment during the ride, and how the environment affected their comfort. Example quotes are presented in Table 7.

Table 7
Example quotes for the theme *Effect of external driving environment*.

Sub-theme	Example quotes
Sensory perception of environment	*"I was happy. I knew the way. So when it felt uncomfortable, I knew we were close because it's just familiar. I knew the route, so that was good. The environment was good, and it didn't affect me, except I knew I was familiar with the surrounding." (P35, F)*
Traffic and road conditions	*"It would be the cyclists or the pedestrians who would get hurt if anything got wrong." (P8, F)*
Road type	*"But I wouldn't trust a car in the inner city of Delft, with all the bicycles. I think that's too difficult for a car." (P22, M)*
Cultural and regional environments	*"I think this car in Paris would be more in trouble than here. Because people in Paris, they drive completely differently. Well, you have the ring road of Paris, five lanes. When people get in here in Holland, for instance, in Amsterdam, people make eye contact. Can you let me in? It's an unwritten rule that one car on the lane lets one car in, and then the next car… In Paris, no, no, no. In Paris, you don't make eye contact. You do, and you just drive. Not one car, but two, three cars in the same spot. It's a game to see whether the other will be afraid. I think it's worthwhile. I think traffic here is more polite. If you go to Rome, in Paris, same problem. That doesn't make the automated car a bad car. No. Problem is that the environment will react differently on such a car than here." (P30, M)*

Note. The "example quotes" column includes Quotes (ID, Female or Male) (Category when applicable).

3.2.1.1. Sensory perception of environment. Many participants explained that the road environment felt familiar to them, perhaps because of the relatively small size of Delft. The familiarity with surroundings, such as the route and locations of traffic lights, gave participants more confidence and more ability to anticipate the vehicle's actions, and therefore contributed to their comfort.

3.2.1.2. Road type. The road types (urban versus highways) were perceived differently. Two participants considered highways as riskier due to higher speed limits, while another two expressed discomfort and a lack of trust in AVs navigating urban environments due to the complex system.

3.2.1.3. Traffic and road conditions. Participants' comfort was affected by the dynamic traffic conditions. Moderate traffic density did not lead to stress. However, dense and populated streets made participants stay vigilant, where other vehicles, cyclists, and pedestrians were around.

3.2.1.4. Cultural and regional factors. Two participants reflected on the cultural and regional differences in the environment. They highlighted the safe road environment due to separate lanes for different road users, and the polite driving culture due to strict traffic regulations in the Netherlands. In comparison, they identified more aggressive and less predictable driving environments, which may pose challenges for AVs.

3.3. Human factors

3.3.1. Affective experience

This theme depicts how participants described their emotional experiences during the automated ride, including positive and negative feelings. Moreover, it involves discussions around the coexistence of comfort and discomfort, as well as the interplay between comfort and other psychological concepts. Example quotes are presented in Table 8.

Table 8
Example quotes for the theme *Affective experiences*.

Sub-theme	Example quotes
Positive states	*"Because when I had no safe feelings, I should be a little bit sweaty hand or something like that. But that wasn't. That was comfortable that." (P2, M) (Presence of ease)* *"It was comfortable. I didn't feel any time like it was getting exciting or dangerous or whatever." (P36, M) (Absence of negative states)*
Negative states	*"I was not completely at ease. I thought of what would happen; if in my case, there would have been an accident. I'm talking about Tesla and things like that. I thought that would be funny, but it isn't funny at all, of course, because people can get hurt." (P33, M) (Safety concerns and trust issues)* *"My comfort is less because I have to pay attention." (P4, F) (Vigilance and uncertainty)*
Coexistence of comfort and discomfort	*"I feel comfortable. A bit dizzy because it's on the screen. That's different as normal. But it's quite comfortable. I only think it's bumpy on the road and it recognized too late." (P25, M)* *"That's I would be more alert, but not necessarily less comfortable." (P8, F)*
Interplay between comfort, trust, and perceived safety	*"Normally, if I drive my own car, feeling safe comes from trusting your car, but also from trusting myself and trusting all the people around. … Now I'm in the back seat and it's all about the car because the car takes care of the driving, not me. The car takes care of what happens in the environment, not me. If I trust the car, I feel safe. For me, it's the same thing." (P30, M)* *"It's all the same. It's safe, feeling safe, trusting. If one of these elements isn't there, then it would have not been a nice experience, I think. If I wouldn't have trusted it, I would have been nervous. But no, not at all." (P23, M)*

Note. The "example quotes" column includes Quotes (ID, Female or Male) (Category when applicable).

