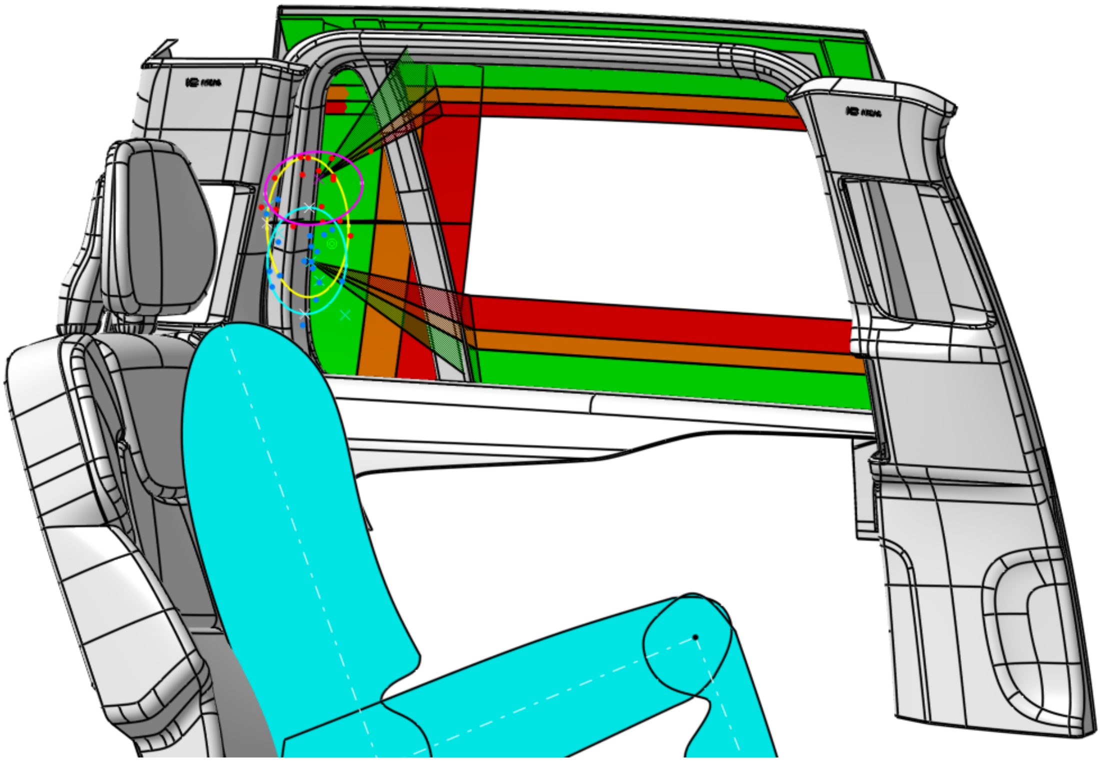

User perception of upper interior space in the rear seat of a car

A human centric approach to assess head roominess

Master's thesis in Product Development

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Department of Industrial and Material Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

MASTER'S THESIS 2020

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Cover: Visualization of the acceptance ranges for the position of Cant rail, Belt line and C-pillar

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Abstract

The upper interior space in a car is an important aspect to consider in the design process for creating overall riding comfort. During the development of sufficient roominess a population's anthropometrics together with ergonomic dimensions and measuring standards are utilized. The interest underlying this thesis study is that head roominess evaluation is considered as a physically measured entity, when it is substantially a combination of physical measurement (objective) and perceived roominess which is subjective to the user. Investigative studies were done at Volvo Cars and recommendations were generated based on the results from the study.

The master thesis study started with literature study followed by three research phases which included qualitative and quantitative studies; Awareness, Identification and Investigation phase. The initial phase (Awareness) was focused in obtaining wider knowledge, and in the final phase (Investigation) involving specific investigation to attain in-depth knowledge. During the second phase (Identification), a qualitative study was applied, and six parameters of the category Vision and Spatial distances were identified as critical for the perceived roominess.

The parameters were analyzed in the Investigation phase, the third and last phase, using a quantitative user study with 34 test persons, divided into two groups based on their sitting height; Short and Tall. The rear-outer seat was studied (behind the driver seat on the left side) in a XC90 car. The rear seat and the driver seat were set in design position (SgRP), the car had light interior trim with a covered panorama roof and the test was performed with the Swedish population. In total thirteen manipulations were randomly performed and a Visual Analogue Scale (VAS) was utilized to assess test person's perceived upper interior space for every manipulation. Nine manipulations were intended for the Vision parameters; Cant rail height, Belt line height and C-pillar forward/rearward position, one change in the Spatial distance (vertical height) and four VAS rating were obtained when the car was in a nominal state. This data together with additionally retained angles and eye points were then statistically analyzed to find trends, tendencies and correlations for all the studied parameters.

For the Vision parameters, the change in Belt line had the highest (negative) influence on the VAS rating irrespective of the Short and Tall group. A high correlation was established between VAS rating and retained angle for the Cant rail. Moreover, C-pillar had the same influence on the Short and Tall group and a common borderline was acknowledge. However, for the Spatial distances, the Tall group had a stronger correlation with these distances than the Short group, who did not establish any correlation with the VAS rating. As recommendations, the acceptable angles for all the parameters have been translated into a definite designed colour range guidance of what would be acceptable, critical or poor for the Vision parameters when perceiving the interior space.

Keywords: perceived head roominess, upper interior space, car, anthropometirc, VAS, vision parameters, spatial distances, statistical analysis

Acknowledgements

This study was performed as a master's thesis at Chalmers University of Technology under the department of Industrial and Material Science for the master's programme of Product Development. The scope of the thesis work was 30 credits with a work plan of 20 weeks. The study was done in collaboration with the Ergonomics team of Volvo Cars, Gothenburg.

We like to take this opportunity to thank Sara Alpsten and Pernilla Nurbo from the Ergonomics team for setting up the thesis work in this interesting area of head roominess. It was their guidance and continuous support in supervision that lead the way to successfully complete the study.

With gratitude, we thank the people who were involved in the user studies that were conducted for the thesis work. To mention, experts from the Product Validation team and experts from Ergonomics team who were involved in the earlier phases of the study. It was with their expertise and feedback that enabled to design the later phases of the study. We also like to thank all the test participants from various departments of Volvo Cars who have participated in user study in later phases amidst the uncertainty caused by Covid19. A special mention of thanks to Mikael Fransson from Complete Vehicle Engineering Quality team at Volvo Cars, who helped us by providing initial knowledge to progress with statistical analysis of subjective data.

This thesis could not have been possible without the academic supervision from our supervisor and examiner Lars-Ola Bligård. We thank him for his approachable nature helping us out whenever we were held back in a doubt, constantly entrusting in our skills and abilities.

Finally, we would like to thank our family and friends for constant support and encouragement throughout this time.

Karthik Gunasekaran and Cornelia Wong Nylander, Gothenburg, 2020

Nomenclature

This chapter contains the definition and explanation to symbols, terms and abbreviations used in the thesis. This page can be referred if the abbreviations and symbols are not explained in the particular section or context.

