Short-Term Comfort Evaluation Of Two Types Of Seats In Level 3 And 4 Vehicles

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1 Introduction

The development of automated driving systems poses new challenges to existing modes of transportation. Automated driving is categorized into six levels, as defined by the Society of Automotive Engineers (SAE) (Society of Automotive Engineers., 2021). Among these, Level 3 Conditional Driving Automation allows the driver to disengage from driving tasks under certain conditions, but they must be ready to take control if needed. Level 4 automation enables the car to drive itself in almost all situations, though human control remains available at the driver's request.

Currently, Level 3 driving assistance systems and below are widely produced. For example, Mercedes-Benz recently announced the world's first certified SAE Level 3 system for the U.S. market. Additionally, Level 4 automation is actively under development. With these advancements, the driver is relieved from the necessity of actively driving the vehicle, allowing greater freedom to engage in non-driving-related activities (NDRAs).

Although in both Level 3 and Level 4 vehicles the "driver" can perform NDRAs and still has the opportunity to take over control of the vehicle, their roles differ significantly. In Level 3, the driver becomes a fallback-ready user once the Automated Driving System (ADS) is engaged. The driver can take their hands and feet off the controls but still needs to remain attentive and respond to requests for intervention (Stegmüller et al., n.d.). In contrast, in Level 4, the driver becomes a *passenger* when the ADS is active and is not required to perform dynamic driving tasks even in the event of a system failure. This difference may influence the driver's choice of performing NDRAs and their perception of comfort level.

Therefore, this study aims to explore the different ergonomic needs when users operate automated vehicles at Level 3 and Level 4 automation. Understanding these needs is crucial for designing vehicle interiors that enhance comfort and usability in the context of automated driving.

NDRAs

In the context of autonomous driving, Non-Driving Related Activities (NDRAs) play a crucial role. Several studies have explored the implications of allowing drivers to delegate control to their vehicles Large et al. (2019) found that when drivers had the opportunity to delegate control, they tended to engage in activities that demand high levels of visual, manual, and cognitive effort. Furthermore, Hecht et al. (2020) observed that drivers typically begin engaging in NDRAs about two minutes after a drive starts.Click or tap here to enter text.

Another study found the range and variety of NDRAs increase significantly in automated driving conditions compared to manual driving (Yang et al., 2019a). Additionally, McKerral et al. (2023) found that drivers reported less fatigue when conducting NDRAs in automated driving modes compared to passively monitoring the situation.

Some studies focused on the NDRAs performed in Level 3 Autonomous Vehicles (Avs). Some of them did observation in simulations e.g. a wizard-of-oz study (Shi & Frey, 2021), while others did questionnaires e.g. (Yang et al., 2019a). A prior meta-analysis by Cai et al. (2024) focused on the changes in NDRAs across level 3, 4 and 5 AVs.

This study aims to further explore the comfort levels of performing NDRAs independently in Level 3 and Level 4 AVs. NDRAs involving other passengers will be excluded from this experiment, as the presence of a companion could influence personal attention, which may significantly affect comfort. (Vink et al., 2012).

Subjective Comfort

Employing a scale to measure comfort and discomfort is an effective method for assessing physical strain (Vink & Hallbeck, 2012a), especially for high force level. According to Vink and Hallbeck's comfort model, expectations are considered to be closely linked to comfort. This gives subjective questionnaires an advantage over purely objective measures, as they can capture the nuanced relationship between user expectations and their comfort experience.

Pressure

Objective measurements of discomfort are also essential because they relate to the physical effects on the human body (Vink & Hallbeck, 2012b). Pressure distribution has been shown as a reliable objective measurement, especially in car seats, where research found that the results are statistically correlated to its local discomfort (De Looze et al., 2003). Pressure distribution could also be used to show variations in sitting (Moes, 2007). The pressure measurements could also be used as a postural monitoring system to evaluate the readiness in vehicle take-over (Zhao et al., 2021). Andreoni et al. (2002) proposed a multifactor experimental protocol for the assessment of postural and seat comfort using skeletal tracking and pressure mapping.

Postures

Wang et al. (2019) reviewed various posture monitoring systems and highlighted that, with proper positioning of the Microsoft Kinect, skeletal data can effectively detect driving postures. Zhao et al. (2021) used Microsoft Kinect to record postures related to vehicle take-over.

Automated vehicles have enabled a variety of non-driving postures. Fleischer & Chen (2020) analyzed postures during non-driving related activities (NDRAs) in level 3 and 4 AVs using manual coding in a car seat with a fixed angle. This method captures postures in one plane but neglects movement in other axes. Reed et al. (2020) used video cameras and seat markers to analyze front passenger posture. Motion capture is another precise method for determining joint locations in 3D space during NDRA posture testing (Shayegan et al., 2023), although it requires sensors on the human body. Posture analysis for NDRAs is crucial as these new postures impact vehicle crash safety (Diez et al., 2023; Leledakis et al., 2021; McMurry et al., 2018).

Analyzing joint angle ranges in driving positions is essential for various assessments (Schmidt, 2014). Kee & Karwowski (2001) mapped joint angles of standing and sitting males, comparing them with comfort levels. Ergonomic software, such as RAMSIS and Jack, is commonly used to determine the correct driving posture (Gao et al., 2021). This posture analysis serves as an objective measurement of comfort.

This research explores comfortable postures during NDRAs in Level 3 vehicles. A subjective evaluation on 2 different car seats will be done with level 3 AV scenario. The evaluation of current car seats and possible improvements will be asked from a passenger point of view. Objective measurements of pressure recordings and joint angles would be extracted for further analysis.

The research questions are set as follows:

1. What is the most comfortable seat adjustments for non-driving-related activities (NDRAs) in Level 3 and Level 4 automated vehicles?
2. How does seat support provide comfort for different activities in terms of joint angles?
3. How is the pressure distribution in current car seats regarding comfort?
4. How do users perceive comfort in current vehicle interior for use in Level 3 and Level 4 automated vehicles?

