Passenger Individual Posture in Level 5 Automated Driving

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Graduation date : August 19th, 2024

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1. Introduction

1.1.1. Literature about the development of AV (Level 5)

This study focuses on Automated Vehicles (AV) driving in Level 5 Full Driving Automation (SAE International, 2020). A level 5 AV can fulfil the role of conventional drivers, which means all vehicle participants are passengers. Without the requirements and restrictions of driving, the passengers in a level 5 vehicle can perform full-time Non-driving-related activities (NDRAs) or tasks while the car is in motion (Pfleging et al., 2016). Compared with driving-related activities (DRAs) that involve all the activities for Dynamic driving tasks, NDRAs include all other tasks like communicating, eating, relaxing, etc. (SAE International, 2020).

According to the NDRAs investigation of Pfleging et al., watching out of the window is the most frequently performed activity (85%), followed by texting (74%), talking to other passengers (72.3%), listening to music/radio/audiobooks (72 %), and drinking and eating (54 %). Additional activities over 10% mentioned are calling (26.7 %), sleeping (22.3 %), and office tasks (16 %). This research focuses on the individual behaviours of the AVs so that the social-related activities are excluded. The selection of NDRAs for this research are A. Smartphone use, B. Rest and relax (looking out of the window), C. Deskwork, D. Eating and Drinking, and E. Sleeping.

1.1.2. Literature about postures

Due to their potential to draw attention from the primary driving task, NDRAs are still ranked as secondary or tertiary priority in the current design process (Yang et al., 2018). However, In the context of highly automated vehicles (HAV), the driving postures related to the DRAs are no longer necessary to be optimised. Compared to the plenty of studies on driving postures, the research on comfortable and preferred postures for NDRAs is lacking (Shayegan et al., 2023). The research of comfortable non-driving postures (NDPs) is more complicated than the study of driving postures, because an NDRA can be performed in a variety of postures and, conversely, the same posture can relate to several NDRAs (Grebonval et al., 2021). As a result, we have a many-to-many issue with NDPs requiring structured posture classification. Fleischer & Chen (2020) conducted a research test with 25 participants and qualitatively classified NDRTs corresponding postures. The study of Grebonval et al. (2021) evaluated the seating postures of 13 participants in quantitative classification and found that preferred joint postures were influenced by several factors, including gender, seat design, driving venue, stature, symmetry, age, etc. (Schmidt et al., 2014). According to Kyung & Nussbaum (2009), asymmetrical postures may be caused by distinct duty requirements on each side of the body (e.g. right side is for controlling tasks while the left side is for supporting tasks), which remain an unexplored territory with NDPs.

1.1.3. Literature about posture collection without seat

All participants in level 5 AVs as passengers have all-time only performing NDPs, resulting in different requirements for the seat and car interior, which should be different from the driving posture-centred interior (Yang et al., 2018). The car seat configuration of level 5 AVs does not need to start from the Accelerator Heel Point (AHP), indicating a fresh perspective in the car seat design. According to Reed et al. (1999), possible human postures exceed the range of postures with current seats.

NASA has documented the neutral body posture (NBP) that muscles in a naturally relaxed position with zero-g space (NASA STD 3000). As shown in Figure 1, the NBP can be presented in segment angles with horizontal and vertical reference axes (Han Kim et al., 2019). The concept of NBP is highly influential in the commercial automotive industry (NASA, 2013). However, sitting posture on Earth is still influenced by one-g gravity. Inspired by the zero-g neutral body posture, the study planned to explore the neutral body posture in a one-g gravitation avoiding the limitations of seats.

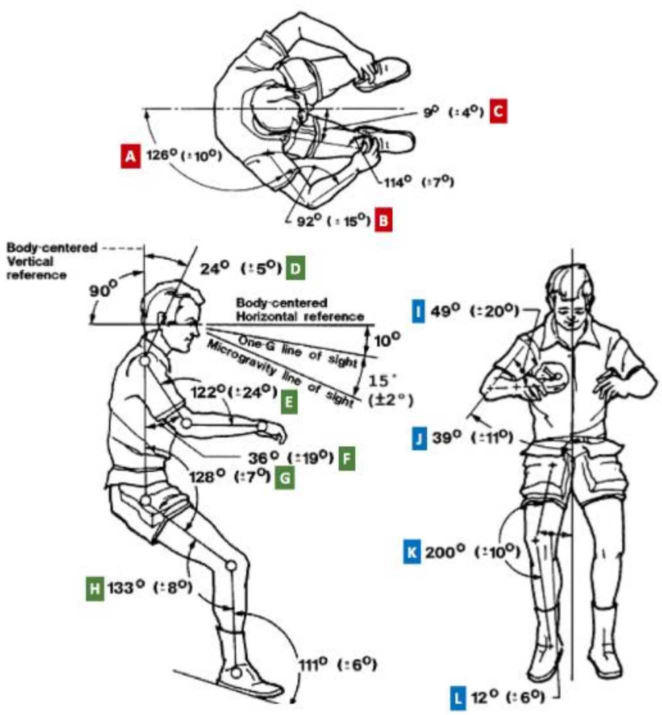

Figure 1. NASA-STD-3000 specifications for neutral body posture. (Han Kim et al., 2019)

1.1.4. Research question

With the absence of driving tasks and the freedom to perform NDRAs in future Level 5 AV and inspired by the zero-g neutral body posture, the study planned to explore the neutral body posture in various NDRAs in a one-g gravitation setting avoiding the restrictions of seats itself. This drives us to the research question on what are the optimal seat postures for the selected NDRAs in Level 5 AV? And how are these postures compared to postures in current car seats and non-gravitational settings?

2. Methods

A study that invites participants to build their own seats with designed building blocks was done to answer the research question. The study compared an ideal seat participants built with a typical car seat in a prototype buck. Prior to the experiment, a pilot study was done with 2 participants and the protocol was adjusted accordingly.

2.1.1. Participants

Thirty-seven participants below 40 years old joined the study. The age was restricted since these people are expected to be passengers of future level 5 AVs. One participant was excluded from the analysis due to invalid data. The participants consist of 18 males and 18 females. Participants were selected based on their BMI and ethnic origins with a maximum age of 40 years old. Their self-reported stature, self-reported weight, ethnic origins, and age were asked during the participant recruitment. The study included an approximate 5th to 95th percentile of the Dutch population stature (1714 to 1942mm for Dutch males, 1598 to 1809mm for Dutch females) based on a survey by Molenbroek et al. (2017). Participants from a European ethnic origin were favoured since the study is done based on Dutch anthropometrics. The maximum age was introduced as level 5 AV is for future cars. Due to the use of 3D scanners with light sensors, participants were screened without a history of epilepsy. Additionally, participants were required to wear light and relatively tight clothing for the test.

2.1.2. Ethics

This research was approved by the Human Research Ethics Committee of Delft University of Technology on January 4th, 2024, application number 3725. Each participant completed an informed consent form before beginning the experiment. Participants were compensated €30 after the completion of this 2-hour study.

2.1.3. Research setup

This task was done with 2 different seat supports/seats.

- Testing environment A: Build-your-own seat with foam blocks. According to Figure 6, the testing region on the ground has a dimension of 2m x 2.7m. This is the space available in a full-size SUV. There was a carpet in the middle of the ground square for better friction.
- Testing environment B: an AAAA seat in the buck shown in Figure 3. The initial setting for this seat was maximum aft, maximum lowest, minimum seat tilt, maximum upright and lowest headrest setting.


Figure 2. Testing environment A


Figure 3. Testing environment B

As shown in Figure 2, the testing environment had various sizes of foam blocks as building options. Partial foam blocks were modified with Velcro for extra fixtures. Figure 4 shows the list of the 43 foam blocks in use. The full block B1 is 72x20x10cm. Based on feedback from the pilot study, backrest support was provided to increase the building efficiency (Figure 2). Participants could freely choose which block to use or not to use without any requirements, and the researchers were not allowed to give suggestions.