%-ile – Percentile, A value (0-100%) that divides a group so that one part of the data falls below that value and the other part falls above it.
CAD- Computer aided design
Catia V5- Computer Aided Three-dimensional Interactive Application
ERQ- Exploratory research question
EX – Position of eye in the X-coordinates
EZ – Position of eye in the Y-coordinates
H - Hypothesis, a supposition or proposed explanation made on the basis of limited evidence as a starting point for further investigation.
NRS - Numerical Rating Scale
P-value - Probability value, measure of significance value
Ramsis- Digital Human Modeling tool used for anthropometric simulation and seating posture prediction
RQ – Research questions
r-value – Correlation coefficient
S – Short group of test participants
SAE – Society of Automotive Engineers
SgRP – Seating reference point
StDev - Standard deviation T – Tall group of test participants
TP- Test person
User test- An experimental study involving TPs to get data on desired aspects
VAS – Visual Analog Scale
VRS - Visual Rating Scale
V90/S60/XC40/XC60/XC90 – Names of Volvo Cars in different segment that are commercially available
Q1 - Lower quartile, 25th %-ile value (statistics)
Q2 - Median, 50th %-ile value (statistics)
Q3 - Upper quartile, 75th %-ile value (statistics)

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1

Introduction

The ergonomics engineering work in vehicle design covers a great deal of aspects. What this thesis investigates is covered within the area of occupant packaging (Bhise, 2011a), but in a more precise description it is about the upper interior space and the user perception of the space in the out-rear seat of a car. The development within vehicle packaging can be grouped in six areas but just two of them will be studied in depth; comfortable seated posture covering roominess aspects, and visibility of interior and exterior areas. Because these two areas are separated at the company, there was an inquiry to investigate if they are affecting each other and in what extent. A generated knowledge would afford new insights and work as a foundation to refine requirements based on the human's experience of interior space.

Little research has been done specifically in this area regarding the perception of interior space in vehicles. However, numerous studies have been conducted in the two subjects separately; perception and interior space, and roominess in vehicles. Firstly, the two areas were studied to collect knowledge of how to connect them and analyze, as well what area would be possible to include in the time frame and resources of this thesis. This are presented in the Theoretical framework chapter (2) and as limitations in this chapter under Delimitation (1.4). Specific limitations for different phases and sub-studies are presented in the Method chapter for respective study. Two studies were conducted in this research to conclude upon parameters to analyze and to find trends, different correlations, measures and angles to arrive at recommendation and guidance for how to emphasis the perception of space in design parameters.

This chapter begins with an overview of the background of the topic to provide a knowledge to understand the area which this thesis touches upon. Following this comes the problem description and the aim for this project. Listed limitations for this research are stated in the limitations followed by explaining the exploratory research questions and research questions for the different research phases. The chapter concludes with a research approach of how to reach the aim where different phases will be introduced with related sub-studies.

As an additional section, the disposition of the report will be described for you, as a reader, to be able to follow the work in a straightforward manner.

1.1 Background

Volvo Cars is a well-known and respected premium car brand with an international market. The stakeholders of the thesis outcome is the Ergonomics team within the Customer Experience Center department at Volvo Cars. The Customer Experience Centre is constantly working towards the aim of satisfy their costumers' desire of a complete car experience. The experts at the department are predicting customer expectations, behaviors and physical prerequisites to be able to provide the cars with what their customer want.

Creating sufficient headroom inside the car is crucial for customer satisfaction. The available upper interior space is directly influenced by the seating position and posture, and is therefore one important part for creating overall riding comfort. The needed upper interior space is depending on both the anthropometry of the users, determined ergonomic dimensions (SAE standards) and also users' expectations regarding type and size of vehicle, cultural differences and usage of the vehicles. Volvo Cars has identified a need to investigate the human perception of head roomi--ness, which here is defined as the upper interior space. In other words, a new way of defining the head roominess is needed as well as creating a standardized way to measure the upper interior space.

Looking into the ergonomics engineering work within the occupant packaging in vehicle design there are defined standards which the SAE International has launched that are commonly used in the vehicle industry. Three SAE papers have mainly been studied for the topic within seating posture and visibility for better understanding of relevant design parameters; SAE standard J1100 – Motor vehicle dimensions (SAE International, 2009c), SAE J1052 – Motor vehicle driver and passenger head position (SAE International, 2017) and, SAE J941 – Motor vehicle drivers' eye locations (SAE International, 2010b).

These papers will be further introduced in the Theoretical Framework, chapter 2, later in the report. However, the conclusion which was drawn after looking into the SAE standards was that only objective measures in respective areas of roominess and visibility were mentioned. A possibility of improving these guidelines was recognized and to identify common design parameters which would connect visibility with roominess. Due to a lack of knowledge and investigations based on the rear seat of the car along with less affecting parameters and complexity of investigation in this subject, compared to the front seat, the left outer-rear seat was chosen to be the fixed position of the study.

1.2 Problem Description

The main problem underlying this thesis study is that head roominess evaluation is considered as a physically measured entity of SAE standards, when it is actually a substantially a combination of physical measurement (objective) and perceived roominess which is subjective to the user.

User's personal and subjective perception is not only based on variations in anthro--pometry such as sitting height and eye position. But it is also about cognitive factors such as compensational behavior, preconception and user expectation (Yanagisawa & Miyazaki, 2019). Therefore, evaluating upper interior space should include objective and subjective analysis. Subjective parameters alter with culture and market, model of a car as well with time (e.g. trends and preferences).

One of the challenges with this thesis is how to measure the subjective perception of roominess and convert it to a objective guidance to be used in combination with the existing measures.

1.3 Project Aim

The aim is to study the perception of the upper interior space of the user. This is done by utilizing methods to identify subjective impressions and objective parameters to conclude *what* and *how* parameters affect the perception of space.

The desired result for this thesis is to create guidance and provide recommendations of how to assess and evaluate the upper interior space in the rear-outer seat of a car. This includes physical measurable design parameters with respect to the perceived roominess regarding the visibility. By developing these recommendations, the SAE standard is studied against perceptiveness and acts as supplement while designing interior spaces in a more human-centric approach.

1.4 Delimitation

Time, available resources and previous study results are considered in arriving at limitations thus defining the scope of the thesis work. Limitations for the designed user studies have also been made but are presented separately in the method chapter respectively. The major limitation regarding the whole project are presented below.

The headroom assessment is performed at Volvo Cars, as well usage of the company's own cars for evaluation. However, only cars with standard roof are used in this research due to proven impact of a panoramic roof on the perceived roominess (Bentioulis & Forsberg, 2015).

Volvo Cars' internal test persons are preferred to be used in the studies. However, other participants are involved, but all test persons fall under the category of adults, from the age of 18.

The study is performed with the Swedish population and is thereby restricted to the Swedish market.

1.5 Specification of Issue Under Investigation

This research includes the identification of parameters that influence the perceived upper interior space in the rear-outer seat. Furthermore, the identified parameters are investigated to find their relations with two differentiated groups dividing the test persons in Short and Tall. What also is investigated is the level of influence of the parameters, interdependencies between them, and the influence of preconception on the user regarding the upper interior space, among others. Based on these research areas, the recommendations consider both objective and subjective parameters to assist the design process to follow a more human-centric approach.