2 Methods

This research was approved by the Human Research Ethics Committee of Delft University of Technology on January 4th, 2024, under application number 3725. Thirty-four participants were invited to take part in this study. G*Power calculations indicated that, using the Wilcoxon signed-rank test (one-tail, with a set criterion), 33 samples are required to identify medium to large effects (0.6) with a power of 0.95. Each participant completed an informed consent form before beginning the experiment. Participants were asked to attend two sessions, each lasting 90 minutes. A voucher of €45 was provided to each participant after completing the entire study. Healthy participants were selected based on the Dutch anthropometric height curve, and individuals with extreme BMIs were also included. A maximum age of 40 years was set, as the vehicle is designed for future use.

The test was conducted indoors using two types of car seats: the AAA (blue seat) and BBB (black seat). Both seats were installed in the front of the buck, which was shaped to the dimensions of an SUV. In the first part of the experiment, participants initially experienced the BBB seat in the driver's position and the AAA seat in the front passenger position. After completing this part, the seats were swapped, allowing participants to experience both seats in different positions to eliminate any layout effects. The driving controls were located on the left side.

Both seats, AAA and BBB, were tested with five NDRAs and a Level 3 Automated Vehicle (AV) driving activity. The BBB seat configurations were measured using the seat's built-in apps, with adjustment features displayed on the screen. The measured parameters were displayed in Fig.1. The AAA seat measurements were taken manually by researchers, as shown in Fig.2. The adjustment controls for the AAA seat were explained to participants at the beginning of each test, and a picture explaining the controls was displayed for reference throughout the test.

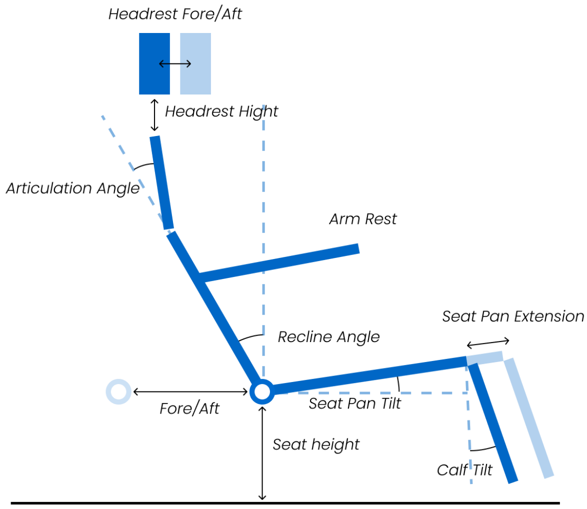
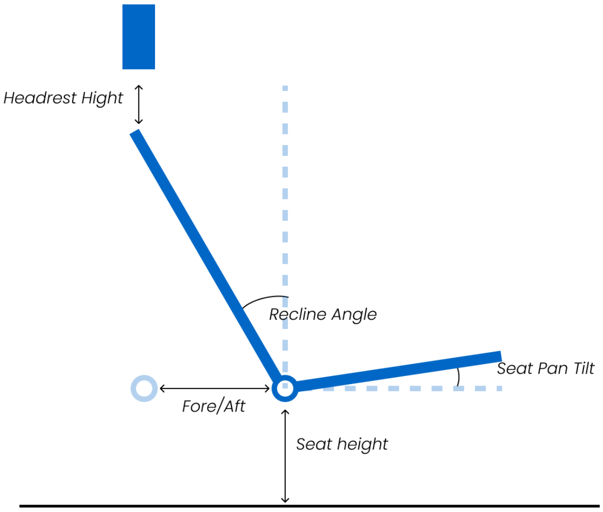
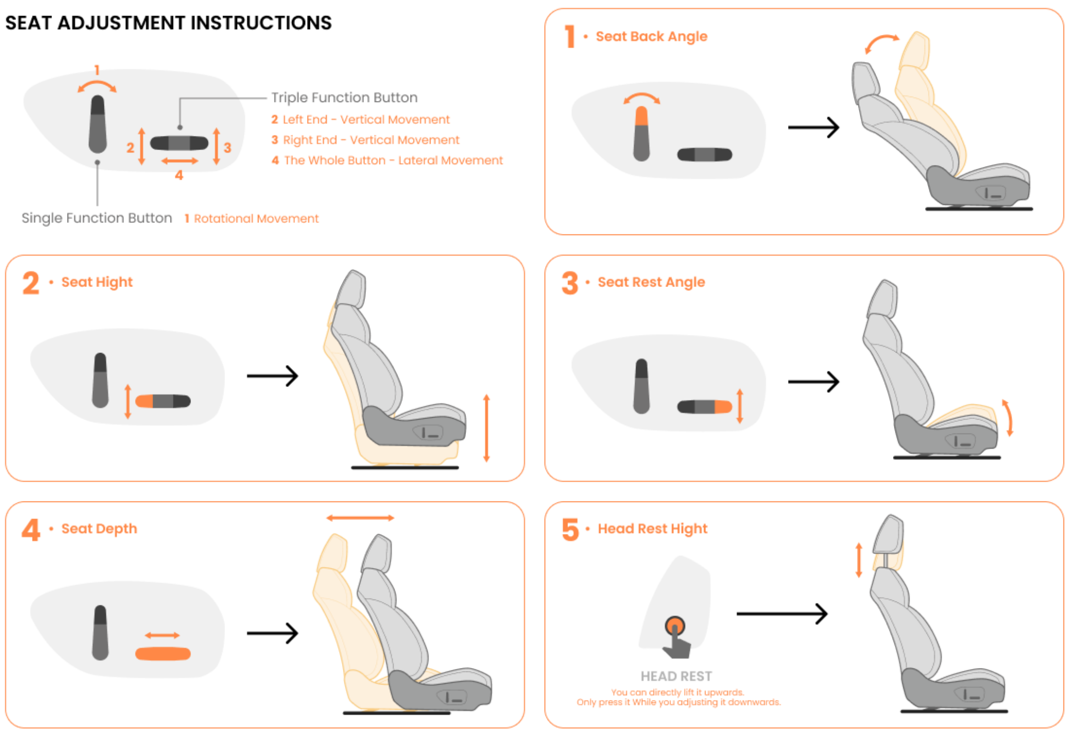


