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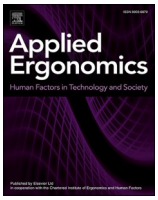

Drivers' overall comfort experiences of reclined positions in a passenger car with an automated driving function

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A B S T R A C T

—Automated driving (AD) in cars enables reclined positions when drivers disengage from driving tasks. The objective was to explore driver comfort in self-selected reclined positions during AD, and whether the chosen seat back angle is affected by stature. The study involved 29 participants in upright and reclined positions during AD on a test track at 30 km/h. After experiencing AD, the participants could adjust their reclined position settings. Seat settings of upright, reclined and adjusted reclined positions were collected, along with questionnaire and interview data about comfort. Statistical tests and thematic analysis were performed. The results implied that drivers may prefer reclined positions during AD, if they can observe the traffic and intervene with the AD system. Regardless of stature, drivers using AD do not want to recline as much as expected from static experiments. The automotive industry should revisit expectations for reclined positions to ensure driver comfort in AD.

1. Introduction

In recent decades, car manufacturers have aimed to design for comfort due to increased customer expectations. Comfort encompasses feelings of well-being, luxury, and refreshment (Zhang et al., 1996), along with the pleasant or relaxed state and individual experiences in response to their environment (Vink et al., 2012). Comfort, a subjective, time-dependent experience related to relaxation and well-being (Vink et al., 2012), is rooted in physical, psychological and functional comfort aspects (De Looze et al., 2003; Helander et al., 1997). Physical comfort is associated with relaxed muscle activity and minimal static loads (Vink et al., 2017). Psychological comfort is associated with individual emotions and is affected by visual, audial, and haptic senses. The sensory input acts as a channel connecting the individual's sense with the environment (Vink et al., 2012; De Korte, 2012). Functional comfort is instead affected by how easy something is to use, and is especially mentioned in the context of workspaces (Vischer, 2007), as the tasks performed while seated affect overall comfort (De Looze et al., 2003; Helander et al., 1997). This multidimensionality makes comfort a complex construct and challenging to assess and therefore studies often focus on the subjective perception of discomfort (De Looze et al., 2003; Helander et al., 1997). Sitting discomfort is related to feelings of pain, soreness, numbness, and stiffness, and arises when inappropriate loadings occur on the body, which can lead to posture changes.

1.1. Comfort and sitting postures in automated driving (AD)

With the emergence of AD technology, drivers may disengage from conventional driving tasks, creating opportunities for alternative sitting postures that can potentially improve their comfort experience. In the context of AD, a study proposed that the participants' perceived overall comfort was a result of several factors, such as environmental, psychosocial, and cognitive factors, rather than strictly physical qualities (Caballero-Bruno et al., 2022). Furthermore, comfort was suggested to be influenced by factors including ease of use, perceived safety, trust, familiarity, engagement in non-driving-related activities, pleasantness, design expectations, and communication. Conversely, discomfort in AD is influenced by factors such as unease, physical discomfort, unmet expectations, perceived lack of safety, lack of control, and distrust in artificial intelligence (Peng et al., 2023). The latter factors are particularly prominent in the context of automation.

Drivers' preferred activities and postures in AD might be impacted by the length of the trip, interior design, and who is in the car while travelling (Vink et al., 2012). For instance, drivers want to sit forward facing, with the possibility to window gaze (Östling et al., 2019), and recline the seat to more relaxed positions (Zhang et al., 1996), especially during short trips in AD, whereas they would like to rotate the seat to a living room position in longer trips (Östling et al., 2019). Another study emphasised that drivers prefer a forward-facing driving position,

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followed by the reclined position facing the driving direction (Yang et al., 2018). When it comes to sleeping, the combination of a 155° backrest angle and a 40° seat pan angle (measured from the horizontal axis) was found appropriate due to increased biomechanical quality, which was defined as the largest contact area with minimum acting pressures, weighted according to local sensitivities (Stanglmeier et al., 2020). Further, the uniformity of the pressure distribution of the seat back and seat pan is correlated with discomfort (Caballero-Bruno et al., 2022), implying that body size and shape may affect the perceived discomfort. Moreover, postures and belt fit were studied in a reclined mock-up seat, showing that the spine posture was changed when the torso was reclined, and thereby the belt fit also changed (Reed et al., 2019a). These preferences and attitudes towards different seat positionings in automated vehicles (AVs) were obtained through online surveys (Koppel et al., 2019), in user tests in simplified physical environments including four chairs in an enclosed area (Östling et al., 2019; Jorlöv et al., 2017) and in mock-ups (Helander et al., 1997; Vink et al., 2017).

A few other studies have investigated drivers' experiences and preferences for different seats in more dynamic conditions. For example, a simulator study comparing comfort perceptions in an upright and fully reclined seat revealed that a reclined seat showed no major disadvantages in terms of discomfort, trust, or safety (Yang et al., 2018), but it also emphasised the necessity for further studies under more naturalistic conditions. Another study investigated different seat back angles (20, 40 and 87°, all with respect to the vertical) for sleeping, in a moving car with a prototype seat on a test track at a speed of 30 km/h (Caballero-Bruno et al., 2022). The study showed that users tended to choose a flat and reclined position (87 and 40°) for long- and short/medium-term use, respectively.