Several exploratory research questions (ERQ) for phase 2 and 3 are developed which are essential to elaborate on to enable conclusive recommendations in the end. The aim for all these exploratory research questions is not only to provide a basis of how the execution and methodology should focus on. But also relate to a set of questions which are the main finding, the research questions (RQ). The ERQ will be presented and answered in the respective chapters.

The thirteen research questions address back to the project aim and lead the research to desired results which are attained in the analysis part of phase 3 – the Investigation phase (chapter 7). These research questions are presented in chapter 6. Hypothesis and Research Questions, before entering phase 3 along with 6 hypotheses (H1-6) that were extracted and created from the result of phase 2, the Identification phase.

1.6 Research Approach

The research approach this project follows is divided into three main phases; Awareness, Identification and Investigation.

Phase 1: Get adequate knowledge within the subject and the research area to plan and design a relevant framework for this thesis. This first phase called Awareness is covered in the *Theoretical Framework* (chapter 2), as well in *Phase 1 – Awareness* (chapter 4) where an evaluation is designed for four cars to create awareness of parameters affecting the perceived roominess.

Phase 2: Named Identification phase, is where a qualitative user study was designed to assess important perspectives and identify the most influential parameters for the perceived roominess. In this study two car models were used where 9 experts within Customer Experience Centre were invited. Specific exploratory research questions (ERQ 2.1-2.4) were answered within this phase and acted as preparative work to design and specify the substantial study in the third phase; Investigation.

Phase 3: The purpose of phase 3, the Investigation, is to understand the impact of the influential parameters on the perceived upper interior space. A quantitative user study was conducted with 34 test persons to collect large amount of data to do statistical analyses. Five exploratory research questions (ERQ 3.1-3.5) were generated to design the user test to provide desirable data to answer the stated research questions later. In the result part of this phase is where the statistical analyses are presented (chapter 7). Description of the used statistical analyses methods are presenter in the *Research Method* (chapter 3), for better understanding of the statistical data.

1.7 Disposition of Report

This report is structured in a chronological order where the fundamental and interest--ing literature studies for this research are presented in chapter 2 *Theoretical Framework*.

All substantial research methods which are used within this thesis are described in chapter 3 *Research Method*. Afterwards will the research phases Awareness, Identification and Investigation be divided into separate chapters (4/5/7) where the method, result, discussion & conclusion will be presented individually for every research phase.

Between the second phase and the third phase chapter 6 *Hypothesis and research questions* is intended to bring clarity of what are investigated in phase 3. All hypotheses, exploratory research questions and the main research question will be presented in this chapter.

Chapter 8 *Compared Analysis* is where the results from the Investigation phase are being compared with each other to bring context to the result presented individually in chapter 7 *Phase 3 - Investigation*. Interrelationships are also identified between various findings for better understanding of the result.

In chapter 9 *Recommendation*, an extended analysis of the critical angles are developed into recommendations for acceptable angles for all parameters. This chapter will act as a concretized guidance when assessing the perceived roominess by manipulating the Vision parameters.

In chapter 10 *Discussion* the bigger discussions regarding the whole research and findings are discussed together with some ethical, social and sustainability aspects. Finally, a short and conclusive description of the main findings are described in chapter 11 *Conclusion*, ending with suggestions of future work.

2
Theoretical Framework

Relevant research papers and information with importance for this project are presented in this chapter. It starts with explaining the anthropometrics, which was of high relevance for this project, where as well the Swedish population was studied. It continues to present a study regarding the sitting posture that was the main source of inspiration for categorizing these posture in the analysis stage of phase 3 (*Sitting posture*). Furthermore, essential measurement from the SAE standards of how roominess and visibility are acknowledged in *Vehicle packaging and measuring standards*. Also, research papers about how to interpret perception and expectations are presented in *Perceived interior space*.

2.1 Anthropometrics

According to Haslegrave (2005) and Bhise (2011a), anthropometrics and biomechanics is the branch of science that deals with body measurements related to size, shape, strength, mobility, flexibility and working capacity. It is based on the fact that humans are variable in dimensions and proportions and that there is a limit of motion and applicable forces before stretching beyond the capacity of the muscles and tendons and where the human is in risk of injure herself.

Hence, the human-centric approach within the department of Customer Experience Centre, needs the knowledge of this variability to design appropriate products for the specific user. By knowing a populations anthropometrics, several dimensions and requirements for a product can be set to accommodate the user.

When studying a population's anthropometrics it reflects a normal distribution that is symmetrical about its highest point, which is used to calculate the percentile values of populations. Due to the normal distribution 50% of the population is shorter than the mean and 50% is taller, the mean can be characterize as the fiftieth percentile, abbreviated as 50th %-ile. Commonly extremes are usually determined below the fifth percentile (5th %-ile) and above ninety-fifth percentile (95th %-ile) which makes it common to design products within the range of 5th to 95th %-ile to include 90% of the population (Pheasant & Haslegrave, 2005).

Because this study aims to create guidelines and provide recommendation to accom--modate the Swedish population, Lars Hanson's research about the Swedish anthropometrics for the product and workplace design was studied (Hanson et al., 2009). In his research he investigated if the anthropometrics of the Swedish population have changed compared with data from 1969. 367 people participated, aged 18-65, representing the Swedish population. 43 anthropometrics data points where measured for 262 female and 105 males and the data was presented in different percentile values of the Swedish population.

The measure of interest for this thesis study was the sitting height. These values were used to differentiate between two data sets which were compared with each other in the the data analysis part of phase 3.

Different percentile values as well the minimum and maximum values for the sitting height covering both female and male of a Swedish population are presented in the table 2.1.

Table 2.1: Anthropometric data for the Swedish population

	Sitting Height (mm)				
	Min	**5th %ile**	**50th %ile**	**95th %ile**	**Max**
Female	773	832	892	949	993
Male	841	883	946	1006	1029

According to ISO 7250 the sitting height (erect) is a vertical distance taken from the vertex of the head to the sitting surface (Taifa & Desai, 2017). The figure below (figure 2.1) visualizes the measure.

Figure 2.1: Measuring sitting height (erect)

In the book *Bodyspace* (Pheasant & Haslegrave, 2005), four different sets of constraints were described within the anthropometrics which are usually causing conflicts between criteria: clearance, reach, posture and strength. Clearance was the constraint that was studied in this thesis, which focuses in providing sufficient space and access. These constraints are usually determined as a minimum acceptable dimension for the larger members in a population (95th %-ile and above).

2.2 Sitting Posture

During the evaluation and investigation of the result obtained from phase 3 in this research, awareness was raised on how the participants were sitting in the seat, in particular where the head was placed in relation to the head rest. In the research paper *Older children's sitting postures when riding in the rear seat* (2011a) were observed with children aged 8-13 years old. Both lateral sitting postures, fore and aft differentiation were documented and a classification system was designed. Three different head positions were identified and combined together with numerous torso position in fore and aft direction as well lateral. Thirteen different sagittal sitting posture were identified and did act as an inspiration source to how this project categorised the sitting postures together with the head positions (Sitting posture section 7.9).