Figure 1. BBB seat parameters



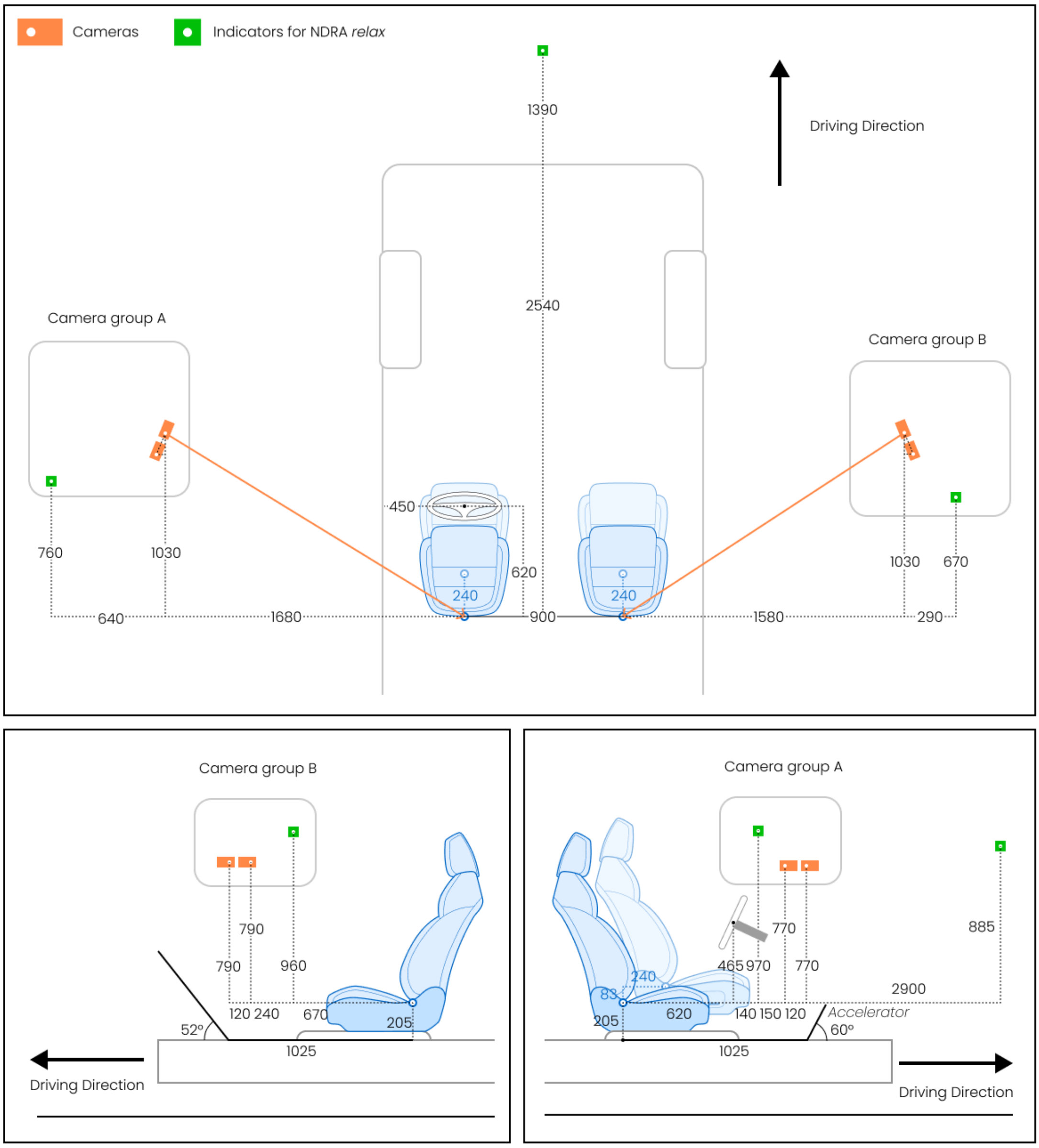
(a)