Hence, previous research indicates that drivers expect and would like to sit in reclined seat positions in AD. However, there is limited research on drivers' comfort experiences of reclined positions in dynamic settings, and the need for studies under naturalistic conditions has been emphasised (Zhang et al., 1996; Vink et al., 2012; De Looze et al., 2003; Yang et al., 2018). Therefore, the objective of this study was to explore drivers' overall comfort experience of reclined positions during AD, and whether the chosen seat back angle is affected by stature, to provide design insights into preferred seat back angles and interior considerations in future AVs. The following research questions were posed.

RQ1: What reclined seat back angle do drivers choose in AD and is this choice affected by their stature?
RQ2: How is the overall comfort experience in AD affected by the chosen reclined seat back angle?

2. Method

The methodology used in this study was based on a previously developed experimental setup for assessing drivers' experiences of seat positions in AD (Makris and Osvalder, 2022).

2.1. Experimental setup

The study was conducted in a passenger car (Fig. 1a) equipped with an AD function designed to simulate high automation (SAE L4) where the driver can take over but is never required to perform emergency take overs. For all tests, the same test leader was seated in the front passenger seat (Fig. 1b), providing oral instructions, handing out questionnaires, and conducting interviews. The car was equipped with an accelerator and a brake pedal on the foot well of the front passenger side, which the test leader was assigned to use in case of an unexpected event. A test engineer was seated in the rear seat on the right-hand side, triggering the availability of AD mode via a tablet interface. The vehicle then provided audio instructions prompting the participants to activate AD mode and to take over the driving task within 30 s of receiving the instruction. AD mode was activated by pressing a physical button on the steering wheel and disengaged by placing the hands on the steering wheel. The vehicle also provided audio instructions prompting participants to activate the reclined position, which was engaged through pressing a physical button on the seat interface module (Fig. 1c) placed on the centre console. After pressing the physical button, the seat automatically transitioned between the upright and reclined positions that participants had chosen before the test run. The transition took about 5–10 s depending on the chosen seat back angles. The shoulder belt was routed via a roller-bar setup on the driver seat (Fig. 1d) to suit both upright and reclined positions.

2.2. Participants

A total of 29 Swedish speaking participants took part in the study, aged 22–54 years old (mean = 42 years; SD = 10 years). The gender distribution was 15 males and 14 females, with an average stature of

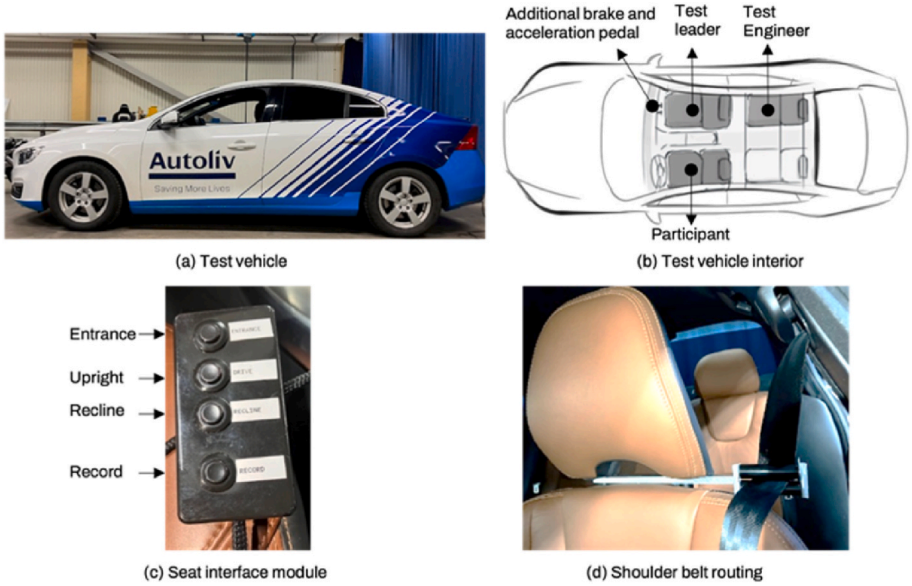

Fig. 1. An overview of the experimental setup.

176 cm (SD = 11 cm) and an average weight of 84 kg (SD = 17 kg). Their average driving experience was 21 years (SD = 10 years), and 25/29 participants had prior experience of at least one advanced driver assistant system such as Lane Centring, Adaptive Cruise control, Automatic Lane Change or Traffic Jam Assist. The participants were found through a recruitment company. The study protocol was submitted and reviewed by the Swedish Ethical Review Authority (No:2022-03787-01).