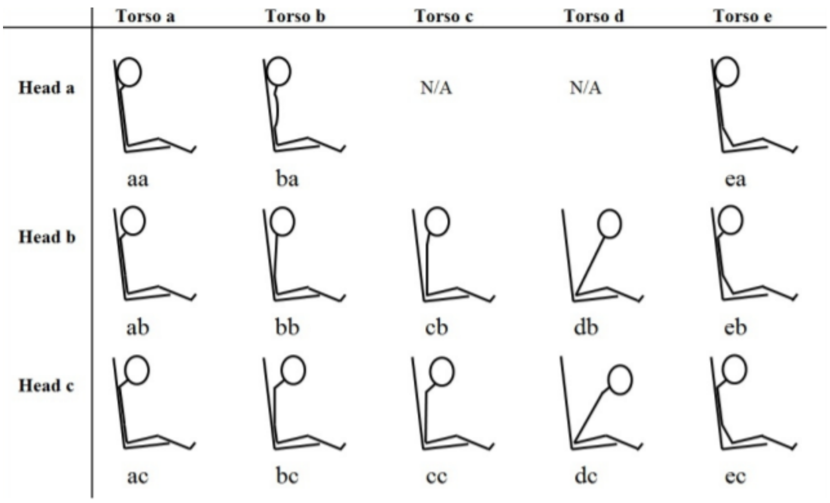


Figure 2.2: Sagittal sitting postures, reprinted from *Older children's sitting postures when riding in the rear seat*
(Jakobsson, Bohman, Stockman, Andersson, & Osvalder, 2011b)

In the figure 2.2, the 13 different sitting postures are visualized. The head position were defined in three positions; 'a' head against the head rest, 'b' head upright relative to the torso, and 'c' head leaning forward relative to the torso. When it comes to the torso position it was categorized in five position (Torso a-e). 'a' was defined as the entire back against the backrest, 'b' the entire back except shoulders are against the backrest, 'c' sitting in a upright position but is not leaning against the backrest, 'd' no contact with the backrest while the torso is leaning forward, and 'e' sitting in a slouched position without having any contact with the backrest and the lower back.

From the figure 2.2 the illustrative sitting postures' for 'aa', 'bb', 'bc' and 'ec' were used to describe the head and sitting posture of the test person in this project. However, other descriptions for these illustration as well categories were used, due to less complex analysis of the person's sitting posture. This is further described in phase 3, *Sitting posture*.

2.3 Vehicle Packaging and Measuring Standards

When talking about clearance and space in terms of a vehicle, occupant packaging is usually the term which is used to describe the placement of systems and components in the vehicle architecture. Apart from the consideration of fitting various components together, for example the powertrain, chassis, electrical components and a body (interior, climate control systems and exterior) the main focus is that the vehicle design has to accommodate the user – the driver and passengers (Gkikas, 2012).

The objective of ergonomics is the evaluation and design of the interaction between people and systems. The interaction can be in the form of physical contact, movement and cognitive interactions. In the literature "Design for ergonomics" (Tosi, 2020) the ergonomic engineering work is described as putting the user and his needs in the centre of the design process by using knowledge and methodological tools. It involves emphasis on anthropometry, biomechanics and psychology to apply the human capabilities and characteristics to design a suitable vehicle (Gkikas, 2012).

Computer Aided Design (CAD) is a tool commonly used for designing a product (Encarnação, Lindner, & Schlechtendahl, 1990). It supports the design process and the architecture of a whole product and produces information which can be accessed globally in a company. When looking into these three-dimensional graphics different design interfaces can be visualized together with defined criteria and standards.

Society of Automobile Engineers International (SAE International) is a global associ--ation leading the development of standards in the automotive, commercial-vehicle and aerospace industries (SAE International, 2020). Three technical research papers, published by the SAE, have been studied to access ergonomics standards regarding motor vehicle dimensions (SAE J1100) (2009c), head position (SAE J1052) (2017) and eye locations (SAE J941) (2010b).

The measurement standards that were considered as relevant were within the area of *Visibility of interior and exterior areas*, which study the location and movement of eye and head during gathering of visual information, and available fields of view. The other area was the *Comforable seated posture*, which studying head and shoulder room. Both areas are consider within the *Occupant packaging* which was described in Bhise book *Ergonomics in the automotive design process* (2011a). Relevant measures are presented below.

2.3.1 Seating Reference Point, SgRP

The seating reference point (SgRP) is a critical reference point which is used to position other feature and defining other important vehicle dimensions, see figure 2.3. It is established at one specific location of its designated seating positions within the range of seat up/down and fore/aft adjustment. Any other location in the travel path of the seat is referred as a designed H-point.

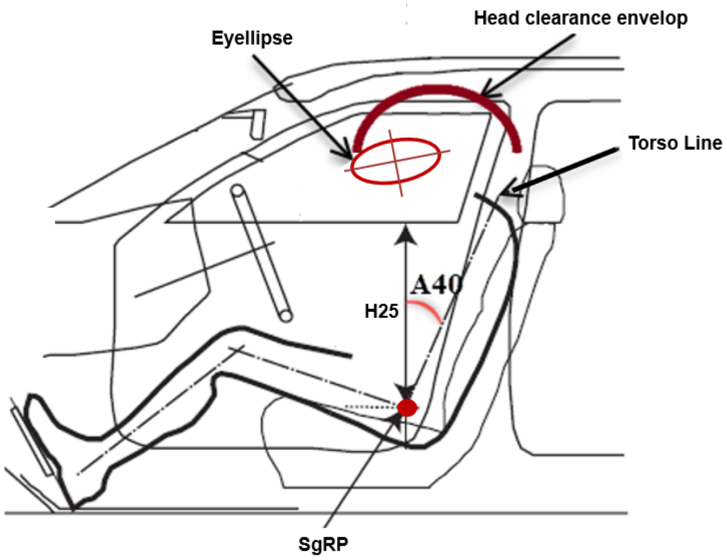


Figure 2.3: Vehicle interior measures and reference points, figure adapted from *Ergonomics in the automotive design process* (Bhise, 2011b)

2.3.2 Torso Angle, A40

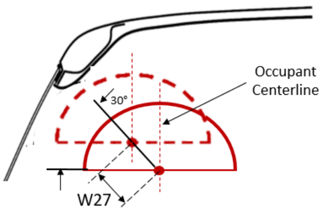
The torso angle, also defined as "back angle" (A40) is referring to a designated seating position of an angle created by the vertical line in SgRP and a line which is parallel to the back pan contour, defined as the torso line. In figure 2.3 both the torso line and A40 are presented.