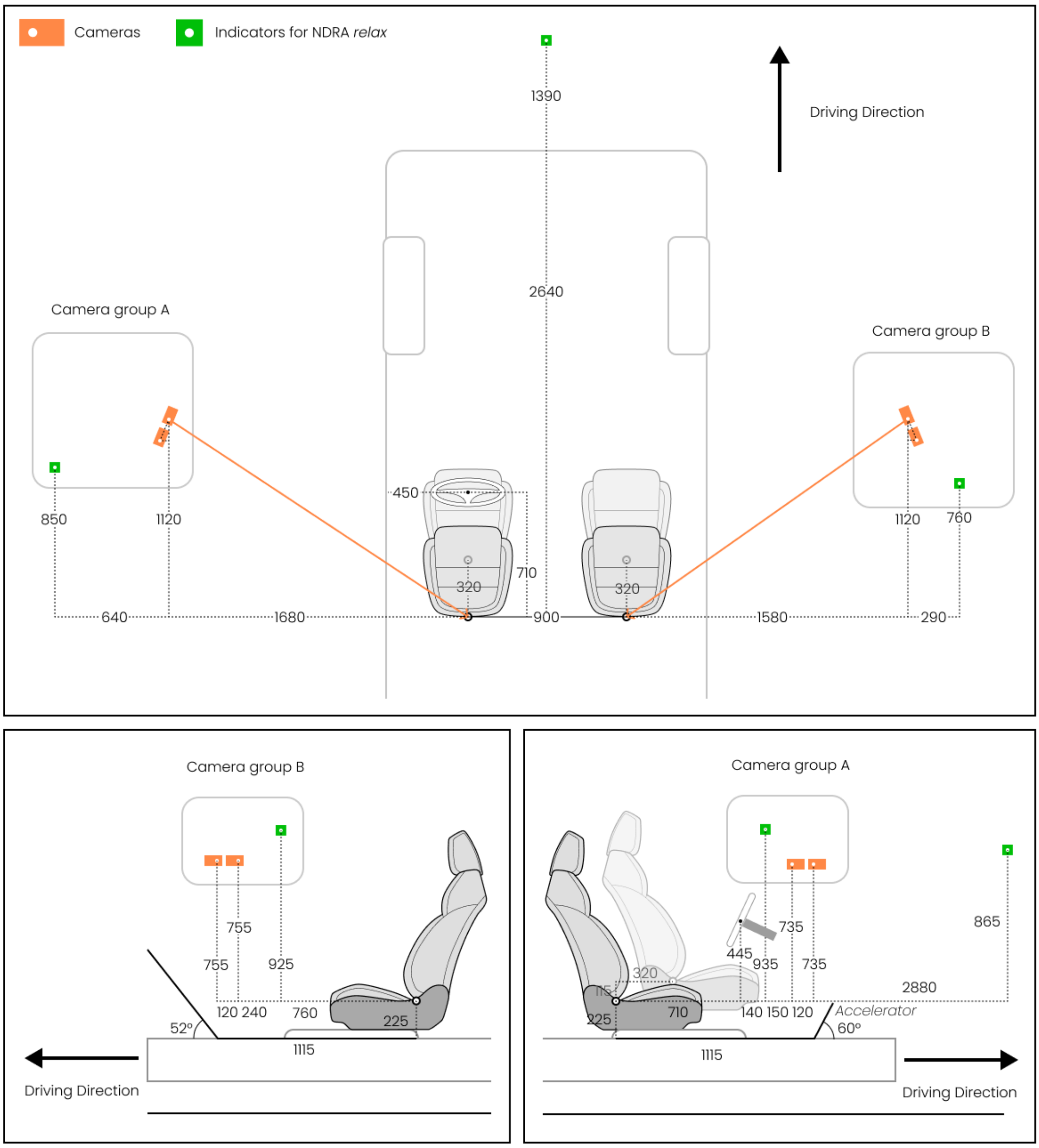
(b)

Figure 2. AAA seat (a) adjustment measured and (b) the instruction for participants.

The experimental setup is shown in Fig.3. Pilot studies revealed that participants were unlikely to adjust the seat further forward if the test began with the seat in the fully rearward position. Therefore, at the beginning of the test, both seats were positioned fully forward and upright. The AAA seat was adjusted to its lowest position, while the BBB seat was positioned at its highest setting due to the calf rest, which prevented it from starting at the lowest position.



(a)



(b)

Figure 3. Layout of the (a) AAA seat and (b) BBB seat.

The experiment began with an explanation of the scenario and setup. The Level 3 and Level 4 scenarios were printed on paper and presented in the buck to ensure participants fully understood them. The Level 3 scenario involved the driver's position, which was equipped with a steering wheel and pedals, while the Level 4 scenario involved the passenger position, where participants could assume a different control mechanism for the car, and they would not be required to drive. A 2x2 within-subject design was used, with all participants experiencing the four setups shown in Table 1.

Table 1. Setups for all participants

	Level 3 AV	**Level 4 AV**
AAA	Blue seat on the driver side	Blue seat on the front passenger side
BBB	Black seat on the driver side	Black seat on the front passenger side

Participants were selected based on their self-reported weight and height during the recruitment questionnaire. Those in the 5th and 95th height percentiles and those with extreme BMIs were carefully included to ensure a spread-out percentile distribution. Anthropometric measurements of participants were acquired using an anthropometric chair and an anthropometer, while a scale measured participants' weights. Participant demographics (age, gender, nationality, and ethnicity) and their experience with ADAS (advanced driver-assistance systems) were collected via Microsoft Forms on an iPad Pro 2018. The sequence in which participants experienced the two seats was controlled with Latin square to eliminate the influence of test order, with the percentage for each test sequence shown in the Table 2.

Table 2. Sequence of the Test

First Part of Test		Second Part of Test		Percentage
AAA (Level 4)	BBB (Level 3)	BBB (Level 4)	AAA (Level 3)	27.27%
AAA (Level 4)	BBB (Level 3)	AAA (Level 3)	BBB (Level 4)	24.24%
BBB (Level 3)	AAA (Level 4)	BBB (Level 4)	AAA (Level 3)	24.24%
BBB (Level 3)	AAA (Level 4)	AAA (Level 3)	BBB (Level 4)	24.24%

When participants sat in the driver side, they firstly adjusted it as they normally would for driving. For those unable to drive, the researchers assisted in achieving the proper driving posture. Each participant was asked to indicate that they were in a comfortable position for each activity, and the researcher will note their current posture. Participants rated the seat using an online Microsoft Forms questionnaire on the iPad, providing a simple comfort score (10-point scale), (10-point scale), and a simple discomfort score (10-point scale) (Anjani et al., 2020). Pressure measurements were taken for this driving position, along with a 4D scan indicating their joints in 3D space.

The test continued with one of five NDRAs (see Table 3) in the same seat, where participants rated the seat and had pressure measurements recorded. Seats were not readjusted to the original settings between activities; instead, participants set the seats to the most comfortable position for each activity. The order of the NDRAs was randomized for each participant but remained consistent for both seats. These activities were conducted individually, so the effects of having another passenger were not measured.