3.3.1.1. Positive states. For the positive affect, two categories were identified. The *presence of ease* encompassed descriptions such as feeling safe, consistently comfortable, relaxed, trusting, at ease, confident, and calm. The a*bsence of negative states* (or relief) referred to the lack of discomfort, as participants described their experiences, such as a lack of anxiety, not feeling stressed, not being worried, an absence of intense feelings, and not feeling afraid.

3.3.1.2. Negative states. Negative feelings during the ride were primarily around safety concerns, trust issues, vigilance and uncertainty. Participants expressed concerns due to a lack of control over the vehicle, particularly when concerned about potential risks such as the possibility of accidents. Regarding trust, some participants described it as something they felt "had to" put in the AV, resulting from their inability to take control or intervene.

Vigilance was another recurring topic, particularly at the beginning of the ride when participants were adjusting to the novel experience. During the ride, some participants noted that their need to remain vigilant and pay attention to the vehicle's behaviour undermined their overall comfort. For example, one participant found that the automated ride required more attention compared to a human-driven vehicle.

3.3.1.3. Coexistence of comfort and discomfort. Several participants described minor discomfort, such as a bumpy ride over speed bumps, which are associated with physical aspects. Regardless of these issues, participants considered the trip to be comfortable overall.

3.3.1.4. Interplay between comfort, trust, and perceived safety. Some participants considered perceived safety as a contributor to their comfort. One participant also reflected that their sense of safety stemmed from their trust in the driver, the AV, and the surrounding vehicles. Moreover, participants considered these three concepts to be interconnected, collectively shaping a nice experience.

3.3.2. *Attitudes to AV/technology*

This theme captures how users' attitudes towards AVs and/or technology were associated with their comfort during the ride. It includes two subthemes: "*trust and mistrust*" which reflects users' trust and preferences for either human drivers or automated vehicles, and "*future outlook*" which depicts users' expectations regarding future use, long-term development of AVs, and age-related considerations. Participants' trust in technology or AVs affected their comfort during the ride, while the ride experience further shaped their visions of AVs. Example quotes are presented in Table 9.

3.3.2.1. Trust and mistrust. Participants who expressed confidence and trust in automated systems, considered AVs to have constant focus, skill, intelligence, and consistency, while humans were viewed as more unpredictable and susceptible to changes due to factors such as emotions or fatigue. However, trust in AV technology of participants was conditional. It was associated with the presence of a safety driver who could intervene, and the fact that the experiment had been approved by authorities, believing it must be safe enough to be permitted on the road. Conversely, those who preferred human control, expressed a lack of trust in technology and machines, due to uncertainties about their reliability, particularly during unexpected situations. This might be because of the novelty of the AV technology.

3.3.2.2. Future outlook. Participants considered the potential future use of AVs beyond their immediate experience. While some participants envisioned owning an AV in the future due to a positive experience, others expected AVs to act as public transport. In comparison, some participants imagined AVs primarily being used as public transport or taxis. Participants also envisioned potential driving scenarios for AVs, such as long-distance travel, which they compared to taking planes. Highways were considered to be suitable for AVs.

Table 9
Example quotes for the theme *Attitudes to AV/technology*.

Sub-theme	Example quotes
Trust and mistrust	*"As long as, people, people are driving, there will be differences like this. Once you have only automated driver, it'll be the same everywhere. But people, they can have bad attitudes behind the steering wheel. They had a row with their wife or they had a bad night's sleep and they're not awake. Those are all things that can happen. The computer is always the same, I think. It's always clear-headed." (P30, M) (Trust and preference for technology/AV)* *"The car did very well. But in the back of your mind, you know he will step in if really necessary. But also for the test, he can only step in at the latest moment because you want to know how far will the car go with being safe." (P26, F) (Conditional trust)* *"I don't trust technology at all ranges. …There's a film Space Odyssey, 2002 or 2001, when technology takes it over again, over the people. There's a limit to what you can give to technology and how it works, I think." (P38, F) (Trust and preference for humans)*
Future outlook	*"I'm sure that in one day decades, there will be a lot of self-driving cars, and that's in development. That is not to stop. So I support also that possibility. And it's and then when it was possible for me to buy tomorrow a self-driving car, I should do it. And when the money was available." (P2, M) (Future use cases)* *"I'm sure that in one day decades there will be a lot of self-driving cars, and that's in development. That is not to stop. So I support that possibility. And when it is possible for me to buy a self-driving car tomorrow, I should do it, when the money is available." (P2, M) (Development expectations)* *"I thought it was very comfortable, but if I wouldn't have known there was the man in the car, I wouldn't have been that comfortable. The human factor is still important for me. But maybe that's an age thing. Maybe younger people have less problems with that. It's because you are probably more used to automatic things than older people.… I don't know. But I can't imagine because everything goes forward very fast and all the people can't always keep up with that. I don't know." (P20, F) (Age-related considerations)*

Note. The "example quotes" column includes Quotes (ID, Female or Male) (Category when applicable).