2.3. Procedures

On arrival, all participants were informed about their rights in accordance with the ethical application, signed a consent form and filled in a questionnaire about demographics and driving habits. The participants received instructions about the study procedure, that they would be prompted to take over only in the upright position and that they would never have to perform an emergency take over. They were informed that they could terminate the test at any time and that the test leader would brake in case of an unexpected event. The participants entered the driver's seat, which was positioned in the same initial position for each participant. Then they received an oral instruction: '*Adjust the seat to a comfortable upright position, as if you were going on 2–3 h' drive on a motorway'*. The participants adjusted the following seat parameters; seat height, seat pan angle, seat back angle, distance to pedals, and steering wheel position. The seat parameters of their chosen upright position were recorded and memorised using the seat interface module. The participants were then positioned in the maximum reclined angle of the seat back (65° from the vertical axis) and provided with the oral instruction: '*Adjust the seat to a comfortable reclined position, as if you were on a 2–3 h' drive on a motorway'*. The participants adjusted the same seat parameters for their preferred reclined position. The seat parameters of the reclined position were recorded and memorised using the seat interface module. The chosen upright and reclined seat parameters were also measured manually using a customised measurement tool (Fig. 2). The head restraint could not be adjusted, and participants received no instructions on whether or not to use it for head support during the test.

Fig. 2. Customised measurement tool used for seat position measurements.

The participants underwent a training session on the test track to familiarise themselves with the test vehicle and study tasks. The training session included one lap on the test track in AD mode, where participants learned how to activate and disengage AD mode and how to alternate between upright and reclined positions. The study consisted of two test runs of 8 min each. Each test run included two laps on the test track at 30 km/h in the straight paths and 15 km/h in the turns (Fig. 3). All participants experienced upright position in AD mode in the first test run, and reclined position in AD mode in the second test run. The order was intended to allow participants to experience and familiarise themselves with AD mode in upright position before reclining. The first test run comprised (1) manual driving, (2) activation of AD mode, (3) remaining seated in the upright position in AD during two laps on the test track, (4) deactivation of AD mode and taking over the driving task and (5) slowing down and parking. The second test run comprised (1) manual driving, (2) activation of AD mode, (3) activation of the reclined position, (4) remaining seated in the reclined position during two laps on the test track, (5) deactivation of reclined position and returning to upright position, (6) deactivation of AD mode and taking over the driving task and (7) slowing down and parking. After each test run, the participants remained seated in the car while completing questionnaires and being interviewed. After the second test run, they were asked if they wanted to adjust their initially chosen reclined position after having experienced it in motion. The adjusted reclined position was then recorded and measured. The procedure was tested in a pilot study which found that more than two laps on the test track became highly repetitive, as the test vehicle was limited to use on an empty test track. Each test run was therefore intentionally kept relatively short to prevent the study duration from becoming excessively long and exhausting for participants. The duration is consistent with previous research, which suggests that durations of around 10 min are sufficient to capture initial comfort experiences in cars (Makris, 2023).

3. Data collection and data analysis

Data were collected before, during, and after the test runs, all in Swedish. The collection of objective data included the participants' stature, seat back angles of the upright and reclined positions chosen by the participants before the test runs, as well as the adjustments of the reclined position made by the participants after the test runs. Both upright and reclined seat back angles were analysed to identify how users want to sit and whether there is a correlation between preferred seat back angle and stature by applying a bivariate Pearson correlation test in Matlab. Descriptive statistics were employed in the analysis of the adjustments of the reclined position to investigate how participants adjusted their reclined seat back angle after experiencing their initially chosen reclined position in motion. A Wilcoxon signed rank test was performed to investigate potential differences between the seat back angle in the initially chosen and adjusted reclined position.

The subjective data included two sets of questionnaires after each test run. In the first questionnaire, the participants graded their perceived physical discomfort related to the head, shoulders, upper back, arms, lower back, backside of thighs, buttocks, knees, calves, and feet on a scale from 0 (no discomfort) to 5 (much discomfort). In the second questionnaire the participants assessed their perceived psychological comfort and attitudes towards AD on a semantic five-point scale. The assessment consisted of six sets of opposite words: (1) 'safe'-'unsafe', (2) 'reliable'-'unreliable', (3) 'relaxed'-'tense', (4) 'comfortable'-'not comfortable', (5) 'natural'-'unnatural', and (6) 'a sitting position I would like to use often'–'a sitting position I would like to use rarely'. A Wilcoxon signed-rank test was used in the analysis of the questionnaires, where comparisons between the results from upright and reclined sitting

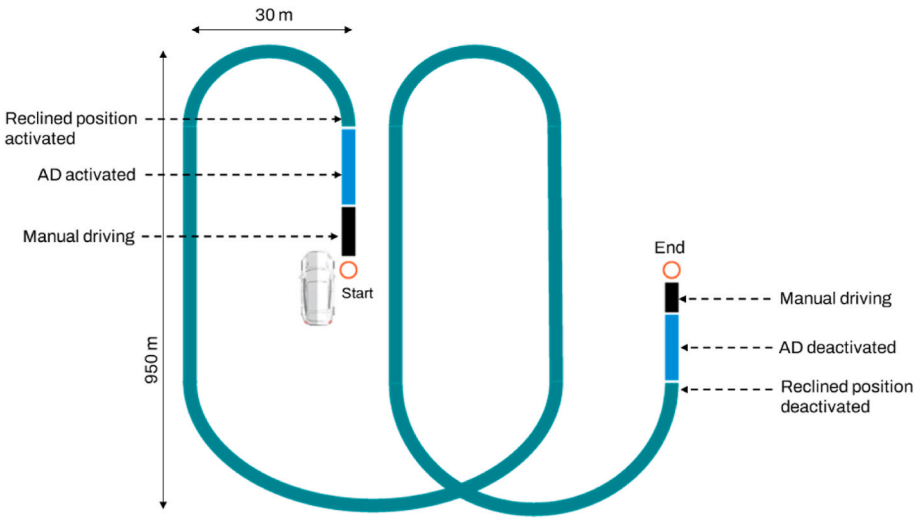

Fig. 3. A schematic illustration of the second test run in a reclined position on the test track. In the first test run the driver remained in upright position in AD, without activating the reclined position.