Table 3. NDRA and instructions

No.	NDRA	Additional devices/instructions
A	Smartphone Use	Smartphone
B	Rest & Relax / sightseeing	Able to see the marks/dolls placed in the room from the windows
C	Deskwork (with laptop)	Use of laptop to work
D	Eat & Drink	Hold a cup and eat a snack (small bread or snack bar)
E	Sleep	In level 3 scenario, participants were informed that in case of an emergency, the car seat would quickly adjust back, and an alarm would ring to wake them up.

When participants were asked to sit in the front passenger side, they were not asked to drive, but directly started with NDRAs. At the end of the session, an interview was done with questions in Table 4. The answers to these questions were transcribed and analyzed qualitatively by the researchers.

Table 4. Interview questions

First Part of Test	Second Part of Test
• Which activity impressed you most (most comfortable or uncomfortable)? And why? • What do you think of the way the seats are adjusted? • Do you have any general feedback of two seats? • Does the level of automation influence your adjustment? Is it more because the mindset of the scenario that we told you or because of the steering wheel and the pedal which physically influenced you? • Did the steering wheel influence your comfort physically?	• Which activity impressed you most (most comfortable or uncomfortable)? And why? • Do you have any general feedback of two seats? Any improvement? • What do you think is important for level 3 seat? And what do you think is important for level 4 seat? (Seat itself / Interaction / Surrounding)

A 4D scanner, the Microsoft Kinect, was used to capture the joint angles of the participants while conducting a specific NDRA. Additionally, a pressure mat (XSensor), was employed to capture the pressure distribution of the seat. The pressure data was recorded as a short video, and the frames were exported to "csv" files for further analysis. A video camera and microphone were also used to capture the qualitative descriptions of each sitting support, with the recordings transcribed via Microsoft Teams. Participants were instructed to wear bright and relatively tight clothing to ensure accurate recording of joint angles.

The 3D coordinates of the joints from the Microsoft Kinect were extracted to calculate the Joint Angles of Isocomfort (JAI) for each participant. This study will calculate the absolute angle of 15 joints as shown in Table 5. The quantitative results were statistically analyzed using Python.

Table 5. Joints

Index	Joint name
1	Hip-lumbar
2	Lumbar-chest
3	Neck-head
4	Left-shoulder
5	Left-elbow
6	Right-shoulder
7	Right-elbow
8	Left-thigh-trunk
9	Left-knee
10	Left-ankle
11	Right-thigh-trunk
12	Right-knee
13	Right-ankle
14	Hip-torso-rotation
15	Neck-torso-rotation

3 Results

This study was done in the laboratory of Delft University of Technology from April to May in springtime in the Netherlands which requires no additional climate control. Thirty-four participants were invited to this study, and 1 participant data was excluded in the analysis due to unreadable postural data.

3.1 Participant Demographics

Please refer to ***Appendix 1*** for results of participant demographics.

3.2 Anthropometric Measurements

Please refer to ***Appendix 2*** for results of anthropometric measurements.

3.3 Subjective Comfort

Please refer to ***Appendix 3*** for results of subjective comfort.

3.4 Seat Adjustment

Please refer to ***Appendix 4*** for results of seat adjustment.

3.5 Contact Pressure Measurement

Please refer to ***Appendix 5*** for results of contact pressure measurement.

3.6 Joint Angles

Please refer to ***Appendix 6*** for results of joint angles.

3.7 Qualitative feedback

Please refer to ***Appendix*** *7* for results of qualitative feedback

4 Discussions

4.1 Demographics & ADAS experience

Nordhoff et al. (2020) showed in 8 European countries that age, gender and ADAS experience have a significant yet small effect on behavioral intention in level 3 AV. This study did not measure the effect of age as participants were selected from a certain age group. This selection was based on the age groups of future AVs.

In this test, 35% of participants did not have a driver's license. According to Lee & Moray (1994), drivers with lower confidence in their own driving abilities tend to trust automated driving systems more. This may result in a general tendency towards more relaxed, reclined seat adjustments while performing NDRAs. According to Metz et al. (2020), the more experience drivers have with ADAS, the more they trust the feature and the more time they spend on NDRAs, particularly tasks involving both hands. In our tests, 11% of participants were familiar with ADAS, which may have made their seat adjustments less influenced by the monitoring condition.

4.2 Subjective comfort

Our experimental results align with those of Mansfield et al. (2021), showing that participants identified the neck as the most uncomfortable region, whether in manual driving or autonomous driving modes.

4.3 Seat adjustments

Yang et al. (2018) discovered that drivers were generally unwilling to adopt a reclined position if there was a possibility of needing to take over control. This reluctance persisted despite the study finding no significant difference in take-over times between reclined and upright positions, suggesting that a reclined posture might convey an inherent feeling of unsafety. Our results also showed that in both the AAA seat and BBB seat, users had a smaller recline angle under Level 3 automation conditions compared to Level 4 (see Appendix). This is because, under Level 3 automation, users have supervisory responsibilities.

Yang et al. (2019) conducted an experiment on NDRAs in autonomous driving and found that, although most postures were similar to traditional driving postures, the seat needed a wider range of adjustments due to the emergence of many extreme postures. The study confirms this finding. In the Seat Reference Point (SRP) travel envelope (see Appendix), many points are located at the envelope's edges. Additionally, for the sleep activity, the third quartiles of the recline angle boxplots are close to the adjustment limit (see Appendix).

In this study, we observed two distinct seat height distribution patterns between the two chairs, likely due to their different initial heights. The initial height of the AAA chair is 205mm, while the BBB chair is nearly 340mm. According to a study by Peng et al. (2018), the preferred seat height of users largely depends on the initial seat height. They categorized subjects into short, average, and tall groups based on height and found that when the initial seat height was very low (150mm), the short group preferred the highest seat height, while the tall group preferred the lowest. This is consistent with our observation of a negative correlation between sitting height and seat height in the AAA chair. In their experiment, when the initial seat height was very high, shorter individuals chose a lower preferred seat height, while taller individuals preferred a higher seat height. This aligns with our hypothesis that a higher initial seat height results in a sitting posture closer to that of an office chair. However, in our results, we did not observe the trend of shorter individuals choosing lower seat heights, likely due to the influence of the calf rest on their choice. However, it is important to note that Peng et al. (2018) required participants to press a clutch, whereas our experiment did not require participants to perform any specific or mandatory leg movements.