Several participants expressed optimism about the future evolution of AV technology. They also acknowledged the current imperfections and limitations of AVs during the phase of development. In particular, a participant expressed uncertainty about whether older adults could adapt to the rapid pace of technological changes.

3.3.3. *Engagement in NDRT*

This theme characterises users' willingness to engage in NDRTs in future AVs, based on their ride experience in the present study, and considerations that affected their attitudes towards NDRT engagement. We anticipate willingness to engage in an NDRT to be an indicator of user comfort in AVs (see also evidence in Forster et al., 2020; Klingegård et al., 2020). Example quotes are presented in Table 10.

3.3.3.1. Attitudes towards NDRT engagement. On the one hand, some participants expressed a willingness to engage in NDRTs in future AVs. Some viewed it as similar to performing activities on public transport, while others indicated they would prefer engaging in less demanding activities, such as using their phones, taking a nap, looking around, or reading a book. On the other hand, participants who expressed hesitation and reluctance towards engaging in NDRTs mentioned various reasons, such as an unfamiliar "mindset" with AVs – finding it strange to leave the driving task to the vehicle while totally focusing on other activities. Other concerns include discomfort with sitting in the front seat while being distracted by NDRTs, a lack of experience with and trust in

Table 10
Example quotes for the theme *Engagement in NDRT*.

Sub-theme	Example quotes
Attitudes towards NDRT engagement	*"I don't feel the need to do anything other than driving the be a passenger or I don't have to work or… It's not like a train. [Yeah, not like a train?] In a train, you can work, but I don't feel the need to do that in the car. [Why is it?] Because I'm experiencing the surroundings and I'm enjoying…I'm enjoying the ride. … I would do the work at home and not in the car." (P22, M) (Positive attitudes)*
Prerequisites for NDRT engagement	*"I think that's a matter of time. It's step by step. … I must not say you're not believing in that work, but you will monitor how it works. I think that's a kind of natural style from human being. You get trust by seeing that it works. It's still working. Otherwise you don't have trust." (P12, M) (Trust and reliability)* *"I would take some time getting used to it." (P8, F) (Acceptance of passive role)* *" It gives more comfort as when I was a relaxed, I look more around me, and I'm not fixed at: What's the speed and what's going on? Then I look more around. And I like more to see what's around and not fixed on what car is doing." (P4, F) (Situational comfort)* *"If you're just crossing a city, that's completely different than reading a book on the motorway." (P34, M) (Environmental factors)*
Vigilance and monitoring	*"But even then, there's not much you can do. But you feel you have to be a witness to whatever might be happening. Because suppose the cyclist, it wouldn't have seen the cyclist. Then you wouldn't have seen it happening. And that's even then, You don't have to because the camera would record what would have happened. So, if you have to go be a witness in a court or something, even then it wouldn't matter. But still, you're programmed to check on things as a human being. because you're physically there." (P2, M) (Perceived necessity of monitoring)* *"no, I think you always have to be aware of your surroundings. I think it's beneficial if you have to go really a long way physically then. But I think you have to watch because you have to step in when necessary." (P26, F) (Need for vigilance)*

Note. The "example quotes" column includes Quotes (ID, Female or Male) (Category when applicable).

AV technology, and a preference for observing the driving.

3.3.3.2. Prerequisites for NDRT engagement. We identified several prerequisite factors that affected participants' willingness to engage in NDRTs. The most frequently mentioned factor was trust. Many participants indicated that they would need more time and more rides to observe the AV's reliable and consistent performance before developing sufficient trust. One participant highlighted the need for clear liability guidelines in terms of responsibility and insurance-related matters for engagement in NDRTs. Participants further noted that they would need time to adjust to the passive role in AVs, and a key prerequisite for performing NDRTs would be having no responsibility for driving the vehicle. One participant mentioned that feeling comfortable was a prerequisite for them to enjoy focusing on observing the vehicle's behaviour and the external environment. In addition, it was pointed out that the road environment, such as highways versus city streets, would affect their willingness to engage in NDRTs.

3.3.3.3. Vigilance and monitoring. Despite the overall comfort of the ride, many participants expressed that they were reluctant to engage in NDRTs because of a desire to remain vigilant to monitor the driving and the AV's decisions, especially in the early stages. Participants explained that they would feel responsible for double-checking the vehicle's actions and staying aware of what is happening, even if they have little ability to intervene. In this case, vigilance does not necessarily imply discomfort; conversely, monitoring the drive and remaining informed could improve users' comfort.