2.3.3 Head Position Contour

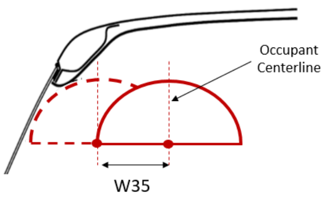
The surface of the head position contour, also called head clearance envelop, is used to help establish an upper interior space with enough room around the head with additional hair, see figure 2.3. The desired head position contour is determined by the three following factors: H-point travel path (fore/aft and up/down adjustment from SgRP), percentile value of accommodation and torso angle (A40). Once the contour is set, different views of normal cut sections are used to determine distances to interior surfaces to create directions for head clearance. The following distances are determined as head clearance measurements following the head position contour of the appropriate percentile.

Head clearance diagonal (W27)
The minimum diagonal distance, at an angle 30 degrees above horizontal, to any limiting surface in X-plane, see figure 2.4.

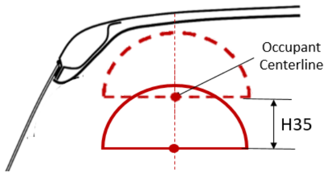
Head clearance lateral (W35)
The minimum lateral distance to any limiting surface in X-plane, see figure 2.4.



(a) W27



(b) W35



(c) H35

Figure 2.4: Rear view section(XX) showing the clearance measurements, figure adapted from *SAE Standards, J1100* (SAE International, 2009b)

Head clearance vertical (H35)
The minimum vertical shift of the head contour section to any limiting surfaces. H35 is regarding the cut on the X-plane, see figure 2.4.

Effective head room (H61)
Along a line through SgRP with a vertical angle leaning 8 degrees rear (Y-plane) creating a distance from the head contour to the first limiting surface, see figrue 2.5.

Head clearance minimum (W38)
Compared to W27 and W35 will W38 refer to the true minimum 3D distance to any surface from the head contour.

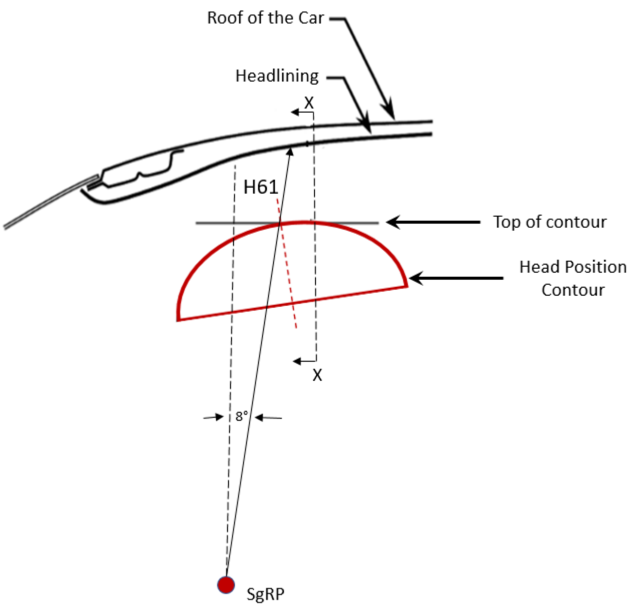


Figure 2.5: Side view (Y-plane) of head position contour with clearance measurement of H61, figure adapted from *SAE Standards, J1100* (SAE International, 2009b)

2.3.4 Belt line

The Belt line is defined by a side view (Y-plane) as the lower edge of a boundary of a transparent area on the surface of a vehicle glass assembly, also known as the design glass outline (DGO), see figure 2.6. Related measures to the Belt line is the Belt height (H25), a vertical distance from the SgRP to the bottom of the side window DGO (in X-plane). The property H25 can be seen in figure 2.3. Interior Belt height (H26) is another vertical distance but is measured from the top surface of the interior trim (excluding window seals in the inside of the car) to the SgRP.

The DGO was used when identifying the parameters Belt line and Cant rail during the research phases Identification and Investigation. Also, the manipulations for the Belt line and Cant rail had the glass outline as the reference point for the different changing levels, see figure 2.6.

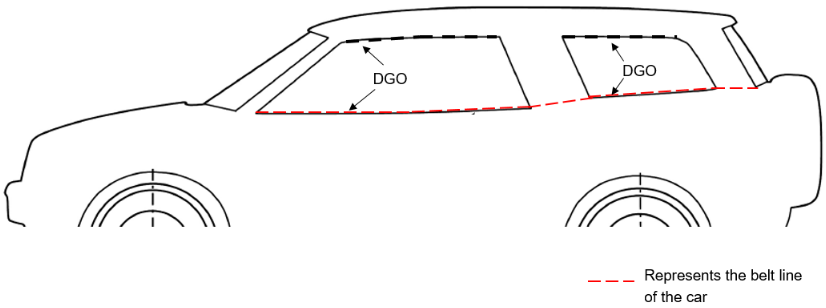


Figure 2.6: Belt line is represented along with DGO, figure adapted from *SAE Standards, J1100* (SAE International, 2009a)

2.3.5 Eye location

By locating the eyes which can be described as eyellipses, visibility analyses can be done as well determine the placement of objects to ensure adequate vision. The mid-eye centroid point which is determined between the right and left eyellipse centroids are located at the centre line of occupant (in line with the SgRP), and can be used as a reference point. In figure 2.7,the mid-eye centoid point are located on the Y-axis of the eyellipse and between the left and right eyellipses' Z/X-axis.

When determining the eye position in Investigation phase (7.1.2.2) of this study, the designed mid-eye centroid point where used as a reference point to understand the participants eye position in relationship to its environment. A side view of the eyellipse and the mid-eye centroid point in context of the car can be seen in figure 2.3.

All the measurements can be determined in different seating position; driver, second row passenger or third row. Since the study was specified to the second row, all the presented measures are referred to the second row outboard passenger on the driver side of the vehicle.

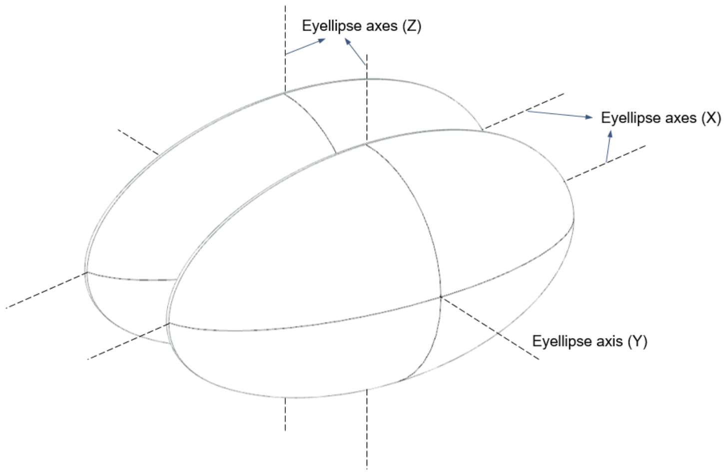


Figure 2.7: The right and left eyellipse with the mid-eye centroid point located between the ellipses, figure adapted from *SAE Standards, J941* (SAE International, 2010a)

2.4 Perceived Interior Space

In the book *Perception* (2003), Maund states perception to be a natural process by which humans understand and acquire knowledge of the objective world around them. But this process of perception is highly subjective, that it differs from person to person or differs in several occasions for the same person. Hence, study about perception would require two different views, scientific as well as philosophical. In the book *Human-Computer Interaction* (Hwang, Kim, Ahn, & Jung, 2011), it is discussed that there is a tendency for the user of the motor vehicles to perceive the interior space more as a psychological space rather than physical space. Though different cars have similar interior space by volume, they can be perceived differently due to other characteristics of the interior space. Thus it is important to study this perceived psychological space in addition to the headroom measures, which has been discussed earlier (section(2.3.3)). In the same study it was concluded that the feeling of narrowness creates a negative feeling with the users. This traces back to the necessity to create a feeling of broader space to create positive feeling among the users.