were made, respectively. Since the participants chose their own seat back angle, a subsequent Spearman's rank correlation test was performed to identify whether there was a correlation between the chosen reclined seat back angle and their semantic differential scale ratings.

After each test run, semi-structured interviews were conducted, focusing on the overall comfort experiences and preferences for upright and reclined positions. The interviews comprised questions about seat belt comfort, line of sight, and preferred seat back position when travelling on different road types. The interviews were transcribed verbatim in Swedish, and a thematic analysis was carried out by two of the authors, who also translated the quotations presented in the results, from Swedish to English. The thematic analysis consisted of two parts. The first part had a deductive character, where the data was coded according to predefined categories, such as positive or negative experiences of the reclined position, to structure the interview data into broad themes. The second part had an inductive character, where new themes, such as control and trust, were extracted from the broader themes without any predefined categories. The interview data was used as a complement to the questionnaire data by further elucidating how participants experienced sitting in a reclined position and how this experience differed from sitting in an upright position. The entire study procedure, including the information session, training session, two test runs, questionnaires, and interviews, took approximately 1 h.

4. Results

In general, the results showed that the physical discomfort was low in both upright and reclined positions, while concerns related to the psychological and functional comfort were more prominent in the reclined position. The results also showed moderate relationships between stature and chosen seat back angle in upright and reclined positions.

4.1. Seat back angle

On average, the participants chose a seat back angle of 25° in the upright position, compared to 42° in the reclined position (Fig. 4). After experiencing their chosen reclined seat back angle during AD, the participants re-adjusted to a slightly more upright seat back position of 38° (Fig. 4). A moderate positive significant correlation was observed between both stature and upright seat back angle ($r = 0.463$, $p = 0.011$), and between stature and reclined seat back angle ($r = 0.382$, $p = 0.041$) (Fig. 5).

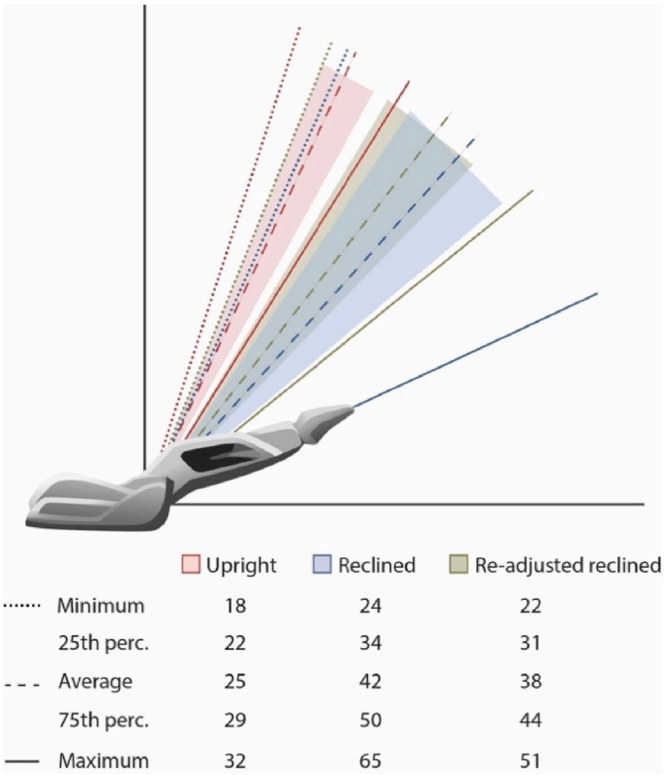

Fig. 4. Seat back angles chosen in upright, reclined and adjusted reclined positions.

4.2. Physical discomfort

The ratings of physical discomfort showed that no or low discomfort was experienced in the lower body region (including backside of thighs, buttocks, knees, calves, and feet) in either upright or reclined positions. These results corresponded well with the interviews, where few participants specifically mentioned discomfort in the lower body region. In general, the ratings showed slightly more discomfort in the upper body region (head, arms, shoulders, upper back and lower back) than for the lower region (Fig. 6).