Several participants noted that they would want to maintain a certain level of vigilance while engaging in minor activities in AVs, reflecting concerns about potential risks and a desire to intervene if necessary. Regardless of the safety of AVs, the presence of other vehicles was viewed as a source of uncertainty, contributing to the desire for vigilance.

3.3.4. Communication with AV

This theme characterises what participants wanted to know and do when interacting with AVs, based on their ride experience, and how it was associated with their comfort needs. Such communication needs include a better understanding of the AV's decisions and actions, a desire to control or influence the AV's decision, and a need for information about the AV. Example quotes are presented in Table 11.

3.3.4.1. Understanding AV systems. A better understanding of the AV's decision-making criteria and capabilities contributed to participants' comfort (see also *AV capabilities* and *effect of AV exposure*), while uncertainties about these were linked to their discomfort and vigilance during the ride. Many participants expressed curiosity about the AV's decision-making processes and showed a desire to better understand the vehicle's operations. They raised questions about whether the route was flexible or pre-programmed, how the vehicle maintained its maximum speed, why it made certain decisions, how it reacted to objects, whether it was guided by GPS or other systems, how it would respond to other vehicles' mistakes, how it anticipated or detected traffic lights, and whether there were delays in its actions. Specific situations, such as when the AV overtook a truck, caused confusion about the rationale behind these decisions.

3.3.4.2. Desire for control and influence. Several participants showed a desire to have the ability to control, intervene, or supervise the AV, when necessary. This was for situations such as when the AV failed to see objects, missing road signs, or if the system was under a cyber-attack. The presence of an "override button" was considered important to increase their comfort, as it would provide a sense of control. In contrast, another participant mentioned feeling so comfortable that they would expect to remain comfortable in the front seat without any means to interact with the driving in the future. Apart from control, participants also expressed a desire for more options, such as selecting different driving styles for particular situations (e.g., being late for an appointment) or customising the driving style with specific instructions (e.g., "cut the corners calmly").

Table 11
Example quotes for the theme *Communication with AV.*

Sub-theme	Example quotes
Communication with AV	
Understanding AV systems	*"I try to look, because I'm a physicist and a canter engineer, I try to look, oh, this is a difficult situation. Oh, yes, to see that these lights are traffic lights and these lights are another car. How can you make a computer do that?" (P36, M) (Decision-making process & actions)*
Control and influence	*"There is also the possibility that somebody breaks in the system and drives 200 miles an hour with the car without you interfering it. There must always be a possibility to interfere very quickly as a driver." (P38, F) (Intervention)* *"I think that would have to be some kind of safe average, but I would like to be able to put a bit of my own style in it. So if I could, program it to say, take your time, don't make that orange traffic light if you don't really have to, cut the corners calmly. And maybe I would be able to program it that way." (P8, F) (Choices)*
Information needs	*"At some points, what I would have liked, if you had the possibility just to get a little more information from the car, for instance, what was the speed it used." (P23, M) (Current status information)* *"I don't hear the sound of the indicator for the direction right or left." (P31, M) (Future status information)*

Note. The "example quotes" column includes Quotes (ID, Female or Male) (Category when applicable).

3.3.4.3. Information needs. Participants expressed a desire for information about the AV's status during the ride, such as its current speed and lane positioning. One participant suggested that their need for specific details, such as rearview information, might come from their habits as an experienced driver. In contrast, another participant noted that when not responsible for driving, such as when taking a taxi, rearview information would not be necessary.

4. Discussion

In this study, we used semi-structured interviews to gather older participants' insights about their comfort during a ride in a Wizard-of-Oz automated vehicle. The following sections discuss the theoretical implications for understanding of user comfort, focusing on relevant factors and their interrelationships. This is followed by discussions on practical implications for AV design, and considerations for future research.

4.1. Factors associated with comfort

Interview questions for this study were designed based on a conceptual framework developed by Peng et al. (2024), which was informed by a literature review and discussions in an expert workshop (see Sections 1.1 and 2.4). In addition to the original factors outlined in the framework, our findings revealed several new factors associated with user comfort. These include 1) *AV capabilities*, reflecting users' perception and judgement of the capabilities of the AV system; and 2) *Effect of AV exposure*, referring to gradual changes in perception and attitudes that occur with increased experience with AVs. The emphasis on driving styles in the conceptual framework by Peng et al. (2024; see also Section 1.1) limits its broader application. While we also took driving styles as a lens to start with, we shifted the focus towards a more generalisable understanding of comfort in automated driving. Therefore, in this work, we propose that our alternative approach, incorporating three overarching factors (Fig. 7), provides a more comprehensive and effective way to conceptualise comfort and structure its determinants. This framework offers guidelines for AV system designers to measure and create comfortable and acceptable experiences, particularly for older adults who are expected to benefit significantly from automated vehicles.