4.4 Pressure map

In the experimental results, the BBB Seat generally performed better than the AAA Seat. However, when users sat in the BBB Seat, they placed more of their body mass on the seat pan. According to Mergl (2006), discomfort in the backrest can often be alleviated by adjusting posture, whereas the sensation in the seat pan is less related to posture and more to the cushion itself. Therefore, we conducted a more in-depth comparison of the pressure distribution on the seat pan.

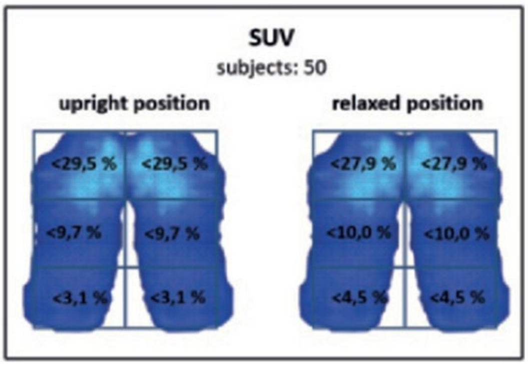


Figure 4 The mean pressure distribution of the preferred postures. (Kilincsoy, 2018)

Kilincsoy (2018) studied the ideal pressure distribution for the rear seat of an SUV with 50 subjects. He found that the ideal mean pressure distribution for the seat pan should be as illustrated in the Figure 4. Comparing our results with Killincsoy's, we found that the pressure distribution in the part closest to the backrest is nearly identical. However, the pressure proportions in the middle part and thigh part are greater than in Killincsoy's ideal pressure distribution (as shown in Figure 5).

Figure 5 Comparison of Seat Pan Pressure Distribution with Kilincsoy's result

The reason might be that, in our study, both seats feature prominent supportive bolsters, as illustrated in Figure 6. This causes the pressure in the middle and thigh regions to have significant components in directions other than perpendicular to the ground. In the AAA seat, the bolsters are positioned closer to the thighs, whereas in the BBB seat, the bolsters' raised sections are positioned closer to the buttocks. This results in greater pressure distribution in the thigh area for the AAA seat, while the BBB seat shows more pressure distribution in the midsection.

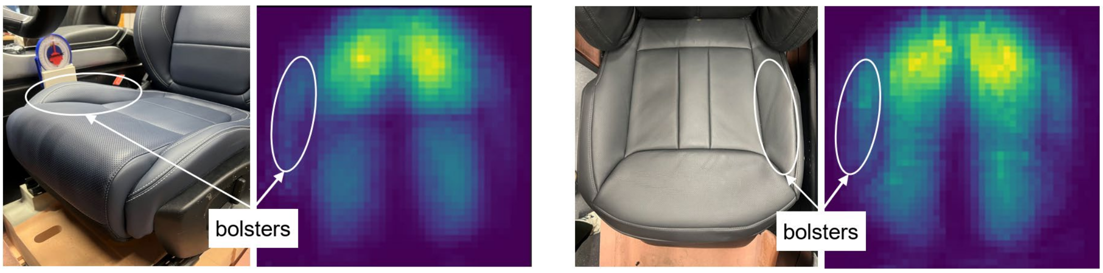


Figure 6. Bolsters on BBB seat and AAA seat

4.5 Joint range

Kyung & Nussbaum (2009) did a study about the comfortable posture for driving, and they recommend comfortable join angles ranges. Comparing with their results, all joints that we detected are within reasonable comfort ranges. This indicates, on one hand, that our data is valid, and on the other hand, that both chairs are capable of allowing participants to maintain a relatively comfortable posture.

4.6 Limitations and future works

This study did not measure the effect on age as the participants were selected from a certain age group, as future users of AV. Studies on a wider range of participants could be done to capture different usecases of different age groups. This experiment was conducted in a stationary car model, with the Level 3 and Level 4 autonomous driving scenarios being conveyed through the facilitator's descriptions, visual cues, and the participants' imagination. Therefore, this setup differs from real-world conditions and focuses on the initial comfort while doing pre-determined activities. In reality, the results may vary due to factors such as vehicle movement, acceleration and deceleration, and participants' experiences of motion sickness. The presence of an additional passenger in the setup might influence the posture as well as the comfort of the participants, which could be studied further in the future. Future studies could consider a longer time span of testing to ensure comfort in for a longer drive, as well as giving freedom for participants to conduct NDRAs based on their actual habits.

5 Conclusions

This study focused on identifying the most comfortable seating positions for users in Level 3 and Level 4 autonomous driving scenarios. By analyzing seat adjustment data, skeleton tracking, pressure distribution, and subjective comfort assessments, several insightful conclusions beneficial for seat evaluation were drawn.

Regarding seat adjustment data, the research revealed the most comfortable settings for users under various Non-Driving Related Activities (NDRA) conditions. It was found that certain seat dimensions did not fully meet users' adjustment needs. Specifically, the AAA seat's Fore/Aft and Seat Height adjustments, and the BBB seat's Seat Height adjustment were inadequate. Additionally, both seats had limitations in their Recline function during sleeping NDRA. A notable finding was that users tended to sit more backward and reclined in Level 4 settings, indicating a preference for a more relaxed posture when the vehicle is more autonomous. Adjustments in Fore/Aft, headrest height, and cushion extension were significantly influenced by individual body dimensions, highlighting the importance of personalized adjustments. Initial seat height also played a crucial role in influencing users' sitting posture, with the slope being more critical than the calf rest. The lower body posture exhibited two adaptive modes that did not affect comfort levels, suggesting flexibility in users' seating preferences.