In the reclined position, the discomfort was more prominent for the

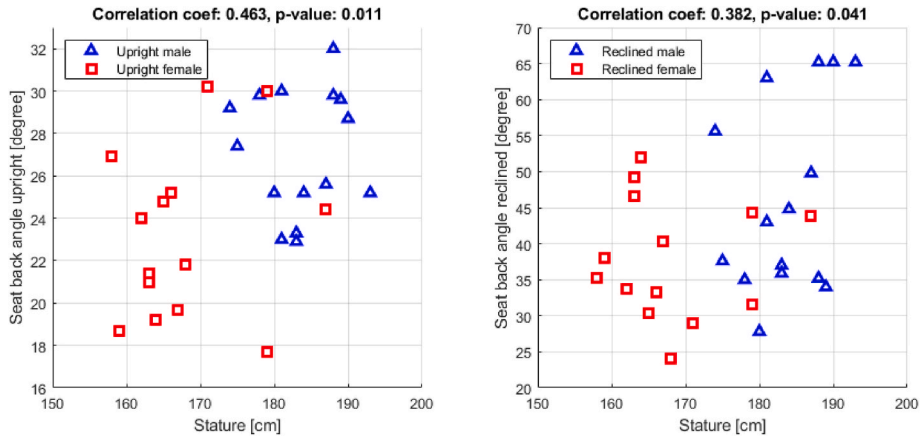

Fig. 5. Correlations between stature and chosen seat back angle in upright and reclined position.

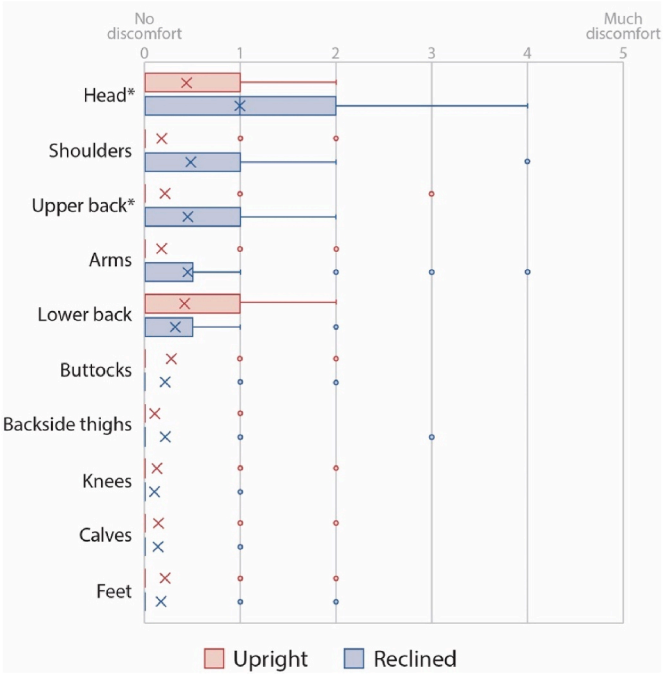

Fig. 6. Physical discomfort ratings of different body parts in the upright and reclined position on a scale from 0 (no discomfort) to 5 (much discomfort). The 'x' shows the average, the '*' indicates statistical difference ($p < 0,05$) between responses in upright and reclined positions, and the circles show outliers.

head, arms, shoulders and upper back compared to the upright position, with statistically significant differences in the ratings for the head ($Z = 2.441$, $p = 0.015$) and upper back ($Z = 2.111$, $p = 0.035$). However, there were no statistically significant differences between the discomfort ratings of upright and reclined position for the arms ($Z = 1.841$, $p = 0.066$), shoulders ($Z = 1.807$, $p = 0.071$), lower back ($Z = -0.749$, $p = 0.454$), backside thighs ($Z = 0.816$, $p = 0.414$), buttocks ($Z = -0.632$, $p = 0.527$), knees ($Z = -0.447$, $p = 0.655$), calves ($Z = 0.000$, $p = 1.000$), and feet ($Z = 1.000$, $p = 0.317$). The thematic analysis of the interviews showed that the lack of head support and not knowing where to put the arms in the reclined position caused physical discomfort. However, it did not show explanations for the significantly increased upper back discomfort in the reclined position.

Even though some participants negatively commented on aspects of physical comfort in the interviews, the thematic analysis showed that many participants felt physically relaxed and comfortable while reclined. For instance, one participant compared it to a comfortable sofa and reasoned that it would be easy to fall asleep while reclined. Moreover, they did not express any discomfort related to the seat belt while reclined, nor did any of them mention motion sickness as a problem, even though a few of the participants reported that they sometimes felt motion sick when travelling.

4.3. Psychological and functional comfort

In addition to physical comfort aspects, the thematic analysis showed that psychological and functional comfort aspects were prominent when sitting in a reclined position during AD. One participant emphasised the distinction between physical and psychological comfort by describing the experience accordingly: *'Even though I am lying comfortably, I do not feel comfortable in the situation that I am in'*. The thematic analysis showed that the perceived lack of control in the reclined position was a concern among most participants, who considered control to be an important factor to feel comfortable during AD. Two activities associated with perceived control were identified in the thematic analysis: being able to observe and being able to intervene. Wanting to be able to observe was mentioned by most participants. They stated that they would like to keep an eye on what happens outside the car, to be attentive and aware of the surroundings. Referring to the reclined position, one participant said: *'It becomes a bit too comfortable; it is almost like some sort of meditation and then I become stressed about being too tired and not being attentive enough'*. When it comes to being able to intervene, one participant stated: '*When sitting upright, you feel more prepared to take over. If something happens with system I can easily reach [the steering wheel], whereas if you are lying down, you need to get into the upright position, so the preparedness is better in a fairly normal driving position*'. Even though many participants experienced that their perceived lack of control had a negative impact on their overall comfort while reclined, a few participants were positive, as sitting reclined forced them to let go of control, which helped them relax. For instance, one participant said: *'Since I could not do anything, I did not focus so much on whether I saw a car in the far distance. Instead, I relaxed much more while sitting reclined'*.