4.1.1. *The three-factor framework*

Vehicle factors include driving styles, AV capabilities, effect of AV exposure, and physical aspects inside the vehicle. ***Environmental factors*** refers to the effect of external driving environment. ***Human factors*** include affective experience, attitudes to AV/technology, engagement in NDRT, and communication with AV. In particular, affective experience represents a state of comfort. We consider the three factors to be interconnected (Fig. 7).

4.1.2. *Cause-and-effect relationship*

We suggest that the relationship between these factors and comfort may vary in terms of cause and effect. On the one hand, the results showed that vehicle factors, such as driving style, and environmental factors were explicitly evaluated by participants, indicating that these factors serve as a cause of comfort. Specifically, ***vehicle factors*** - such as smooth driving style, the ability to handle complicated situations, and increased AV exposure - can have a direct impact on users' physical and psychological comfort (see Section 3.1). Similarly, ***environmental factors***, particularly external road environments, can also affect both physical and psychological comfort (see Section 3.2).

On the other hand, the relationship between ***human factors*** and comfort is more complex, varying in cause or effect. Our results showed that the theme *affective experiences* primarily represents psychological comfort. For example, the subtheme *positive states* illustrates how individuals feel when they reach a psychological comfort state, which may allow for the presence of certain physical discomfort (see the subtheme *coexistence of comfort and discomfort*). This suggests that affective states are an expression of how we can conceptualise comfort (see more detailed discussion on our definition in Section 4.1.1). Our results also indicated that participants' trust in technology or AVs, as part of their *attitudes to AV/technology*, can serve as a cause of their comfort. Furthermore, our results highlight that effective communication with AV can contribute to a higher level of user comfort (i.e., cause) (see the themes *communication with AV*). Finally, engagement in NDRTs is often considered a key benefit of AVs (e.g., Hecht et al., 2019; SAE, 2021), many studies focus on enhancing AV comfort by reducing motion sickness to facilitate NDRT engagement (e.g., Brietzke et al., 2021; Kremer et al., 2022). However, our findings, as reflected in the theme *engagement in NDRT*, show that mere (physical) comfort is not sufficient to convince users to engage in NDRTs, particularly in the early stages of AV adoption. Various other prerequisites should be met to facilitate NDRT engagement. In other words, the actual engagement in NDRT is likely to be an outcome of psychological comfort.

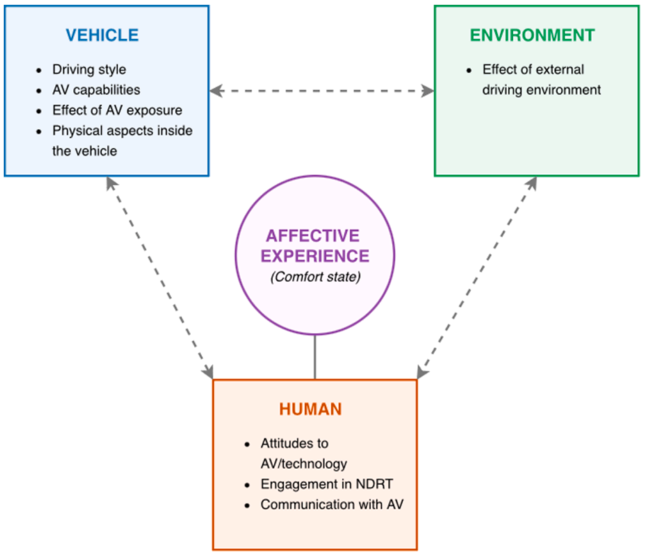

Fig. 7. Factors associated with user comfort in automated driving, from the perspectives of vehicle, human, and environment. "Affective experience" is considered part of the Human factors.

4.1.3. *Comparison with other frameworks*

The overarching factors – vehicle, environmental, and human factors – are in line with the injury prevention paradigm for road safety (Haddon, 1972) and a recent study by Domova et al. (2024). Based on a literature review, Demova et al. categorised comfort-influencing factors into external factors (or environment), vehicle-related factors (including physical features and automation), and user-related factors (including individual characteristics, activity, and understanding of the system). However, Domova et al. mixed comfort/discomfort with a range of other psychological concepts, such as acceptance, trust, user experience, situation awareness, motion sickness, and mental workload. In their framework, the concept "comfort" can be interpreted more broadly as positive experiences. While we share a similar positioning with the paper in terms of overarching conceptual factors, our study has revealed subtle differences with respect to other concepts, whilst acknowledging the potential bidirectional relationship. The differences identified may have been observed as a result of the exploratory nature of our study, which allowed participants to freely acknowledge their experience with an "automated" ride on real roads, and provided insightful discussion immediately following the experience.