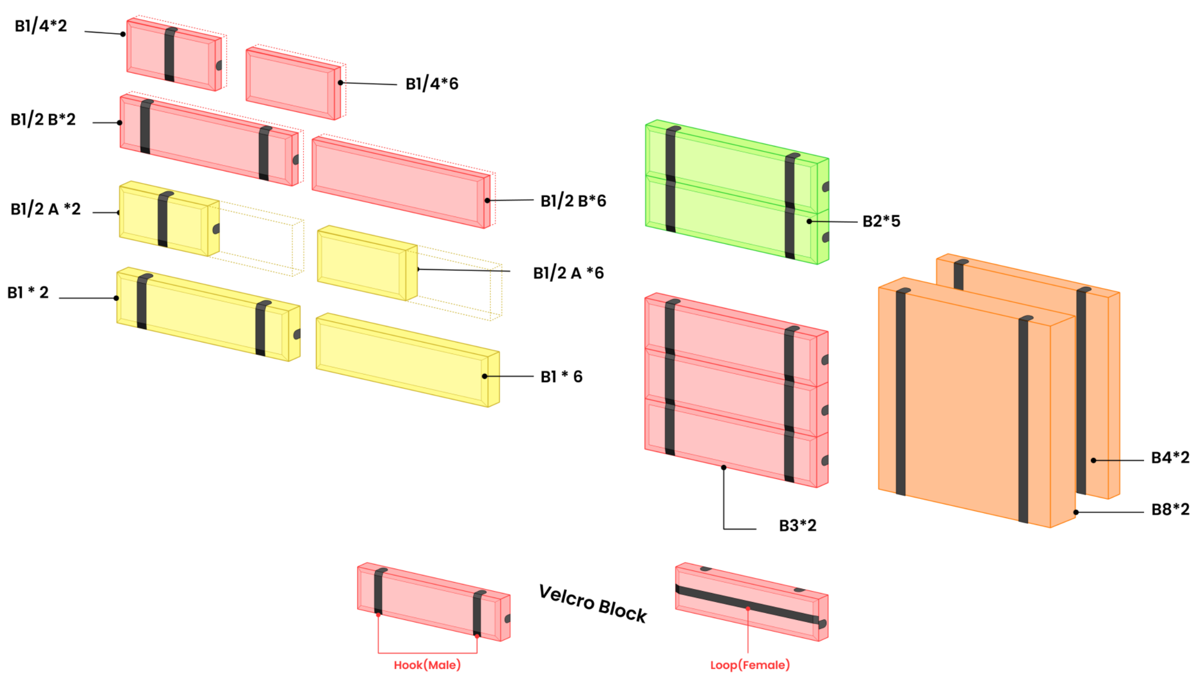

Figure 4. Foam block size and number and hoop-loop mechanism

2.1.4. Procedure

The procedure begins with an introduction, including a background description and a pre-test questionnaire (Figure 5). The testing space is prepared to the original position as shown in Figure 2 and Figure 3. Participants then undergo anthropometric data collection and receive an explanation and practice of the building rules for foam blocks. In Part A, participants build their own seat, confirm the first most comfortable posture for one NDRA, undergo 3D scanning, and confirm any additional comfortable postures before completing a post-questionnaire of comfort and discomfort scales. This process is repeated for NDRA 2-5. In Part B, participants sit on the AAAA seat, adjust it for comfort with the same NDRA, confirm comfortable postures, and then complete the same post-questionnaire, also repeated for NDRA 2-5. The session concludes with an interview. Participants are divided such that half start with Part A and the other half with Part B, with the NDRA sequence (A. Smartphone use, B. Rest and relax/watching out of the window, C. Deskwork, D. Eating and Drinking, and E. Sleeping) randomised for each participant.

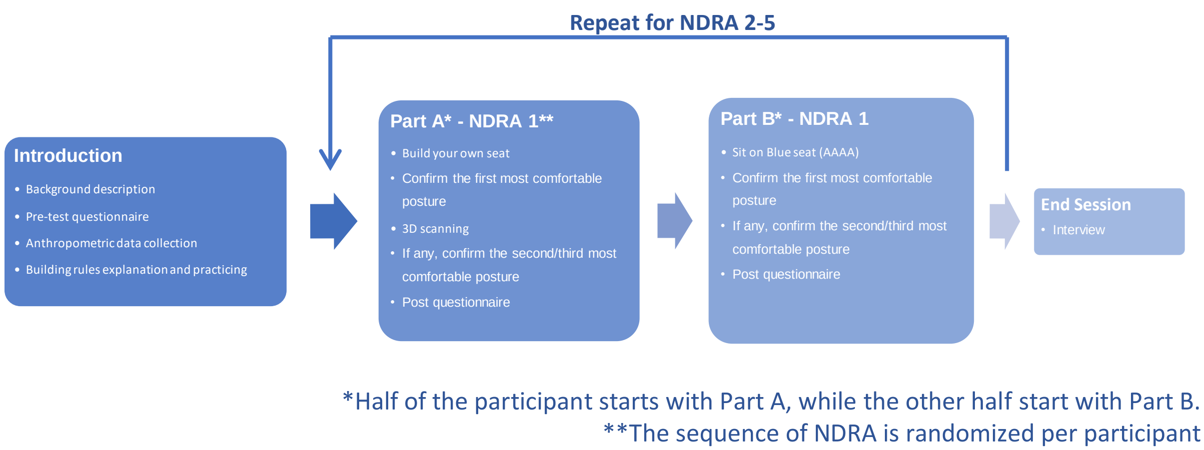

Figure 5. Test procedure

2.1.5. Measurement methods

All anthropometric measurements were conducted using the DINED method (Molenbroek et al., 2017). Anthropometric data collection includes measuring body weight, stature, and sitting height. Additional measurements involve shoulder sitting height, hip breadth, shoulder breadth, and the distance from buttock to knee. Popliteal height, buttock to popliteal distance, and eye height while seated are also recorded. These measurements provide comprehensive data on body dimensions.

A pretest questionnaire was made to collect participants' previous experience with automated driving and their preference towards NDRAs. A post-questionnaire was created to assess each participant's comfort or discomfort after each activity. A 0-10 scale simple comfort and discomfort score and a 0-10 scale local postural discomfort was used as this study was in an early design phase and focused on non-experts (Anjani et al., 2021).

Video recording was made for process documentation, while a 3D scanner of Artec EVA was used for posture documentation. A set of joint angles with kinematic constraints can describe and specify the body postures (Reed et al., 1999). A skeleton tracking recording was made for optimal postures using the Microsoft Azure Kinect DK as the 4D camera. The distribution of Kinects in Testing environments A and B is shown in Figure 6, Figure 7, Figure 8, and Figure 9.

Special equipment was required for NDRAs. While each participant was asked to use their smartphone for A. Smartphone use, a weight scale was used to collect the smartphone's weight. The weight scale was used to document the weight of the laptop in use for each participant for Deskwork. As shown in Figure 6, Figure 7, Figure 8, and Figure 9., Dolls were placed in both test environments as the view of looking out of the window for NDRA B. Rest and relax. The placement of the dolls was done to be able to see left, front, and right and also far and near.