In terms of joint angles, both seats maintained a reasonable comfort range across different activities, indicating that the seat designs were generally effective in accommodating various movements and positions.

Pressure distribution analysis showed that the BBB seat outperformed the AAA seat in several key metrics, including mean and peak pressures, coefficient of variation (CV), and seated pressure distribution percentage (SPD%). These findings suggest that the BBB seat provides better overall pressure management, contributing to enhanced comfort.

Subjective comfort data further supported the superiority of the BBB seat, as it received better ratings than the AAA seat, particularly in the upper back and neck areas. Users favored the BBB for its comfort and adjustability, while the AAA was appreciated for its ease of adjustment through physical controls. The steering wheel had a notable physical impact on seat adjustment but influenced comfort more psychologically due to the supervisory responsibility it entailed. Additionally, armrests were found to be a useful feature, whereas calf rests were not particularly preferred by users.

In summary, this study provides valuable insights into seat design and adjustment for autonomous vehicles. The findings emphasize the importance of adaptable seat features and personalized adjustments to enhance user comfort in various driving scenarios. The superior performance of the BBB seat in both objective and subjective measures highlights the need for continuous improvement in seat design to meet the evolving demands of autonomous driving.

This study focuses on the initial comfort while doing pre-determined activities in a stationary car model, with the Level 3 and Level 4 autonomous driving scenarios being conveyed through the facilitator's descriptions, visual cues, and the participants' imagination. In reality, the results may vary due to factors such as vehicle movement, acceleration and deceleration, and participants' experiences of motion sickness. Future studies could consider the effects of additional passengers, longer time span of, as well as the freedom to choose NDRAs.

6 Design Guidelines

1. **Calf rest is not necessary, foot rest is more important.**
   The calf rest is difficult to accommodate the needs of individuals of all heights. Moreover, it only provides support when both feet are completely off the ground, meaning that, aside from sleeping, it may not only fail to be helpful during other NDRAs but could also become an obstacle.
   Users tend to prefer having good foot support.

2. **Headrest should be able to be adjusted more backward.**
   In all experimental settings, users frequently reported neck discomfort. Additionally, in the BBB seat, many headrest fore/aft-adjustments exceeded the rear limit. This suggests that in Level 3 and Level 4 automation scenarios, maintaining a direct line of sight to the road is no longer a top priority. Instead, supporting the neck and head should be prioritized, with the headrest positioned further back.

3. **Backrest should be able to be adjusted to recline more.**
   During the sleep activity, the backrest adjustment frequently reached its limit, indicating that users desired to recline more.

4. **Armrest should be introduced.**
   In both automation levels, the armrest usage rate was very high, significantly enhancing user comfort. During the experiment, some users even habitually searched for armrests after transitioning from the BBB seat to the seat chair. However, the adjustment mechanism for the armrest needs to be optimized.

5. **The environment for desk work needs optimization.**
   Desk work was identified by users as the most uncomfortable NDRA, primarily due to the lack of a proper place to position their laptops, forcing them to place the device on their laps. This resulted in the screen being too low, requiring them to look down to align their view with the screen. Additionally, the bolsters pushed their arms forward, while the laptop was positioned further back, making it difficult to type comfortably. To address these issues, a movable desk or tray could be provided for desk work.

7 References

Andreoni, G., Santambrogio, G. C., Rabuffetti, M., & Pedotti, A. (2002). Method for the analysis of posture and interface pressure of car drivers. *Applied Ergonomics*, *33*(6), 511–522. https://doi.org/10.1016/S0003-6870(02)00069-8

Anjani, S., Kühne, M., Naddeo, A., Frohriep, S., Mansfield, N., Song, Y., & Vink, P. (2020). PCQ: Preferred Comfort Questionnaires for Product Design. *Manuscript Submitted for Publication*.

De Looze, M. P., Kuijt-Evers, L. F. M., & Van Dieén, J. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*, *46*(10), 985–997. https://doi.org/10.1080/0014013031000121977

Diez, M., Abajo, J., Vázquez de Prada, J., Negro, A., & Fernández, M. T. (2023). Sitting posture influence in autonomous vehicles for the evaluation of occupant safety in side impact. *Safety Science*, *159*, 106002. https://doi.org/10.1016/j.ssci.2022.106002

Fleischer, M., & Chen, S. (2020). How Do We Sit When Our Car Drives for Us? *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *12198 LNCS*, 33–49. https://doi.org/10.1007/978-3-030-49904-4_3

Gao, Y., Kaiser, R., Wagner, P.-O., Abendroth, B., & Paternoster, S. (2021). *Driving Posture Assessment: A New Approach* (pp. 639–646). https://doi.org/10.1007/978-3-030-74608-7_78

Hecht, T., Feldhütter, A., Draeger, K., & Bengler, K. (2020). *What Do You Do? An Analysis of Non-driving Related Activities During a 60 Minutes Conditionally Automated Highway Drive* (pp. 28–34). https://doi.org/10.1007/978-3-030-25629-6_5

Kee, D., & Karwowski, W. (2001). The boundaries for joint angles of isocomfort for sitting and standing males based on perceived comfort of static joint postures. *Ergonomics*, *44*(6), 614–648. https://doi.org/10.1080/00140130110038044

Kilincsoy. (n.d.). *Digitalization of posture-based Seat Design Developing car interiors by involving user demands and activities*. https://doi.org/10.4233/uuid:419e4678-cb27-4c03-9725-7fb5b0fd3a12

Kyung, G., & Nussbaum, M. A. (2009). Specifying comfortable driving postures for ergonomic design and evaluation of the driver workspace using digital human models. *Ergonomics*, *52*(8), 939–953. https://doi.org/10.1080/00140130902763552

Large, D. R., Burnett, G., Salanitri, D., Lawson, A., & Box, E. (2019). A longitudinal simulator study to explore drivers' behaviour in level 3 automated vehicles. *Proceedings - 11th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2019*, 222–232. https://doi.org/10.1145/3342197.3344519