Overall, our results highlight the multifaceted nature of comfort as a concept. An understanding of this concept will be discussed in the next section (4.1.1).

4.1.4. *Implications for conceptualising comfort*

Among the themes under ***human factors***, *affective experience* reflects participants' feelings during the ride. These feelings seem to be the most appropriate gauge of how participants were expressing their current comfort levels, providing guidance on how comfort should be conceptualised. Gaining a deeper understanding of the concept of comfort is crucial, as it informs the measurement and enhancement of the psychological states of comfort in future research and practice.

We found that the positive affective aspects of comfort can be understood through two dimensions (see the subtheme *positive states)*: the absence of negative feelings and the presence of ease, varying in terms of valence or intensity. To enhance user comfort, designers could address these states progressively, beginning with the elimination of negative sensations, such as reducing vehicle vibrations and noises. This categorisation aligns partially with the comfort theory proposed by Kolcaba & Fisher (1996) (also see Kolcaba and Kolcaba, 1991). Their theory, drawn from literature from multiple domains, identifies three fundamental states of comfort: relief (the experience of having a specific need met), ease (a state of calm or contentment), and transcendence (the state in which one's ordinary powers are enhanced). Our finding regarding the absence of negative feelings aligns with the relief dimension, while the presence of ease maps to the ease dimension. The third state, transcendence, which refers to, for example, "enhanced powers, strengthened motivations, and positive attitudes and outlooks for meeting the life challenges" (Kolcaba and Kolcaba, 1991), was not encompassed in our findings. As our experimental setup provided solely a basic driving experience without an infotainment system or user intervention, this likely explains the absence of insights regarding the more active comfort state (transcendence). However, further investigation is warranted to determine if this absence reflects lower comfort expectations and needs among older users.

While the relationship between comfort and discomfort has long been a topic of debate (e.g., Cohen-Lazry et al., 2022; De Looze et al., 2003; Helander and Zhang, 1997), we observed the *coexistence* of both states. As shown in the subtheme *coexistence of comfort and discomfort*, participants mentioned a range of physical discomfort elements, such as a bumpy ride over speed bumps, while they emphasised that the trip was comfortable overall. This suggests that, despite experiencing physical discomfort for certain aspects of a journey or for a shorter period of time/situation, users can still experience a sense of psychological comfort. This finding supports the notion that comfort is more than just the absence of discomfort, aligning with insights from previous research in automated driving (Peng et al., 2024) and research on broader ergonomics, such as seat comfort (Helander and Zhang, 1997; Zhang et al., 1996). This evidence also presents a counterexample to the discomfort model proposed by Cohen-Lazry et al. (2022), which suggests overall comfort can only be achieved when comfort is achieved in all relevant dimensions. However, the coexistence of comfort and discomfort might be attributed to the driving environment, where the intensity of both states remained within a certain range, allowing them to coexist.

The three psychological concepts – comfort, trust, and perceived safety – have been investigated in the context of automated driving, with research attempting to explore their interrelationships (He et al., 2022; Nordhoff et al., 2021; Paddeu et al., 2020). Although our interview questions about the relationship between comfort and the other two concepts were not always easy for participants to answer, we gathered valuable and insightful perspectives (see the subtheme *interplay between comfort, trust, and perceived safety*). Feeling safe can come from users' trust in AVs, the presence of safety drivers, and surrounding vehicles. Improving both perceived safety and trust can contribute to users' comfort. As these three concepts together constitute a nice experience, it is challenging to separate them for users to evaluate, especially in a daily, normal, driving environment. More attempts could be made in different scenarios involving varying levels of risks and participants with different levels of trust in technology or AVs.

Regarding the definition for comfort, Peng (2024) proposed a comprehensive description based on their conceptual framework: "*In automated driving, user comfort is a state involving subjective feelings of ease and pleasantness, and the mere elimination of discomfort is not enough to ensure user comfort in automated vehicles (AVs). Comfort in AVs has both physical and psychological dimensions, which affect each other… User comfort is a dynamic concept, evolving in response to users' expectations, their communication with automated vehicles, and the varying environmental and traffic conditions.* (p. 191)." Building on this description and our further exploration, we propose a refined definition specifically for comfort, which provides more practical guidance for measurement.

> *In automated driving, users' perception of comfort refers to the absence of negative states and the presence of ease. It is an outcome of the interaction among vehicle, environmental, and human factors, and encompasses both short-term and long-term elements.*

Notably, older users appear willing to tolerate a certain level of physical discomfort while still feeling psychologically comfortable.