When it comes to the possibility to view the road, the thematic analysis showed that the participants who experienced they had a good view of the road when reclined often had less reclined seat back angles (an average of 37°), whereas the participants that were unsatisfied with their possibility to view the road often had more reclined seat back angles (in average 53°). Further, the thematic analysis showed that most participants emphasised the importance of having a clear view of the road regardless of the chosen reclined seat back angle. This factor was highlighted as crucial for feeling safe, in control and able to trust the AV. For example, one participant stated: *'Since I am not driving, I don't really need to see the road, but I want to see the road because I don't trust the technology. It is a matter of control; I want to be in control and able to see*

[what is happening]'. However, the analysis of the semantic questionnaire did not show any relationship between the participants' specific seat back angle and how they rated their experience, the highest Spearman's rank correlation being $r(27) = 0.09$ and all corresponding p-values showing no statistically significant correlation. Even though there was no correlation between the participants' chosen reclined seat back angle and semantic questionnaire ratings, most participants chose a more upright position when they were given the opportunity to adjust their reclined angle after the second test run (Fig. 7). On average, the participants adjusted to a 4-degree higher upright seat back angle (from an average of 42° in the initially chosen reclined position to an average of 38° in the adjusted reclined position). The Wilcoxon signed-rank test revealed a significant difference between the participants' chosen reclined position in AD and the adjusted reclined position after the test runs ($V = 18$, $p = 0.001$). The thematic analysis indicated that the participants opted for a more upright seat back angle to enhance their ability to observe their surroundings.

When it comes to perceived trust towards the AD system, the analysis of the semantic scales showed that the participants felt less safe while reclined ($Z = 2.389$, $p = 0.017$), and that the reclined position felt more unnatural than the upright ($Z = 3.344$, $p < 0.001$). The thematic analysis of the interviews showed that the perception of natural and unnatural were associated with former experience and familiarity of the different sitting positions. For example, one participant said: *'It was not that unfamiliar or unpleasant when sitting upright, but when I lied down it became much more unfamiliar because I could not see so much. It went from being comfortable and familiar to being unfamiliar and almost unpleasant'*. Furthermore, many participants discussed that the reclined position was a new experience and that the perceived safety and trust towards the AD system would increase with more experience and knowledge about how the car handles different traffic situations. For example, one participant reasoned: *'If you would have done this 100 times, you would have trusted the car. But this is the first time so of course I'm a bit on my guard'*. However, the other items, relating to the reliability of system ($Z = 0.914$, $p = 0.361$) and how comfortable ($Z = -1.054$, $p = 0.292$) and relaxed ($Z = 0.187$, $p = 0.852$) the participants felt, were all rated similarly for upright and reclined positions (Fig. 8).

Regarding the preferences for the upright and reclined positions, the semantic scales showed that most participants were more positive towards using the upright position during AD ($Z = 2.921$, $p = 0.003$), whereas the enthusiasm for the reclined position deviated in a wider range from 'something I would like to use often' to 'something I would like to use rarely'. These responses were further explained in the interviews, and the thematic analysis showed that most participants had different preferences depending on the context. When asked about their willingness to sit reclined during city, country road, or motorway driving, almost all participants responded that they would not like to sit reclined during city driving. A few participants were positive towards sitting reclined on country roads, whereas most of the participants could imagine that they would like to sit in a reclined position on motorways. The thematic analysis showed that the reasons behind their preferences were related to perceived control. Some participants reasoned that they wanted to be more in control during city driving as it was considered unpredictable, whereas motorway driving was argued to be more organised and controlled, not requiring so much attention. The reasonings behind the preferred position on country roads deviated between the participants. Some found country road driving unpredictable and would therefore like to sit upright. Others referred to the lower speed on country roads and argued that sudden hinders, such as animals, could be detected and handled in time by the car.