Lee, J. D., & Moray, N. (1994). Trust, self-confidence, and operators' adaptation to automation. *International Journal of Human-Computer Studies*, *40*(1), 153–184. https://doi.org/10.1006/IJHC.1994.1007

Leledakis, A., Östh, J., Davidsson, J., & Jakobsson, L. (2021). The influence of car passengers' sitting postures in intersection crashes. *Accident Analysis & Prevention*, *157*, 106170. https://doi.org/10.1016/j.aap.2021.106170

Mansfield, N. J., Walia, K., & Singh, A. (2021). Driver seat comfort for level 3-4 autonomous vehicles. *Work*, *68*(s1), S111–S118. https://doi.org/10.3233/WOR-208010

McKerral, A., Pammer, K., & Gauld, C. (2023). Supervising the self-driving car: Situation awareness and fatigue during highly automated driving. *Accident Analysis & Prevention*, *187*, 107068. https://doi.org/10.1016/j.aap.2023.107068

McMurry, T. L., Poplin, G. S., Shaw, G., & Panzer, M. B. (2018). Crash safety concerns for out-of-position occupant postures: A look toward safety in highly automated vehicles. *Traffic Injury Prevention*, *19*(6), 582–587. https://doi.org/10.1080/15389588.2018.1458306

Metz, B., Wörle, J., Hanig, M., Schmitt, M., & Lutz, A. (2020). Repeated usage of an L3 motorway chauffeur: Change of evaluation and usage. *Information (Switzerland)*, *11*(2). https://doi.org/10.3390/info11020114

Moes, N. C. C. M. (2007). Variation in sitting pressure distribution and location of the points of maximum pressure with rotation of the pelvis, gender and body characteristics. *Ergonomics*, *50*(4), 536–561. https://doi.org/10.1080/00140130601138585

Nordhoff, S., Louw, T., Innamaa, S., Lehtonen, E., Beuster, A., Torrao, G., Bjorvatn, A., Kessel, T., Malin, F., Happee, R., & Merat, N. (2020). Using the UTAUT2 model to explain public acceptance of conditionally automated (L3) cars: A questionnaire study among 9,118 car drivers from eight European countries. *Transportation Research Part F: Traffic Psychology and Behaviour*, *74*, 280–297. https://doi.org/10.1016/J.TRF.2020.07.015

Peng, J., Wang, X., & Denninger, L. (2018). Effects of Anthropometric Variables and Seat Height on Automobile Drivers' Preferred Posture With the Presence of the Clutch. *Human Factors*, *60*(2), 172–190. https://doi.org/10.1177/0018720817741040

Reed, M. P., Ebert, S. M., & Jones, M. L. H. (2020). *Naturalistic Passenger Behavior: Postures and Activities*.

Shayegan, S., Beurier, G., Denninger, L., & Wang, X. (2023). *Preferred Postures for Doing Non-driving Related Activities in Reclined Seating Configurations in Highly Automated Vehicles* (pp. 238–247). https://doi.org/10.1007/978-3-031-37848-5_27

Shi, E., & Frey, A. T. (2021). Non-driving-related tasks during level 3 automated driving phases–measuring what users will be likely to do. *Technology, Mind, and Behavior*, *2*(2). https://doi.org/10.1037/tmb0000006

Society of Automotive Engineers. (2021). SAE J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. *SAE.*

Stegmüller, S., Duwe, D., & Herrmann, F. (n.d.). *The Value of Time-Potential for user-centered services offered by autonomous driving*. https://www.researchgate.net/publication/344769668

Vink, P., Bazley, C., Kamp, I., & Blok, M. (2012). Possibilities to improve the aircraft interior comfort experience. *Applied Ergonomics*, *43*(2), 354–359. https://doi.org/10.1016/j.apergo.2011.06.011

Vink, P., & Hallbeck, S. (2012a). Editorial: Comfort and discomfort studies demonstrate the need for a new model. *Applied Ergonomics*, *43*(2), 271–276. https://doi.org/10.1016/J.APERGO.2011.06.001

Vink, P., & Hallbeck, S. (2012b). Editorial: Comfort and discomfort studies demonstrate the need for a new model. *Applied Ergonomics*, *43*(2), 271–276. https://doi.org/10.1016/j.apergo.2011.06.001

Wang, H., Zhao, M., Beurier, G., & Wang, X. (2019). Automobile Driver Posture Monitoring Systems: A Review. *J. China Journal of Highway and Transport*, *02*, 1–18.

Yang, Y., Gerlicher, M., & Bengler, K. (2018). How does relaxing posture influence take-over performance in an automated vehicle? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *62*(1), 696–700. https://doi.org/10.1177/1541931218621157

Yang, Y., Klinkner, J. N., & Bengler, K. (2019a). How Will the Driver Sit in an Automated Vehicle? – The Qualitative and Quantitative Descriptions of Non-Driving Postures (NDPs) When Non-Driving-Related-Tasks (NDRTs) Are Conducted. In S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander, & Y. Fujita (Eds.), *IEA 2018, AISC 823* (pp. 409–420). Springer, Cham. https://doi.org/10.1007/978-3-319-96074-6_44

Yang, Y., Klinkner, J. N., & Bengler, K. (2019b). How Will the driver sit in an automated vehicle? – The qualitative and quantitative descriptions of non-driving postures (NDPs) when non-driving-related-tasks (NDRTs) are conducted. *Advances in Intelligent Systems and Computing*, *823*, 409–420. https://doi.org/10.1007/978-3-319-96074-6_44/TABLES/2

Zhao, M., Beurier, G., Wang, H., & Wang, X. (2021). Driver posture monitoring in highly automated vehicles using pressure measurement. *Traffic Injury Prevention*, *22*(4), 278–283. https://doi.org/10.1080/15389588.2021.1892087