4.2. Implications for AV design

Our results can be used to inform AV design, in particular, driving styles. Driving style is important for user comfort, not only because it can affect passengers' comfort directly, but also because it can be seen as a reflection of AVs' capabilities (see theme *driving styles* and *AV capabilities*). Overall, our results of the theme *driving styles* suggest that smooth, cautious, and anticipatory features of automated driving contributed to user comfort, which aligns with previous findings (e.g., Carlowitz et al., 2024b,; Peng et al., 2022; Yusof et al., 2016). It is worth noting that our goal was not to quantify precise thresholds (e.g., "sufficient" distance or "delayed" response time) but to understand the factors that contribute to comfort from the user's perspective. The qualitative data provides the "what" and the "why" behind comfort, which can then inform future quantitative studies that aim to define the "how much." Moreover, we found a positive attitude of participants to adapt to driving styles that were different from their own (see subtheme *adaption to AV*). This suggests that a great deal of personalisation might be unnecessary (see examples investigating personalised driving styles: Butakov and Ioannou, 2015; Delmas et al., 2023, 2024).

In our study, as indicated by the theme *kinematics*, participants paid attention to the vehicle's speed, linking it to their comfort and expressing a desire for more speed-related information (also see the subtheme *information needs*). While in a moving vehicle, the human body is more sensitive to changes in speed (i.e., acceleration and deceleration) than to continuous, constant speed, via the vestibular system. Visual cues also contribute to the perception and estimation of speed (Hosman et al., 2011). Previous studies on comfort in (automated) driving have largely focused on the effects of acceleration and deceleration (e.g., Bae et al., 2022; Barabino et al., 2019; de Winkel et al., 2023). However, our findings indicate that even though speed itself may not directly affect physical comfort, it might be associated with psychological comfort around understanding vehicle status. Providing users with speed information and enhancing their visual input to perceive speed could improve their overall comfort.

Regarding interactions with other road users and infrastructure, the subtheme *interaction with OREs and ORUs* suggests that maintaining a sufficient distance from other road users was a crucial factor for user comfort. This is in line with a conceptual suggestion (Summala, 2007) and simulator-based studies focusing on perceived safety (He et al., 2022). Another simulator-based study on comfort did not show significance of distance-relevant metrics (Peng et al., 2025), which might be explained by the simple nature of the driving scenario. The relative importance of proxemic factors among all vehicle factors in more complicated scenarios needs further investigation for quantification.

Overall, the themes *driving styles* and *AV capabilities* suggest that AV driving styles and overall design should not be seen as constant, but flexible in response to different road conditions and traffic dynamics. This is because other objects on the road can be unexpected, unpredictable, or even emergent. Quick, early, and flexible reactions are crucial to ensure user comfort by showing AVs' constant capabilities and establishing users' confidence and trust in AVs. In particular, early reaction, for deceleration or braking, to other road users and infrastructure elements should be considered (see the theme *AV capabilities*). It aligns with Bellem et al.'s (2018) finding that early motion feedback for lane change was preferred for comfort. Before users established sufficient confidence and trust, the theme *communication with AV* suggests that allowing users to retain certain control over AVs, for example, braking for emergent situations, could enhance user comfort, which aligns with previous research on cooperative driving (Mertens et al., 2020; Peintner et al., 2025). Moreover, providing options for users to adjust driving styles for different trip purposes and situations is important to ensure user comfort time by time.

4.3. Limitations and future outlook

First, whilst the findings provide valuable input from the perspectives of the general public, particularly older adults, there are certain limitations associated with inclusivity. As evidenced by the participant who could not participate in the study due to mobility difficulties and the design of the vehicle, the study was unable to gather input from participants with mobility impairments, whose contributions might differ considering their specific requirements. Future research could potentially benefit from the inclusion of individuals with disabilities.

Second, the context of the Netherlands, where roads are usually narrow, but separations of lanes for vehicles, cyclists, and pedestrians are well established. This presents certain strengths and limitations for the findings of the present study. While we obtained a range of contextual information, such as the aberrant behaviours of other cyclists or narrow roads, there may be external factors that our participants did not encounter during their ride or within their regular transport environments. Consequently, the results should be interpreted with consideration of the effects of personal travel experiences and regional and cultural factors.

Third, the relationship between different factors and comfort, in terms of the direction of effect, was not thoroughly discussed in this manuscript. We consider different factors play a role in different stages of comfort. For example, attitudes to technology might affect comfort before any automated rides, while driving styles could affect comfort during the ride. Whether engagement in NDRTs is a precursor of comfort or output or comfort deserves further discussion and investigation. Causal relationships need more research to be understood.