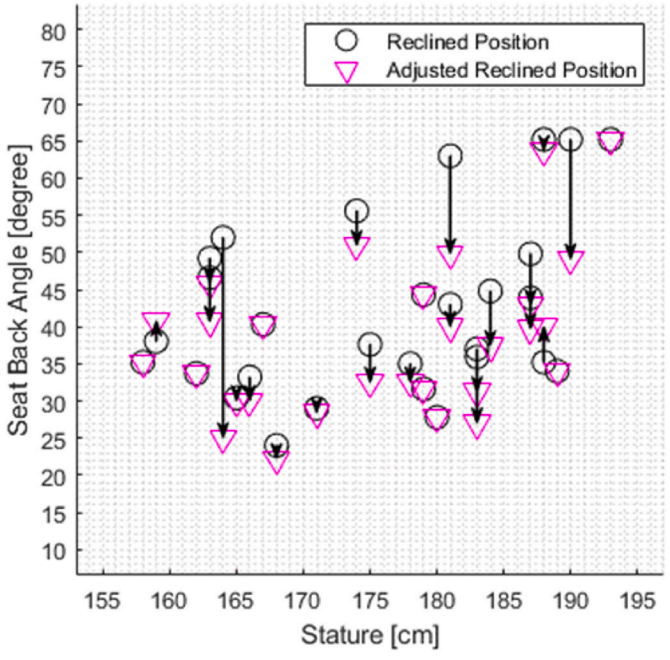

Fig. 7. Reclined position (during AD) and adjusted reclined position (after the test runs) according to participant stature.

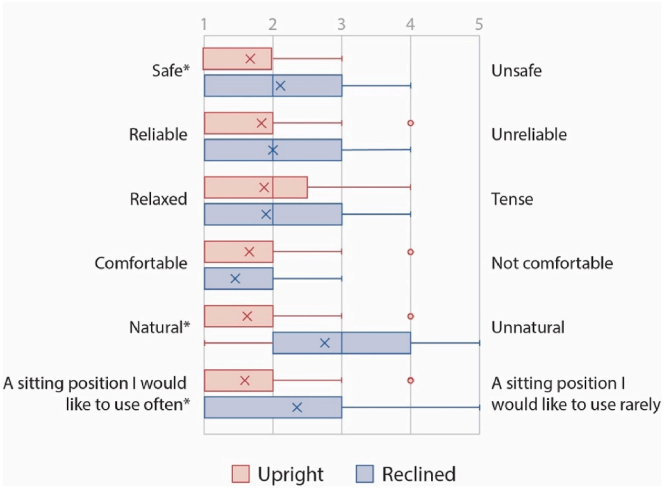

Fig. 8. Responses from the semantic differential scales for upright and reclined positions. The 'x' shows the average and the '*' shows statistical difference ($p < 0.05$), and the circles show outliers.

5. Discussion

This study explored car drivers' overall comfort experiences (in terms of physical, psychological, and functional aspects) and preferences concerning reclined positions during AD in a moving car. The results showed that physical discomfort in general was rare in both upright and reclined positions, and that the participants found the reclined position relaxing. However, slightly more physical discomfort related to the head, shoulders, arms, and backside of the thighs was reported in the reclined position. The general explanation was that the physical support for these body parts was inadequate in the reclined position as the seat was not specifically designed for reclined positions. Reclining current car seats typically results in the seat back moving upward relative to one's back (Reed et al., 2023), potentially contributing to inadequate support and perceived discomfort of the mentioned body regions. The physical discomfort was particularly prominent for the head, likely because the head restraint could not be adjusted. This limitation resulted in insufficient head support in the reclined position, as comfortable head postures are suggested to require different adjustments depending on seat back angle (Reed et al., 2019b). These findings

highlight the importance of designing seats that are intended for reclined positions in AVs, which also has been emphasised in previous research (Reed et al., 2019a; Reinhard et al., 2022). Furthermore, no physical discomfort related to the seat belt was reported in the upright or reclined position. Hence, it may be of interest to further investigate this type of seat belt anchorage, where the seat belt is anchored on the seat via a roller setup.

The reclined position caused concerns related to psychological comfort aspects among most of the participants, who experienced a lack of control. The perceived lack of control was associated with a reduced view of the road and thereby reduced ability to observe the traffic, as well as with decreased ability to intervene with the AD system in case of an unexpected event. This further relates to functional comfort aspects, as the ability to intervene requires the driver to reach control functions, such as pedals and the steering wheel. This shows that the importance of control was evident even though this driving study was performed at only 30 km/h on a test track, with a test leader present in the car, who could intervene in case of an unexpected event. It further highlights design implications, where it is important from a comfort perspective that drivers have the possibility to observe the surroundings and control the AD system when reclined.

Although the semantic scale ratings of reliability, comfort, and relaxation were similar in the upright and reclined positions, the thematic analysis of the interviews still indicated that sitting reclined caused more concerns related to functional comfort compared to sitting upright. Furthermore, there was no correlation between chosen reclined seat back angles and the semantic differential scale ratings, despite interviews showing that the participants in more reclined positions expressed increased discomfort. These discrepancies could possibly be explained by the fact that much of the discomfort mentioned in the interviews related to functional aspects, such as the ability to observe and intervene, which were not specifically addressed in the questionnaires. This further confirms that comfort is a complex concept with multiple dimensions (Vischer, 2007; Caballero-Bruno et al., 2022) and highlights the importance of the functional comfort aspects of drivers' overall comfort experience. It also suggests that interview data of comfort perception allow for a deeper understanding of participants' individual reasoning compared to questionnaire data, advocating for a mixed methods approach.