In Yanagisawa and Miyazaki's paper regarding extracting expectation effect in user-product interactions (2019) the Kano-model with the definition of Must-be and Attractive qualities are used to define design with perceived qualities. The Must-be and Attractive qualities need to be translated into engineering properties to be able to meet customers' requirements and expectations. Studying the user in a time sequence of user-product interaction a cyclic interaction of action, sensation and meaning will be performed. Inbetween the states the sensor modality is changing. For the different transition of states, the user usually predicts these in advance from previous experience as well from evaluation of the perceived qualities on perceived features. For example, by just looking at some object the person will create an assumption and expecting it to smell in a specific way, as well taste or predict its weight. Whenever the expectation does not meet the actual experience a disconfirm--ation exists and evokes feelings as dissatisfaction, disappointment or surprise. However, the level of prior expectation does affect the experience which is due to cognitive processes, for example emotions and a desire for rewards.

In Deliza and MacFie's study (1996) two patterns of expectation effect were distin--guished; *contrast* and *assimilation*. When the user is experiencing a difference between prior expectation and post perception, then *contrast* is defined as a bias that amplifies the difference; low expectation leads to a high perception. While assimilation on the other hand is a bias that diminishes the difference.

If applying these expectation effects into an example with a vehicle's size and the expectation of perceived interior space. What will happen when *contrast* occurs is that the user has a low expectation of the upper interior space due to a small car and get surprised when perceiving the space to be bigger than expected. *Assimilation* will then be when the user having high expectation of the interior space due to a big size car, and gets disappointed when perceiving it. Tolerance can also be linked with the expectation effect where in *contrast* tolerance will consequently increased and in *assimilation* decreased the perceived feature that satisfies product qualities as Must-be and Attractive.

Sensory organs play the vital role in information intake for humans, the process of perception is also predominantly governed by multiple senses, so-called perceived qualities. These senses are what evoke feelings, impressions and emotions toward a specific matter (Yanagisawa & Miyazaki, 2019). However, in the book *The enigma of perception* (2013) Maclachlan mentions that vision and audition to be the dominating senses for perception and other senses can be used to confirm the initial perception through vision or audition. But this can change based on the environment in which the user is present and senses that provide more information are prioritized.

From this discussion the perception of the upper interior space in a car is dominated by the visual sense; the eyes. The upper interior space inside the car is affected by the space around the head, which is constrained by the surrounding objects (features of the car interior). Also, theoretically as mentioned in (2.3.3), headroom is the measure of distance and it can be perceived by accessing the distance to this surrounding object.

Perception of real spaces depends on a pictorial cues to provide information about the distance from the user. These cues specifically affecting size and distance are called depth cues. In an article discussing perception of hedonic attributes (Lageat, Czellar, & Laurent, 2003) depth cues are explained together with four important cues; occlusion, relative size, height in visual field and aerial perspective. These cues can be extended to the interior of the car to understand the perception of headroom. However studying these cues were not included in the thesis study since it would be too big of a research scope if also addressing these parameters.

In the experimental study done by Yang et al. (2015), the authors have aimed to improve perceived roominess by applying principles of optical illusions to specific interior car parts. As a result of their study, they have concluded that perspective, geometric, and concave/convex illusions can be used to improve the perceived roomi--ness in the car. But the optical illusions have to be applied to the parameters that affect the headroom and these parameters can change with different cars. Hence, the thesis study constrained in identifying the parameters that affect the headroom and their subjective relation to the users.

In a thesis study done previously at Volvo Cars (2015), Bentioulis and Forsberg conducted the evaluation of headroom in three different cars. As a result of their subjective study, it was concluded that the panoramic roof had improved the percep--tion of the headroom. Important discussion is that the measured vertical headroom in the panoramic roof car was less than the car with no panoramic roof. However the presence of panoramic roof had positively improved the perceptive head roominess. The users felt that the presence of panoramic roof made the space airier and lighter and improved the roominess.Bentioulis and Forsberg have also said that it may be due to the reason that the panoramic roof had let more light inside the car, in the essence to improve the feeling of space. By this argument we can arrive at other important factors that affect the perception of roominess to be lighting and colour in the interior space of the car.

Manav and Yener have also studied the effect of lighting in the spatial arrangement (1999). They discussed that the measure of illuminance inside the car affected the roominess feeling for the users. Since there were conclusive evidence from previous study and literature, it was decided to not include the panoramic roof in the study. The lighting was kept constant by performing the study in a controlled indoor environment.

3

Research Method

The research approach of the thesis was divided into three phases. These phases required to adapt different research design approaches to arrive at the intended results of the phase. Some phase adopted only a single research design, and some used a combination of several research designs. The research designs, statistics related methods and the appropriate tools that were used are stated and explained in this chapter.

3.1 Qualitative Research Design

Due to the new research area where there was a lack of theoretical paradigms describing the perceived roominess in a vehicle it was necessary to establish and develop a set of working theories. In the book *Global Research Design* (Darian-Smith & McCarty, 2017), it is stated that an exploratory research would then be the approach to be employed to produce useful knowledge. In another research paper the author relates this approach to a flexible design of how the data collection is gathered. The role of the researcher is described as an *"instrument of data collection"* hence to be skilled to absorb new information quickly, be adaptive and flexible to intervene with new interesting aspects or unexpected issues (Boeren, 2015).

Qualitative methods are usually associated with a flexible design and are used in exploratory researches. In Check and Schutt's book *Research Methods in Education* (Check & Schutt, 2011), qualitative methods are described to *"capture educational reality"* and where the subjectivity and the experience of the participants are the focus points. It is about understanding what the participants really felt or did at some point in time. Furthermore, focus groups, participant observations and intensive interviewing are activities referred to qualitative methods. Analyzing raw qualitative data usually means study words, expressions and texts, where there is no existing formula of how to transform the data into findings though unique for every inquirer. Small-scale of data and participants is enough to achieve desired results, hence qualitative data analysis should *"focus on meanings rather than on quantifiable phenomena"* and *"collection of many data on a few cases"* (Denzin & Lincoln, 2002).

Phase 1 and 2; Awareness (chapter 4) and Identification (chapter 5), was aimed to gain knowledge and were both designed to be an exploratory research. However, it was in phase 2, Identification, where a qualitative study was conducted. The test persons' expressions and words were studied and were used to identify influential parameters.