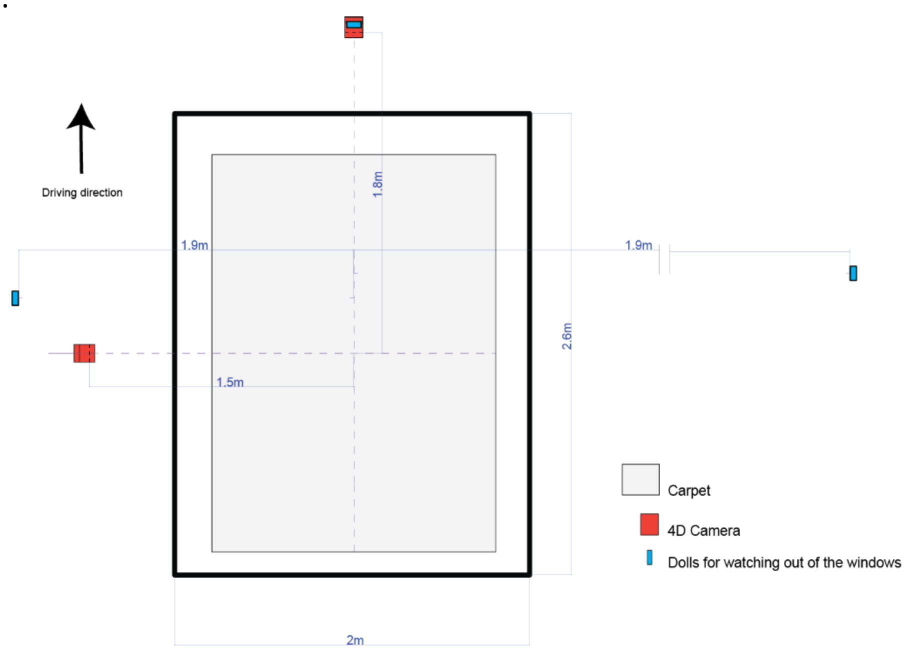

Figure 6. Testing environment A - Top view

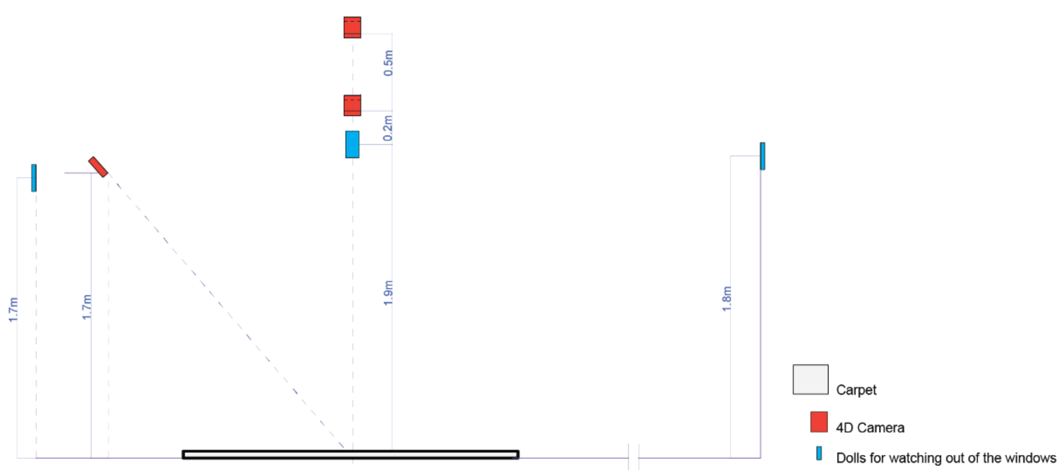

Figure 7. Testing environment A - Front view

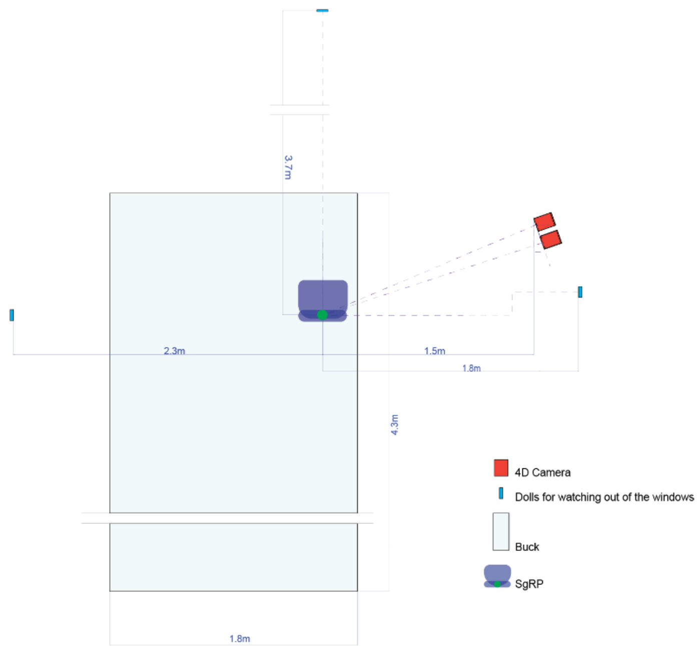

Figure 8. Testing environment B - Top view

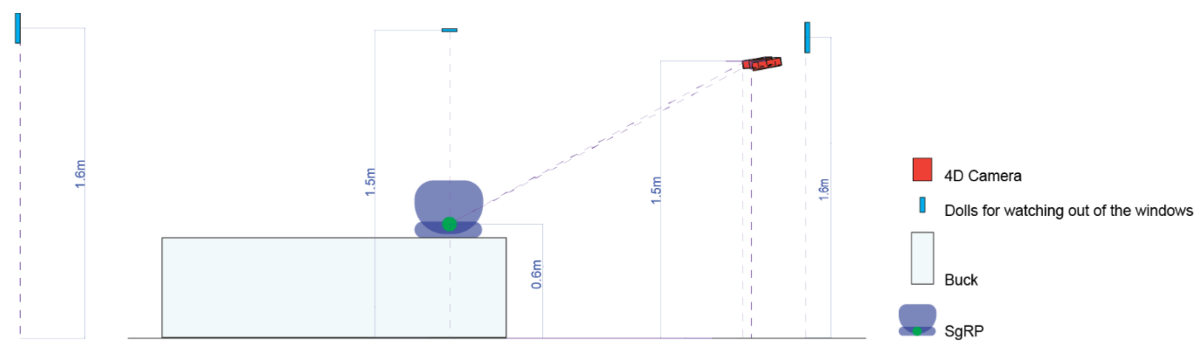

Figure 9. Testing environment B - Front view

2.2. Data analysis

With the multiple data collection equipment, five types of data were collected: 1) demographic data with anthropometric data and participant's previous automated vehicle experience; 2) subjective comfort and discomfort questionnaire results after each NDRA; 3) skeleton tracking joint position data of the optimal posture for each NDRA; 4) 3D scanning meshes of the optimal posture for each NDRA of testing environment A; 5) video recordings with interview transcriptions.

The first three numeric data were imported into the Python NumPy version 1.26.4. A Wilcoxon signed-rank test is conducted to determine if there are differences in the mean ranks between various variables and clusters. The Wilcoxon test is employed because Comfort, discomfort, and joint position typically do not follow a normal distribution. A Spearman's Rank-Order Correlation analysis is conducted to discover if there are correlations between anthropometric data and joint angle distribution. The 4) and 5) non-numeric data were combined for a visual categorization of posture support. Qualitative assessments of the 3D scan results were independently coded by two researchers, and the conflicts were discussed. The transcription of the final interview from video recordings was summarized into qualitative insights.

2.2.1. Joint position into Joint angle of the optimal posture

Azure Kinect body tracked joints' position relative to the global frame of reference of the depth sensor (Microsoft, 2022) in Figure 11. Then the targeting Joint angle was defined by the combination of relevant joint positions (Figure 10). The numbering of the joint angles was based on the study of Saputra et al. (2022). Calibrations were performed at the right knee angle using manual measurements for each participant. This resulted in an accurate measurement of the sensor. Based on a literature review by Schmidt et al. (2014), the detailed methodological descriptions of the methodological assessment of joints are essential for understanding angles related to the human body.