Fourth, while our study showed short-term experience with AVs could increase user comfort and other experiences during the ride, these influences are more on reducing novelty-related discomfort. More studies on long-term experience with AVs are needed, in terms of, for example, the relationship between users' understanding of AV systems and capabilities through usage and their comfort.

Lastly, our study had methodological limitations. As indicated by the sub-theme *Experimental setup and vehicle design* (see also Appendix 2), some participants reported discomfort due to factors such as the size and the refresh rate of the display, the seating position in the rear of the vehicle, and the ventilation. The findings suggest that the participants' overall evaluations may have been influenced by the experimental setup. Simultaneously, the results may indicate that variability in the physical design and implementation of these vehicles could impact the dimensions associated with comfort experience in automated vehicles, thereby providing some degree of external validity to our study. Future studies should address these methodological issues to provide a more immersive experience for participants, which would in turn elicit more detailed opinions and evaluations.

CRediT authorship contribution statement

Chen Peng: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **İbrahim Öztürk:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Ruth Madigan:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Sina Nordhoff:** Writing – review & editing, Resources, Project administration, Methodology, Conceptualization. **Sascha Hoogendoorn-Lanser:** Writing – review & editing, Resources. **Marjan Hagenzieker:** Writing – review & editing, Resources, Project administration, Funding acquisition. **Natasha Merat:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

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

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Appendix 1. The list of semi-structured interview questions

1 Generally speaking, how was your ride experience?
  Probe: How comfortable/uncomfortable was the experience?
  Probe: Motion or the driving style of the vehicle
  Probe: Other factors
2 What do you think of the AV's driving style?
  Probes: Speed etc. But **only** to be included after they've provided some information
3 *[Remind participant]* You mentioned … when we talked about your expectations before the ride. After your experience with the self-driving vehicle, have your expectations about self-driving vehicles changed in any way?

  a. Possible follow-up: If yes, why do you think your expectations changed?
  b. When you compare your previous expectations and your actual experience, do you think the differences affected your comfort or discomfort?

  Probe: Did actual experience match expectations? Did the match or mismatch affect your comfort?
4 During the ride, did you notice anything physically or psychologically impacting your comfort level?
  Probes: remind physical or psychological if the participant does not touch the other one
5 How natural/familiar was the vehicle's driving style? Here, a natural driving style means how closely it matches what you would expect to experience in a manually driven vehicle?
  a. Follow-up: How did this natural or unnatural feeling affect your comfort level?
  Probes: driving styles of your own, of your friends, of your family members
6 Throughout the ride, did you notice any changes in your comfort (either positive or negative)?
  a. Follow-up: If so, what factors or situations do you believe contributed to this change? OR, why?
7 During the ride, how did what was happening around you affect your comfort? Such as the road environment, and the presence of pedestrians, cyclists and so on.
8 How safe did you feel about the self-driving ride?Probe: Were there any situations that made you feel unsafe or at risk?
  a. Follow-up: How did this feeling affect your comfort level?
9 Did you trust the self-driving vehicle during the ride?
  a. Follow-up: How did this feeling affect your comfort level?
10 Did you notice any changes between the manual and automated driving modes?
11 Imagine you use such an automated vehicle in the future, how comfortable would you feel when engaging in other activities?
  Probes: what activities
12 Is there anything else you would like to share about your experiences with the automated vehicle?

Appendix 2. Effect of experimental setup and vehicle design

This theme captures participants' reflections on how interior-related factors, such as screens, seat position, space, information, and overall experimental setup, affected their comfort. While the setup may not be fully generalisable, it provides insights for future studies to enhance their experimental designs. It is important to test the interior set-up of any new vehicles prior to their roll-out.

Several participants noted that the screen led to physical feelings of discomfort, such as dizziness, low refresh rates, and a mismatch between their visual and physical sensations of vehicle movements. It also led to psychological discomfort because of concerns and uncertainty about the vehicle's speed and positions, poor usability of the side screens, and a perceived larger psychological distance from the driving experience.

Participants desired front-seat visibility to have an overview of the driving, and sitting in the back led to both physical and psychological discomfort. Regarding physical discomfort, the seat position, located over the rear axle, intensified the sensation of bumpy rides. Regarding psychological discomfort, for example, one participant noted that the back seat gave them a reduced sense of responsibility and less of a feeling of control over the vehicle. The experience of sitting in a "black box with only three screens" was uncomfortable, particularly for those who were used to being in the driver's seat.

Participants acknowledged the experimental nature of AVs. While providing some positive feedback, participants desired for improvements, such as ventilation and the inclusion of windows. Several participants noted that rearview information was missing. The interior space was perceived as too closed. Participants also showed a desire for windows, noting that the lack of connection to the outside created a sense of isolation.

Data availability

Data will be made available on request.

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