3.2 Quantitative Research Design

Compare to the qualitative data analysis quantitative analysis are more focused on the numbers rather than interpret figures and subjective matters. Quantitative research is utilized to confirm assumptions and theories, hence being theory driven (Bhandari, 2020). Hypotheses are commonly stated in advance and tested in a quantitative research design. It falls under methods that are used during explanatory researches to explain and predict existing theories (Darian-Smith & McCarty, 2017). The higher aim with the explanatory research would be to provide new insights and challenge existing theory. In Boeren's research paper she presents that quantitative research design also falls under a fixed term where the data collection process would be considered to not be flexible for the researcher to intervene (Boeren, 2015).

Furthermore, it is a strict design with a fixed approach with a probability sampling (random sampling). In order to present representativeness in the result, unbiased representation of the subject/population probability sampling is needed (further presented in section 3.2.1). It was also discussed that the probability sampling is not achievable with a small-scale survey, though require a large data collection with many respondents. Moreover, quantitative data analysis can also be associated with statistical techniques to determine variation in numerical measures as well relationships between two or more variables (Check & Schutt, 2011). Example of statistical analysis which can be done are cluster analysis, frequency distributions, measures of central tendency, correlation coefficient and reliability tests.

Phase 3, Investigation, incorporated the use of a explanatory research design to do statistical analyses to investigate the formulated hypothesis and research questions. Significant number of test persons were involved in the study and the collected data was processed to arrive at results.

3.2.1 Random Sampling of Test Runs

Considered to be an important sampling method is the simple random sample. In an experimental setting, a simple random sample of size n is obtained when items are selected from a fixed population or a process in a way that every group of items of size n has an equal chance of being selected as the sample (Mason, Gunst, & Hess, 2003). In addition to its use in the sampling of observations from a population, simple random sampling has another important application in the subject of scientific and engineering experiments. Among the more prominent uses of simple random sampling in experimental work are the selection of experimental units and the randomization of test runs. By adhering the concept of simple random sample, all the test persons were tested with a fixed set of test setups but in a randomized test run (Mason et al., 2003). The main goal of this test run sampling is to eliminate the effect of biasing and clustering.

The authors of journal *Handbook of medical imaging* (Van Metter, 2000), had discussed upon the importance of presenting the various test setups in random while conducting a subjective test. This random sampling of the test setups was stressed in order to avoid bias of the users during rating in subjective assessments.

3.3 Interview Approach

Three commonly known interview approaches are structured, unstructured and semi-structured interviews which are used in different scenarios and research approach--es. During this project a semi-structured interview has been conducted to extract important findings during the Identification phase. While a more structured interview approach was conducted in the third phase, Investigation, to fit the quantitative research design.

What differentiate the interview approach is mainly the kind of questions that are to be asked during the interview. Closed-end and open- -ended questions are distinguished where closed-ended questions are used in structured interviews, also called standardized interviews. The questioner/interview is rather strict and not deviating between respondents and are used for larger sample groups. While open-ended questions are used to allow extended probing and where the interview is very flexible to be able to make the interview more personalized (Adams, 2015).

Unstructured interviews are characterized with mainly open-ended questions. The advantage with this approach is that the interview becomes more casual and free--flowing hence creating a relaxed environment for the interviewee and as well obtain honest answers with inductive reasoning (Boeren, 2015). Disadvantages will then be that it is a time-consuming approach where the interview takes time as well the analysing in the end. The approach does also require interviewer sophistication and techniques to be able to create an environment for the interviewee to open him-/herself up and keep the conversation within the topic (Adams, 2015). In one of Leech's article where he presents different techniques when asking interview questions, he recommends the interviewer to be professional and generally knowledge--able. But in some cases on the particular topic of the interview the interviewer should act less knowledgeable than the interviewee (Leech, 2002). Leading, presuming, loaded and double-barrelled questions are stated in the article to avoid. Furthermore, the interview and setting are aimed to be pleasant and neutral to make the respondent comfortable.

Semi-structured interviews are following what is called an interview guide which is creating an outline of the planned topic where some questions are prepared (Adams, 2015). In this way it follows a bit of a structured interview, however in a semi-structured interview it is allowed to ask follow-up questions which makes it also following an unstructured interview approach (Leech, 2002). With this approach the data can be more easily compared between the respondents comparing to unstructured interviews and its data where objective comparison of data is not possible (Pollock, 2019).

3.4 Measurement Scales

For the three phases of the research approach appropriate tools were used. One such important tool was the scales. Different scales were used to measure the perception of upper interior space as in a feedback from the test participants. The scales also served as an input medium to receive intended data from the test persons that were later used in the analysis. The various scales that were used in the different phases of the research are explained in this chapter.

3.4.1 Visual Analogue Scale

Visual Analogue Scale (VAS) is used to gather information about internal feelings, perceptions, or sensations that are difficult to measure. It is for example a very popular tool to use to assess pain intensity (Eliav & Gracely, 2008).

The VAS takes a form of a linear line anchored at both ends with the two extremes of the attributes to be assessed. Several authors have discussed the length of the line used in VAS to be 100 mm as satisfactory (Eliav & Gracely, 2008) (Briggs & Closs, 1999). Hence the same length was applied to develop the VAS used in this evaluation during the Investigation phase. The line was then anchored with *"Very narrow"* on the left end and *"Very spacious"* on the other side (Figure 3.1). It was then used to indicate how the respondent was perceiving the upper interior space by placing a marker somewhere on the line. A ruler is commonly used to determine the score from where the marker is placed to the end of the line (Lazaridou, Elbaridi, Edwards, & Berde, 2018).

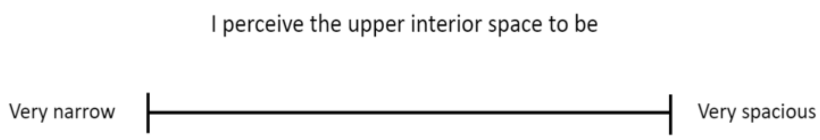


Figure 3.1: The Visual Analogue Scale with anchoring words used in the Investigation phase

Due to working with multidimensional experience it is an advantage to work with a VAS compared to a scale with predefined intervals (Lee & Kieckhefer, 1989). Another benefit of the VAS is that the scores have the qualities of ratio data and can be used in statistical studies(Correll, 2007). Furthermore, the VAS has large number of response categories when compared to other measuring scales, for example the Verbal Rating Scale. This means that it can avoid confusion of the choice of descriptive words and provides accurate data about the test person's subjective opinion. The scale is sensitive to changes and is simple to use which are seen as beneficial properties (Caballero, Trugo, & Finglas, 2003).

One of the disadvantages with this method is that it is too simple for some people, making it difficult to find a correlated answer on the line translating a multidimensional experience (Briggs & Closs, 1999). Another troublesome characteristic is that the VAS is having top ceiling, which makes it difficult for a participant to document an even worse experience if the upper-end is already used (Correll, 2007).

3.4.2 Verbal Rating Scale

Verbal rating scale (VRS) is another subjective method which is commonly used to measure pain as well attitude (Lazaridou et al., 2018) (Roberts, 1997). What is distinguishing VRS form other subjective scales is that descriptive adjectives are used to determine and describe different levels of what is called an item. Two different approaches are usually presented when designing a VRS, the Thurstone (Thurstone & Chave, 1929) and Likert (Likert, 1932).