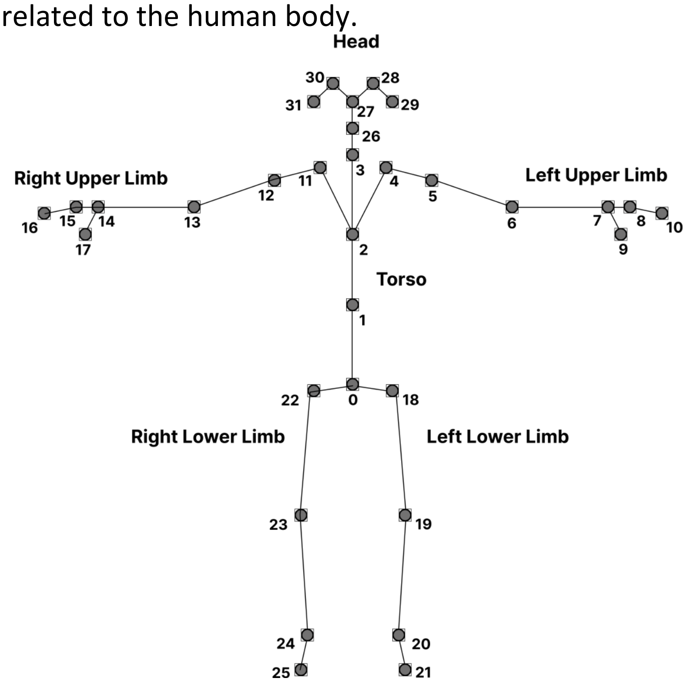

Figure 10. The division of the joint group and the joint ID

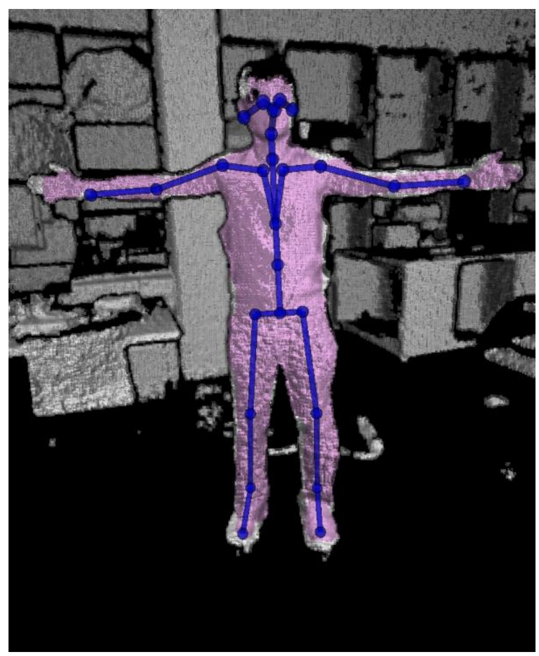

Figure 11. example of 4D camera detection

See Appendix **Error! Reference source not found.** for a detailed explanation of joint angle construction. There are three methods of joint angle calculations in this study. Internal comparison results of joint angles are calculated with the default method, while the external joint angle comparisons are computed both with the reference planes and absolute angles methods, following the procedures of Han Kim et al. (2019)and Kyung & Nussbaum (2009).

With the method of NASA-STD-3000 and Han Kim et al. (2019), Figure 12 shows the construction of the front reference plane with H points as the X axis, while the line of mid H point and mid clavicle point as the Y axis. As shown in Figure 13, the right elbow joint is projected to the front reference plane and P12 to P14 referred to the projected points.

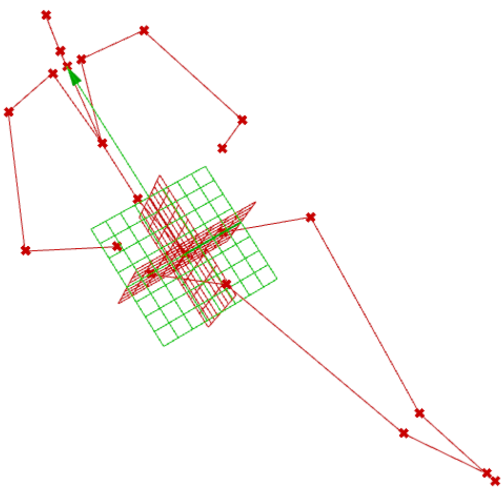

Figure 12. Skeleton reference plane

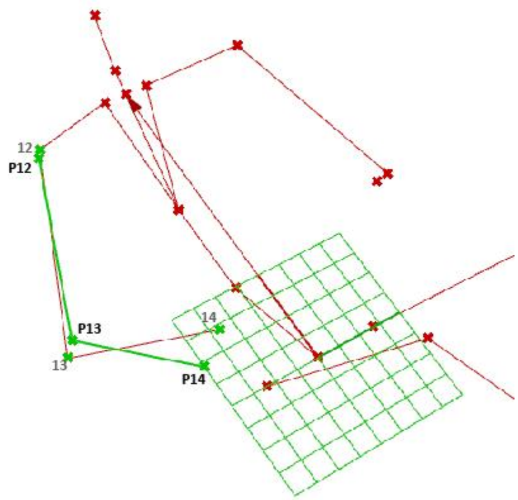

Figure 13. 3D joint projection with reference plane demonstration

According to Kyung & Nussbaum (2009), the joint angle calculation method can be shown in Figure 14. Except for the Torso angle and neck angle are calculated with the vertical axis, the rest of the joint angles are absolute angles in the 3D dimension.

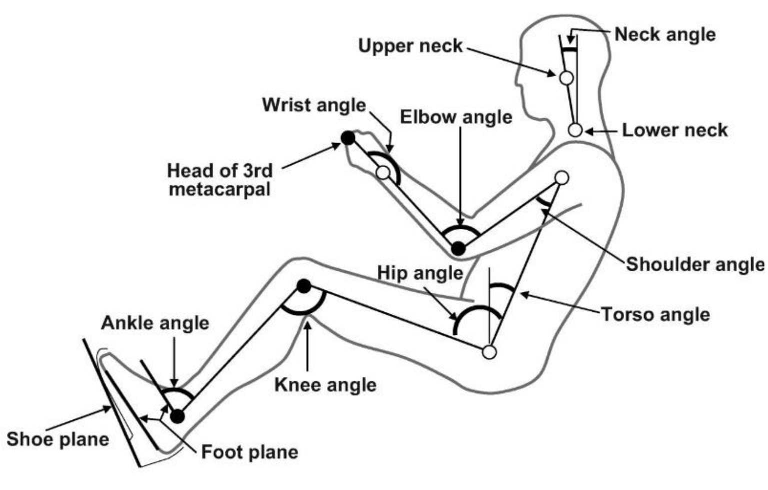

Figure 14. Joint angle definition (Kyung & Nussbaum 2009)

The program used in this study did not give an accurate finger level detection, therefore hand gestures would not be discussed further.

2.2.2. Posture support classification

Without an existing seat in testing environment A, participants could build various supports for their optimal body posture from foam blocks. The non-numeric data of 3D scanned meshes and video recordings were combined for a classification of posture support types, including armrest, central table, lower leg support, etc. During the test, it was discovered that participants used more foam blocks than they actually interacted with. Based on that, only the foam blocks that give postural support or have direct contact with the body of the participants are considered. Two researchers independently classified the additional support from the front-view 3D scan meshes based on the coding in Table 1.

Table 1. Coding of seat support based on 3D scan meshes.

Category		Explanation
Armrest	Left	
	Right	
Table	Left side-table	Only side-table as an extension of armrest.
	Right side-table	Only side-table as an extension of armrest.
	Central table	Including tables in the middle and tables that span left to right.
Leg support	Lower leg-support	To support the legs up, e.g. having crossed legs on the seat.
	Calf support	Only having the calf supported, without the feet touching the ground.
Side support	Laying on the side	If the participants sleep in a flatbed on their side.
Symmetrical seat-support		Whether the seat has a symmetrical support for the posture.