The interviews showed that the willingness to use a reclined position would most likely be affected by the type of traffic environment it was to be used in. They reasoned that they wanted to be more in control in city traffic and therefore sit more upright. Motorway driving was, however, considered to require less control due to more predictable traffic, and therefore many participants could imagine sitting reclined during AD in motorways. The willingness to sit in a reclined position in different traffic situations may also be linked to the perceived trust towards the AD system. These results align with those of Ekman and colleagues (Ekman et al., 2021), who found that trust towards AVs is influenced by how difficult the traffic situations are perceived to be. Therefore, it is necessary to perform studies of drivers' experiences of reclined positions in different traffic environments at different speeds, road complexities and numbers of other road users.

A limitation of this study is the relatively short sitting duration, which may be insufficient for adapting to a preferred posture and evaluating comfort. However, previous research suggests that even short durations of sitting - around 10 min - can capture initial comfort experiences in cars (Makris, 2023). Similarly, this study revealed indications of differences in drivers' comfort experiences and preferences. Nevertheless, comfort is inherently a time-dependent experience; therefore, future studies should explore the effects of longer sitting durations (Vink et al., 2012). Additionally, the consistent order in which participants experienced the seat positions may have introduced an order effect, potentially influencing the results. Despite this, the reclined position was frequently rated lower on the semantic scales, suggesting that the impact of the reclined position was more significant than the familiarity with the AD mode, as participants always experienced the upright position first.

Taller individuals tended to choose a more reclined seat back angle in both the upright and reclined positions, but the correlation between stature and chosen seat back angle in the reclined position was slightly weaker. This suggests that stature influences seat settings for upright driving, where accessibility to pedals, steering wheel and road visibility is essential. In contrast, the reclined position shifts focus away from the driving task, possibly explaining why the stature plays a lesser role. Hence, individual preferences and attitudes such as trust in AD functions likely influence the choice of reclined seat back angle. In addition to the seat back angle, the participants adjusted seat parameters including seat pan angle, seat pan height from floor and the distance from the edge of the seat pan to the brake pedal. These parameters influence the overall comfort experience, in terms of affecting physical support but also the ability to view the surroundings and intervene. Therefore, further investigation into how other seat parameters impact the comfort experience and the selection of seat settings is needed when designing reclined seats for AD.

Even though the participants chose their initial reclined seat back angle themselves, the vast majority re-adjusted to a more upright seat back angle after having experienced their initial choice in motion. Hence, despite that previous studies have shown that drivers frequently express their request for reclined seats in future AVs (Zhang et al., 1996; Helander et al., 1997), this study shows that an initially preferred setting might not be as comfortable as expected after having tested it in motion. This discrepancy can be explained by the fact that sitting in a reclined position in an AD mode is a new, unfamiliar experience. The challenges of perceived control in terms of wanting to observe the traffic and wanting to be able to intervene may not be as obvious to drivers before experiencing the reclined position in a moving car. This suggests a trade-off between the most physically comfortable reclined position and what feels comfortable in terms of psychological and functional comfort aspects. It implies that the preferred reclined position in AD mode will depend on the interaction among physical, psychological and functional comfort aspects. It also suggests that static tests overestimate the preferred reclined seat back angle. Hence, the findings from this study highlight the importance of performing user studies in AVs in naturalistic settings, i.e., where participants travel in a moving car. The results also indicate that the participants preferred less reclined seat back angles, at least initially, as they further reasoned that they probably would become more comfortable after gaining more experience of sitting reclined during AD. These results indicate that the adoption of AD and reclined positions will take time. This finding is consistent with previous studies that show that adoption of AD requires trust (Buckley et al., 2018), which forms through continuous experience (Oliveira et al., 2019).

6. Conclusion

This study is novel when it comes to exploring drivers' overall comfort experiences and preferences for reclined positions during AD. It shows that drivers' willingness to sit in a reclined position while travelling is influenced by the overall comfort experience in terms of physical, psychological and functional aspects. The study shows a moderate correlation between the participants' stature and chosen seat back angle in both upright and reclined positions. Stature plays a lesser role while reclined in AD, where the driver's involvement in the driving task is reduced. Perceived control is important when choosing a reclined position in AD, especially until sufficient experience and trust towards the AD system is developed. Further, the study shows that drivers may prefer to sit in a reclined position in AD if they can observe the traffic and easily intervene with the system if needed. Additionally, the results imply that drivers prefer a more upright seat back angle when reclined in AD compared to their initial preference before experiencing the reclined position in AD. In conclusion, regardless of stature, drivers

experiencing AD in motion do not want to recline as much as expected from static experiments, due to perceived lack of control. Therefore, the automotive industry needs to revisit their expectation for reclined angles and how to design to make drivers feel comfortable and safe during AD. Further studies should investigate drivers' experiences in seats that are designed for reclined positions, at various speeds, and on different road contexts over longer periods of time, as well as different seat back angles and design solutions that enable drivers to observe the surroundings and maintain control.

CRediT authorship contribution statement

M. Makris: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **A. Muthumani:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **M. Herrera:** Writing – review & editing, Methodology, Investigation. **D. Wang:** Visualization, Software, Formal analysis, Data curation. **M. Johansson:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation, Conceptualization. **A.-L. Osvalder:** Writing – review & editing, Supervision, Methodology, 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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