2.2.3. Crossed-leg postures classification

It indicates that adequate leg space is essential for a positive perception of comfort (Stanglmeier et al., 2021). The non-numeric data of 3D scanning meshes, and video recordings were further analysed for crossed-leg posture classification. To mark outlier posture, the postures were classified into crossed-leg postures and non-crossed-leg postures. As shown in Table 2, the crossed-leg postures were then categorized into four categories of ankle on the ankle, knee on the knee, ankle on the knee (Ahn et al., 2013), and crossed leg with both legs on the seat pan.

Table 2. coding of crossed-leg postures

Crossed leg Category	Explanation	Illustration
Ankle on the ankle	The lower limbs posture that participant put their ankle above another ankle	

Knee on the knee	The lower limbs posture that participant put their knee above another knee	
Ankle on the knee	The lower limbs posture that participant put their ankle above or under another knee	
Crossed leg with both legs on the seat pan	The lower limbs posture that participant put their crossed leg both on the seat pan.	

3. Results

3.1. Participant demographics

Thirty-six participants were invited to participate in this study. All participants were healthy adults with a maximum age of 40 years old. This age limitation is present as fully automated vehicles are planned for future development. Participant demographics are presented in Table 3. Half of the participants were male, and the other half female, which represents the world gender distribution. The ethnicity of the participants was mainly Western European as this study was conducted in the Netherlands. The question of their dominant hand was also asked to later explain the symmetrically if their posture, where this study has 92% right-handed participants.

Table 3. Participant demographics

Participant data		Percentage
Age	23.9 ± 2.9 Years old	
Gender	Male	50%
	Female	50%
Ethnicity	Western Europe (e.g., Germany, Sweden, United Kingdom)	64%
	East and Central Asia (e.g., China, Japan, Uzbekistan)	22%
	Eastern Europe (e.g., Hungary, Poland, Russia)	6%
	South and Southeast Asia (e.g., India, Indonesia, Singapore)	6%
	Sub-Saharan Africa (e.g., Kenya, Nigeria, South Africa)	3%
Nationality	Dutch	36.1%

	Chinese	11%
	German	8.3%
Dominant hand	Left	8%
	Right	92%

3.1.1. Anthropometric measurements

Participants were selected to cover the full distribution of Dutch anthropometric measurements based on the DINED TU Delft database (https://dined.io.tudelft.nl). During the recruitment, a sign-up questionnaire was filled-in by participants which include self-reported height and self-reported weight. As shown in Figure 15 and Figure 16, the selection of height and BMI spans the P5 to P95 population, ensuring an even distribution. This approach provides a representative sample, accommodating a wide range of body types and promoting inclusivity in the study. The participants in this study were spread out evenly based on their popliteal height and seated hip breadth shown in Figure 17. Both measurements plotted are not correlated to each other, therefore could show a better spread out of the participants recruited.

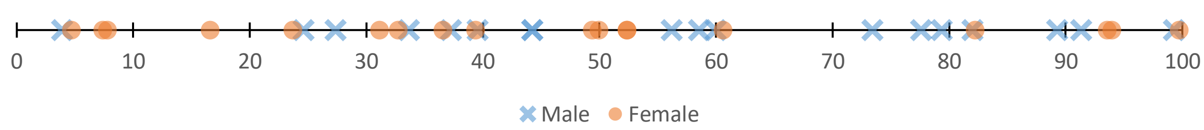

Figure 15. Height distribution percentile from the Dutch anthropometrics database for Adults 20-60 years (Source: DINED database TU Delft (dined.io.tudelft)

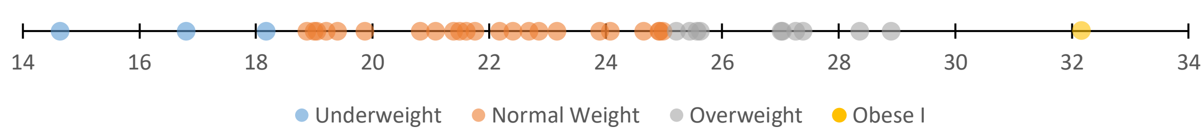

Figure 16. The BMI (kg/m^2) distribution of the participants.

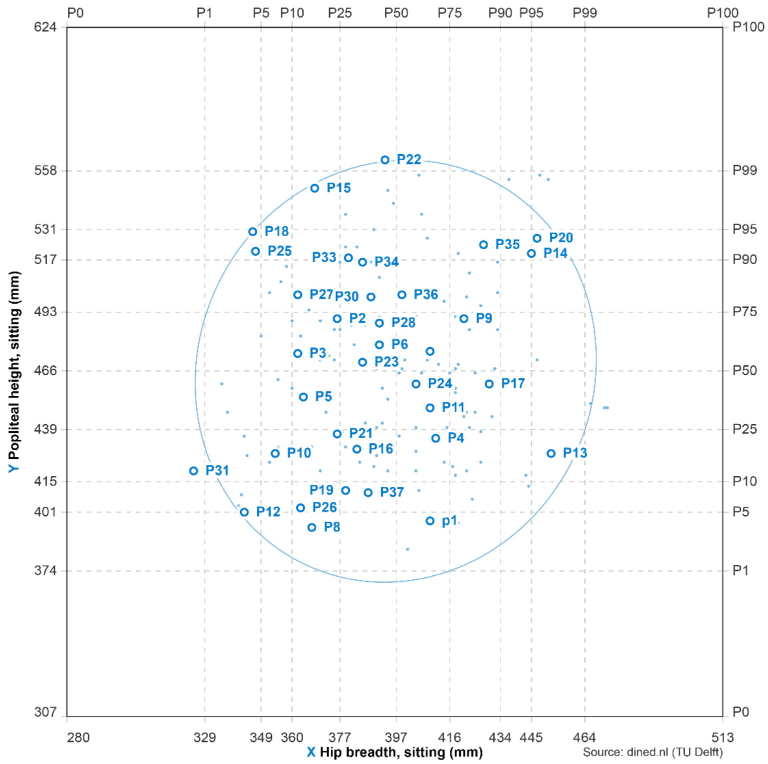

Figure 17. Distribution of participants based on their popliteal height and seated hip breadth in the Dutch anthropometrics database for Adults 20-60 years Source: DINED database TU Delft (dined.io.tudelft)

Prior to the tests, researchers measured each participant with an anthropometric chair, anthropometer and body weight scale. The average and standard distribution of these measurements are present in Table 4. Most anthropometric measurements of the participants have a high standard deviation, which indicates a good spread of the participants.

Table 4. Participant anthropometric measurements

Anthropometric measurements	
Body weight	71 ± 15.7 kg
Stature	1754 ± 115.0 mm
BMI	23± 3.6 kg/m^2
Sitting height	910 ± 47.5 mm
Shoulder sitting height	583 ± 36.5 mm
Hip breadth	389 ± 30.4 mm
Shoulder breadth	415 ± 41.3 mm
Buttock to knee	699 ± 41.7 mm
Popliteal height	470 ± 46.8 mm
Eye height seated	794 ± 46.1 mm

3.1.2. AV experience

22.2% of the participants have experienced a fully automated vehicle, 63.8% will and 36.2% maybe be willing to use an AV in the future. NDRAs are already done by people on different transport modes when they don't have the task of driving shown in Figure 18, and with the absence of a driver role, the occurrence of these NDRAs could increase. This figure shows that smartphone use, and rest and relax were NDRAs frequently done in other transportation modes. More participants were doing desk work in trains and airplanes, compared to in the cars, busses, and trams. This might be due to the longer travel durations spent in trains and airplanes, compared to the other modes.

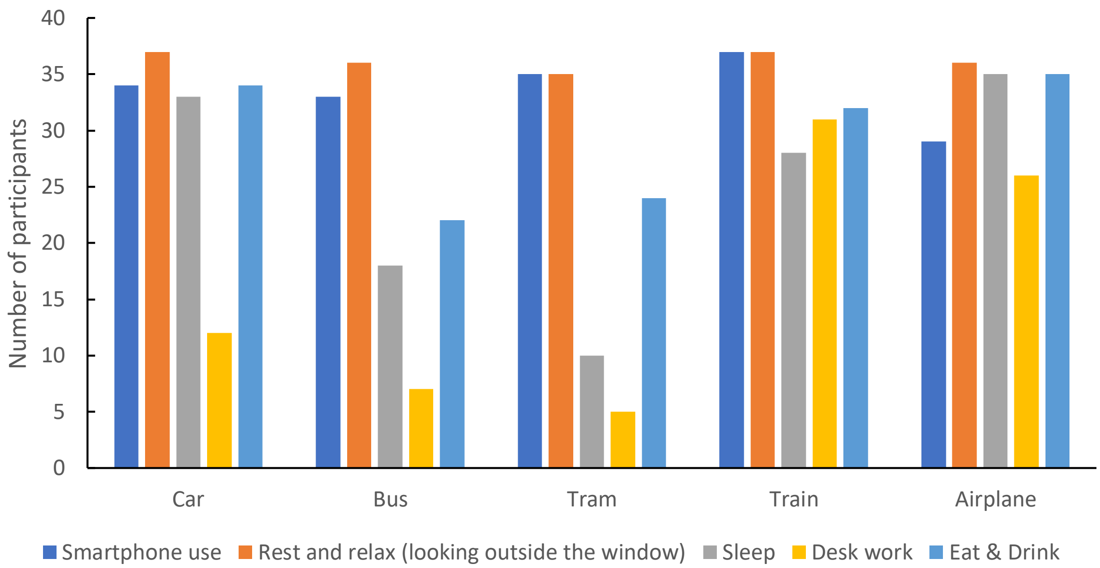

Figure 18. NDRAs currently done in different transport modes.

3.2. Subjective Comfort

Participants were asked to rate their current comfort by filling in a questionnaire which contains subjective comfort (0-10), subjective discomfort (0-10), and local postural discomfort (LPD) (0-10). These ratings were analysed by comparing the Build-Your-Own seat in setup A to the current car seat in setup B, as well as zooming in on specific NDRAs conducted in the setup.

3.2.1. Overall subjective comfort and LPD of the Build-Your-Own seat compared to current car seats

Result see Appendix C

3.2.2. Subjective comfort of each NDRA

Result see Appendix C

3.3. Joint angles

The joint angles data collected through the Azure Kinect was further calculated with the default method(Appendix B) for internal result comparisons, including the comparison between the Build-Your-Own seat and AAAA, each NDRA and correlation with anthropometric data.

3.3.1. Joint angle comparison between Build-Your-Own seat and AAAA

Result see Appendix D

3.3.2. Joint angle comparison of each NDRA with Build-Your-Own seat

Result see Appendix D

3.3.3. Correlation of anthropometric data and Build-Your-Own Seat joint angle data

Result see Appendix D

3.4. Posture support classification

The foam blocks provide ultimate possibilities for posture support, which is crucial to understanding further the relationship between posture and NDRAs.
Table 5 demonstrates the classification result of all postures into six categories. Lower leg support includes calf support, side support while lying down and other support for the cross-leg posture. Cohen's Kappa interpretation was conducted to testify the agreement of the classification between the researchers. A Kappa value of 0.79, which is greater than 0.6 and nearly reaches 0.8, indicates substantial agreement between the raters (Landis & Koch, 1977). Only the classification agreed upon by both researchers is included in
Table 5. Figure 19 to Figure 23 show examples of posture support, including armrest, central table, lower leg, calf support and side support for laying down posture.

In this study, armrests were preferred for smartphone use and rest & relax, providing necessary support for these tasks. 56% of participants built a central table for desk work, highlighting its importance for this activity. Calf support was favoured for sleeping, smartphone use, and rest and relax for around 30% of the participants, indicating a need for lower leg comfort in these scenarios. Additionally, 25% of participants preferred to sleep on their side, which cannot be accommodated by the current car seat.

Figure 19. Armrest support example

Figure 20.Central table support example

Figure 21.Lower leg support example

Figure 22.Calf support example

Figure 23.Side support (laying down) example

Table 5. Posture support classification with NDRAs

	Right armrest	Left armrest	Central Table	Lower leg support	Calf support	Side support (laying down)	Symmetrical support
A	67%	58%	3%	53%	31%	3%	72%
B	74%	69%	6%	43%	31%	0%	71%
C	48%	50%	56%	17%	11%	0%	83%
D	51%	49%	19%	22%	14%	0%	69%
E	28%	28%	0%	75%	33%	25%	83%
all	54%	51%	17%	42%	24%	6%	76%

3.5. Crossed-leg postures classification

Since the foam blocks can offer ultimate freedom for participants' posture, there are some common relaxing postures with crossed legs, whereas uncommon postures like lying down on the side are also observed. With only one posture for each NDRA, 66.7% of the participants had at least a crossed-leg posture during the study, while 25% had three or more crossed-leg postures. It indicates that some participants strongly prefer crossed-leg postures, and they perform them in most of the NDRAs. Table 6 shows the classification result of crossed-leg postures with each NDRA. It is shown that crossed-leg postures of the ankle on the ankle are common in each NDRA, while 11% of participants tend to put their ankle on the knee only with Rest and relax activity. The classification of crossed-leg postures can provide selection criteria for further joint angle analysis.

Table 6. Outlier postures with crossed legs in each NDRA

Activity	Crossed leg in general or not	ankle on the ankle	knee on the knee	ankle on the knee	Crossed leg and both legs on the seat pan
A. Smartphone use	36%	25%	6%	3%	3%
B. Rest and relax	43%	26%	3%	11%	3%

C. Deskwork	26%	20%	0%	0%	6%
D. Eat and drink	26%	17%	0%	3%	6%
E. Sleep	25%	22%	0%	3%	0%

3.6. One-g neutral body posture

As postures collected without existing seats, the Build-Your-Own seat Joint angle data can be interpreted as the one-g neutral body posture with the influence of gravity on Earth. According to Appendix B, One-g neutral body posture (Build-Your-Own seat posture) results are presented in different calculation methods: including default, with reference planes, and absolute angles. Due to the program's inability to accurately detect finger levels, hand gestures will not be discussed further in this study.

3.6.1. Posture selection of One-g NBP

Outlier postures included in the results of the One-g NBP dataset-0 need to be further identified and excluded to be able to be compared with other research. Table 7 explains the exclusion of the postures in the new datasets after exclusions. Dataset-1 excludes the postures in which participants build the foam blocks as beds while lying on the side and prone. Dataset-2 further excludes all the crossed-leg postures that are classified in 3.5 Crossed-leg postures classification.

Table 7. One-g NBP Joint angle data set description

One-g NBP Dataset name	Description
Dataset-0	Build-Your-Own seat original data
Dataset-1	Data set 0 excludes postures lying down on the side, and prone position
Dataset-2	Data set 1 excludes crossed-leg postures

3.6.2. One-g NBP with reference planes

Result see Appendix E

3.6.3. One-g NBP and AAAA with absolute angles

Result see Appendix E

3.7. End Interview

Participants generally expressed a preference for the Build-Your-Own seat configuration due to the increased space and customization it offered. Many found it more comfortable and appreciated the ability to adjust the seat to their liking. However, some participants noted that the AAAA did not fit their body size well, resulting in discomfort, although the adjustability of the AAAA buttons was appreciated. The need for better support, especially for the neck, was highlighted by a few individuals for both seats. Overall, the Build-Your-Own seat was favoured for providing more freedom and comfort, though additional support in certain areas was desired.

4. Discussions

4.1. One-g NBP with zero-g NBP

This study will compare the results of One-g NBP with reference planes to the updated NBP of the NASA-STD-3000 (Han Kim et al., 2019) with results of 3.6.2. The projected joint angles outside the 95% confidence interval of the bootstrap will be highlighted for further discussion.

4.1.1. Overall one-g NBP with Updated zero-g NBP data

Discussions see Appendix F.1.1

4.1.2. Each NDRA of one-g NBP with Updated zero-g NBP data

Discussions see Appendix F.1.1

4.2. One-g NBP and AAAA with recommended Joint angle for SUV

As shown in Appendix B, the joint angle of One-g NBP and AAAA was calculated following the method of Kyung and Nussbaum (2009) with absolute angles in 3.6.3. The data that is out of the recommended range of Kyung and Nussbaum (2009) is marked for further analysis.

4.2.1. Overall one-g NBP and AAAA with recommended Joint angle for SUV

Discussions see Appendix F.2.1

4.2.2. Each NDRA of one-g NBP recommended Joint angle for SUV

Discussions see Appendix F.2.1

4.3. Limitation and future works

The calculation method of the NBP joint angle is symmetrical, while the joint angle of the Build-Your-Own seat is not symmetrical in the real case, which may cause an error in the comparison result. Future studies focusing on the asymmetrical posture in a neutral body posture would be needed to increase comfort in future vehicles. Moreover, the sitting duration for each participant in each posture was short, neglecting the long-term effects of posture, especially with crossed-leg postures. Longer test durations that exhibit changes in posture overtime will be also necessary to ensure that the adjustments of the seating support in future vehicles could cater to a comfortable position.

5. Conclusion

This study is done to explore the postures assumed by passengers in the absence of DRAs. The freedom of conducting various NDRAs in future Level 5 AV will allow passengers to be in a more NBP. This study introduces a neutral body posture in various NDRAs in one-g gravitation settings avoiding the restrictions of seats itself. Participants were asked to construct a Build-

Your-Own seat out of foam blocks to be able to conduct NDRAs in a comfortable position. Joint angles and seat setting of the Build-Your-Own seat in one-g gravitation settings are present and compared to the use of the current car seat and zero-g NBP.

Thirty-six participants (half male, half female) were invited to participate in this study with a spread-out BMI and anthropometric distribution based on the Dutch anthropometric measurements. Participants rate the Build-Your-Own seat higher in comfort, and lower in discomfort and all LPDs compared to AAAA. The LPD ratings of the upper body and extremity limbs were significantly improved in the Build-Your-Own seat.

Joint angles of the participants were measured, and significant differences were found in the right shoulder, left and right thigh-trunk, left knee and left and right ankle between the Build-Your-Own seat and AAAA, suggesting further posture optimization with these joint angles. The postures assumed in the Build-Your-Own seat show much less correlation between body measurements and angle ranges, indicating that participants adopted more diverse and incoherent postures. The NDRA of Rest and Relax and Sleep exhibited more diverse postures compared to other NDRAs, suggesting that posture freedom equates to comfort.

The seating support in Build-Your-Own seats was studied and found that armrests were preferred for smartphone use and rest & relax, and a central table was necessary for desk work. Calf support was favoured for sleeping, smartphone use, and rest and relax for around 30% of the participants, indicating a need for lower leg comfort in these scenarios for certain groups of users. Additionally, 25% of participants preferred to sleep on their side, which cannot be accommodated by the current car seat.

With a single posture recorded for each NDRA, 66.7% of participants adopted at least one crossed-leg posture during the study, and 25% exhibited three or more crossed-leg postures. This suggests that some participants have a strong preference for crossed-leg postures, frequently adopting them across most NDRAs. Crossed-leg postures with the ankle on the ankle are common across all NDRAs, whereas 11% of participants place their ankle on the knee only during Rest and Relax activities.

The comparison of one-g NBP results with reference planes shows that the two datasets have similar counts, but Dataset 1 exhibits a higher standard deviation than Dataset 2, indicating that Dataset 2 offers more consistent results. The one-g NBP results with absolute angles show that the joint angles in Dataset 1 are generally flatter than those in AAAA, indicating a more comfortable range. Both the one-g NBP analyses—using reference planes and absolute angles—reveal that the angles for the NDRA of sleep are different from those of the other NDRAs.

Participants expressed a preference for the Build-Your-Own seat configuration in their interview due to the increased space and customization it offered, though additional support in certain areas was desired. The need for better support in the neck was also highlighted by a few individuals.

The comparison results highlight the challenges of directly applying zero-g NBP to future car seat designs due to the significant influence of gravity on posture. Compared to the updated NBP data, dataset 2 (without crossed-leg postures) shows the same statistical differences as dataset 1. In dataset 2, while the joint angle ranges for Eat and Drink fall entirely outside the 95% confidence interval, the deskwork data includes three additional angle categories within the interval, indicating greater postural similarities. The comparison results suggest that directly applying NBP to future car seat designs is challenging due to the significant impact of gravity on posture.

The postural results of the Build-Your-Own seat and AAAA are further analysed and compared to comfortable ranges in an SUV in the literature. Differences in torso, right hip, left hip, right ankle and left ankle were found in Build-Your-Own seat and literature, but only torso difference was found for the AAAA. Without the limitations of existing seats, the optimal joint angle set can extend beyond established boundaries, incorporating flatter angles. This might indicate that the current car seats should be further improved to accommodate NDRAs in future Level 5 AV.

Future studies focusing on the asymmetrical posture in a neutral body posture would be needed to increase comfort in future vehicles. Longer test durations that exhibit changes in posture over time, including cross-ed leg postures, will be also necessary to ensure that the adjustments of the seating support in future vehicles could cater to a comfortable position.

6. Reference

Ahn, S., Kim, S., Kang, S., Jeon, H., & Kim, Y. (2013). Asymmetrical change in the pelvis and the spine during cross-legged sitting postures. *Journal of Mechanical Science and Technology*, *27*(11), 3427–3432. https://doi.org/10.1007/s12206-013-0865-5

Anjani, S., Kühne, M., Naddeo, A., Frohriep, S., Mansfield, N., Song, Y., & Vink, P. (2021). PCQ: Preferred Comfort Questionnaires for product design. *Work*, *68*(s1), S19–S28. https://doi.org/10.3233/WOR-208002

DINED. (n.d.). https://dined.io.tudelft.nl/en

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

Grebonval, C., Beillas, P., & Wang, X. (2021). *Experimental investigation of preferred seating positions and postures in reclined seating configurations*.

Han Kim, K., Young, K. S., & Rajulu, S. L. (2019). Neutral Body Posture in Spaceflight. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *63*(1), 992–996. https://doi.org/10.1177/1071181319631129

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (1979). Applied statistics for the behavioral sciences. http://ci.nii.ac.jp/ncid/BA44543583

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

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. Biometrics, 33(1), 159. https://doi.org/10.2307/2529310

Microsoft. (2022, September 2). Azure Kinect body tracking joints. Microsoft Learn. https://learn.microsoft.com/en-us/azure/kinect-dk/body-joints

Miller, K. H. (1986). Man/System Integration Standards for space Systems. *Proceedings of the Human Factors Society Annual Meeting*, *30*(4), 358–362. https://doi.org/10.1177/154193128603000411

Molenbroek, J. F. M., Albin, T. J., & Vink, P. (2017). Thirty years of anthropometric changes relevant to the width and depth of transportation seating spaces, present and future. *Applied Ergonomics*, *65*, 130–138. https://doi.org/10.1016/j.apergo.2017.06.003

NASA (2013). NASA Standards Inform Comfortable Car Seats, Spinoff, pp 61.

Pfleging, B., Rang, M., & Broy, N. (2016). Investigating user needs for non-driving-related activities during automated driving. *Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia*, 91–99. https://doi.org/10.1145/3012709.3012735

Reed, M., Manary, M. A., & Schneider, L. W. (1999). *Methods for Measuring and Representing Automobile Occupant Posture*. 1999-01–0959. https://doi.org/10.4271/1999-01-0959

SAE International. (2020). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. *SAE International Journal of Connected and Automated Vehicles*, *3*(1), 12-03-01–0003. https://doi.org/10.4271/12-03-01-0003

Saputra, A. A., Besari, A. R. A., & Kubota, N. (2022). Human Joint Skeleton Tracking Using Multiple Kinect Azure. *2022 International Electronics Symposium (IES)*, 430–435. https://doi.org/10.1109/IES55876.2022.9888532

Schmidt, S., Amereller, M., Franz, M., Kaiser, R., & Schwirtz, A. (2014). A literature review on optimum and preferred joint angles in automotive sitting posture. *Applied Ergonomics*, *45*(2), 247–260. https://doi.org/10.1016/j.apergo.2013.04.009

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

Stanglmeier, M. J., Schulte, F., Schauberger, G., Bichler, R. J., Schwirtz, A., & Paternoster, F. K. (2021). Effect of legroom proportions and individual factors for sitting with crossed legs: Implications on the interior design of automated driving vehicles. *Ergonomics*, *64*(11), 1393–1404. https://doi.org/10.1080/00140139.2021.1933201

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

DESIGN FOR our future

TU Delft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Zeng 7020	IDE master(s)	IPD ✔ DfI ☐ SPD ☐
Initials	N.Z.	2nd non-IDE master	
Given name	Ni	Individual programme *(date of approval)*	
Student number	5429692	Medisign	☐
		HPM	☐

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Wolf Song	dept./section	Sustainable Design Engineering
mentor	Shabila Anjani	dept./section	Sustainable Design Engineering
2nd mentor			
client:			
city:		country:	
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Wolf Song Date 12 feb 2024 Signature

CHECK ON STUDY PROGRESS

To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ______ EC

Of which, taking conditional requirements into account, can be part of the exam programme ______ EC

★	**YES**	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name Robin den Braber   Date 27 feb 2024   Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name Monique von Morgen   Date 6 Mar 2024   Signature

Personal Project Brief – IDE Master Graduation Project

Name student Ni Zeng **Student number** 5,429,692

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Fully automated car seat design with the constraint of identified activities

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The automation of driving tasks liberates individuals from driving, enabling the pursuit of new activities previously inaccessible during manual control. This research project focuses on prioritizing Non-driving Related Activities (NDRAs) within self-driving vehicles, specifically targeting SAE autonomy driving level 5.

The project would be based on collaborative research between the TUD research team and JLR (Jaguar Land Rover) to design a car seat from the inside out by exploring the postures that people conduct without the boundaries of an existing seat and car exterior. The JLR has a huge interest in gathering posture data of NDRAs from the research, which can offer scientific references for future car seats design. Meanwhile, the TUD research team aim to draw more in-depth insights from the research and validate the research outcome by executing design practice. With the research and design practice, the project can lead to a brand-new exploration of car seat design restraints and possibilities for fully automated scenarios, bringing benefits to end users.

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introduction (continued): space for images

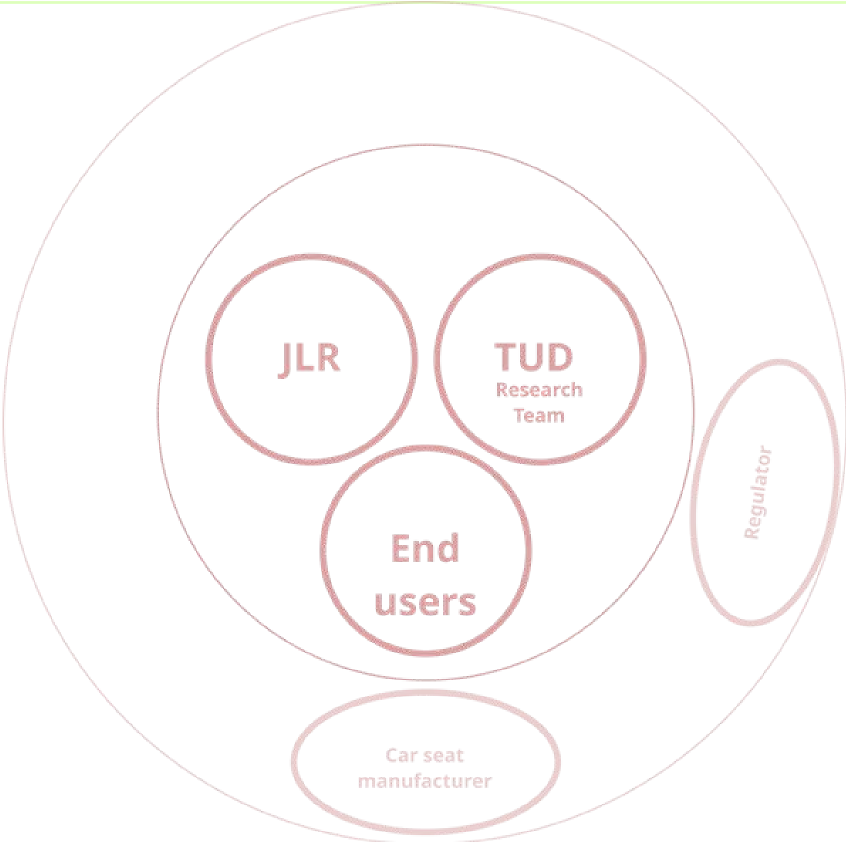

image / figure 1

image / figure 2

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Based on the scientific research setting, the test will be conducted in a bold way that will let the participants build their seats from scratch with building blocks while executing the Non-Driving Related Activities (NDRAs). The initial research planned to collect various types of data, ranging from joint angles degree, participants sitting 3D scan, physiological data, etc. With the data collected from the collaborative research, the design problem would be how to analyse the data and draw effective insights to create constructive constraints for level 5 car seat design. The novel approach can lead to a fresh perspective to define car seat design in the future, which can be a bold trial for both the TUD research team and JLR.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Create a guideline to design the car seat based on the posture data of passengers' NDRAs in fully automated vehicles.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The project approach would consist of three crucial phases: conducting research, analyzing data, and forming design guidelines. The research phase will focus on the quantitative data collection of joint angles degree, physiological data, anthropometric data, comfort evaluation, etc. with a combination of qualitative approach of observation and objective feedback while the participants are conducting Non-Driving Related Activities (NDRAs). After the data collection process, the data would be deformed, cross-validated and analysed to form numerous specifications and meaningful insights. Then the insights and specifications would be translated into design guidelines for future car seats of automated vehicles, which would be supported by a design example. A car seat design under the generated guideline would be tested and evaluated to complete the feedback loop for the project.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting****,* ***mid-term evaluation meeting****,* ***green light meeting*** *and* ***graduation ceremony****. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	12 Feb 2024
Mid-term evaluation	8 Apr 2024
Green light meeting	4 Jun 2024
Graduation ceremony	12 Jul 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	20
Number of project days per week	5,0

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Throughout my master's study, I have had a huge interest in ergonomics, which I believe can have a strong correlation with physical embodiment design. With my future career plan, I want to still focus on physical product development or experience. Based on that, I have acquired some related ergonomics experience in my ACD, AED course, and cognitive ergonomics electives. However, I have not yet explored the full process that the ergonomics research result triggers and guides the design practice. The graduation project will fulfil my need to connect front-end research with back-end design development. Through the graduation project, I plan to broaden my knowledge and competencies in ergonomics research about seating comfort. I want to learn more about how to set up scientific research, leading to design guidelines. Moreover, I plan to enhance my technical skills like blender, grasshopper and python, improving my analytical skills.