The difference between them is that Likert's approach is a multi-item scale which refer to a statement or research question as an item and having a standardized way of measuring the respond to these statement with levels of agreement/approval and disagreement/disapproval (Bartikowski, Kamei, & Chandon, 2010). While Thurstone approach, a calibrated verbal rating scale, is a more extensive scale which is unique to every question, hence appropriate items needs to be determined to cover a full attitudinal continuum. What is called as a calibration phase is required for a Thurstone scale to not only determine appropriate items for indicating different levels but as well construct an equivalence of internal-level. Comparing Thurstone and Likert scale between each other, Likert's scale is more commonly used in surveys due to the ease of use. But Thurstone is however a valid and reliable method that are supported with empirical data which Likert's method is lacking (Likert, 1932) (Bartikowski et al., 2010).

Furthermore, discussing the advantages and disadvantages, VRS are most used due to the high compliance rate while being easy to use, interpret and administer for different application and responder (Hjermstad et al., 2011). Disadvantages might then be the distinctive categories that can be rather discriminative for senses and being less sensitive to changes compare to a Visual Analouge Scale. Due to using descriptive words the VRS is dependent on the patient ability to read as well interpret the words. This might cause error and inconsistency in the result.

3.4.3 Numerical Rating Scale

If comparing a Numerical Rating Scale (NRS) with the already described scales (VAS and VRS), NRS would be considered as the simplest scale method. With just having a series of numbers, written in ascending order, together with some anchoring descriptive words on both ends of the scale to represent the best and worst scenario, it is easy understood and administered as well having cross-cultural validity to it (Selvaratnam, Niere, & Zuluaga, 2009) (Roberts, 1997) (Brunelli et al., 2010).

By having eleven levels it can be compared to have the same sensitivity as a VAS and acknowledge small changes (Brunelli et al., 2010). Other advantages with NRS is that the method has a well-documented validity and correlates positively with other measures (Roberts, 1997). It can be used for all ages, from a young age as 5 years old to elderly. The main disadvantage with NRS is that it does not have ratio qualities, similar problems as VRS (Thurstone approach). In other words, if comparing the numerical interval between 2-4 and 7-9, even if the interval is numerically equal, it may not represent equivalent intervals in terms of scaling the intensity of the subjective feeling (Lazaridou et al., 2018) (Selvaratnam et al., 2009).

3.5 Paired Comparison

According to Stone, Bleibaum, and Thomas, paired comparison is the first developed method to access preference (2012). Further described in Iijima et al.'s research paper (2020), a paired comparison method is considered to have a quality to identify the hierarchy of personal values hence comparing values to one another. While evaluating products, the test involves one or more pairs of products and the respondent may evaluate one or more pairs of samples.

The test is extensively used in the area of test design, statistical analysis and mathematical models (Stone et al., 2012). Explained in Ljubuncic book *Problem-Solving in High Performance Computing* (Ljubuncic, 2015) the amount of binary comparisons of N elements would be determined by using following equation:

$$x(N) = N(N-1)/2 \tag{3.1}$$

Bradley and Terry discussed about the flexibility of this test procedure in subjective testing in their research paper (1952). By using this procedure, it can be assumed that the standards of judging is uniform, eliminating respond style bias while ranking the preferences in a comparative nature (Bradley & Terry, 1952). Due to this reason the method was used in the thesis study when studying the influence of various parameters affecting the upper interior space by ranking them in the order of influence in phase 2 and 3's user test.

Moreover, this method provided a structural test procedure considering the high number of parameters without making it difficult for the test person since they had to compare all of them mentally, assuming weighted score before providing the ranking to them. Using this method two parameters were compared at a given instance of time, for which the test person must give their preference based on the question *"Which of these two options is more important"*. At the end of the test, every parameter was compared with each other and based on aggregation, the final ranked list of parameters was obtained.

3.6 Analysis of Statistical Data

A quantitative approach was taken for phase 3 that required processing of data to arrive at statistical results. The following section contains the methodology that was used to handle the data and to process it. Also, several statistical concepts were adopted that included predictive tests, hypothesis tests and use of standard coefficient. These are stated and explained in this part to create a clear view of how they were used and when they were used in the analysis of the data in phase 3.

3.6.1 Data Analysis Methodology

Due to a large possession of data after the quantitative user study in the Investigation phase a structured methodology was required to handle the data. The data analysis process as explained by Huber in the book *Data Analysis: What Can Be Learned from the Past 50 Years* (2012) was adopted as the data analysis process. This procedure guided to handle the data and provided a step by step process to analyse it.

Table 3.1: The data analysis process with the purpose of the steps

Step Number	**Step**	**Purpose**
1	Identification	To get familiar with the new dataset, quality control including identifying distributions, outliers, clusters and preliminary error checking
2	Error Checking	Checking for errors including plausibility and consistency checking of data and the dataset
3	Modification	Arriving at derived dataset, preparation of the data for the upcoming analysis and simulations
4	Comparison	Comparison of data and a relevant model. In case of moderate sized samples, serves as signal to avoid over-interpretation of data
5	Modelling and Model Fitting	Modelling of the data for the purpose to interface in data analysis packages
6	Simulation	To create simulated data, prepare synthetic datasets and to analyse them, if required
7	What-If analysis	Includes analysis that are alternatives based on theory, amended dataset or subset
8	Interpretation	Quantification of conclusions based on theoritical values (P-values, significance levels, co-efficients, etc.)
9	Presentation of Conclusion	Presentation of the results from the above mentioned steps in a chronological way that is more appropriate for the analysis work

The data analysis process as discussed by Huber is summarized in the below table 3.1 and the purpose of each steps are explained against it. It is also stated that the below-mentioned steps are more of a common approach and some steps can be revised or skipped based on the purpose of the data analysis.

3.6.2 Continuous Data

Before doing any statistical data analysis an understanding of the collected data was needed to know what kind of analysis was able to be done. This also provides a basic understanding in choosing the test types that holds valid for the specific type of data.

Numerical data is divided into being discrete or continuous data. The distinct difference of them is that discrete data is values that can be counted and can take only the possible or finite values, e.g. number of heads while tossing a coin for 10 times. While for continuous data, the possible values cannot be counted and can be described only as intervals on the real number line, e.g. the height of a person measured in mm (Rumsey-Johnson, 2011).

Thus, the data collected during the user test in the Investigation phase (measuring Spatial distances and the VAS rating of the perceived upper interior space) fall under the data category of numerical continuous data. Hence be used in statistical analysis or tests that require the data to be numerical and continuous in nature.

3.6.3 P-value

The probability value, P-value, is the measure of significance of the results obtained from hypothesis tests. All hypothesis tests use the P-value to determine the strength of the result to provide statistical evidence. In hypothesis test, the claim is considered as the null hypothesis (H0) and its validity is tested against the alternative hypothesis (H1) which is the opposite of the null hypothesis. The P-value takes up a number between 0-1, and determines which hypotheses stays true for the selected data (McCormick, Salcedo, & Poh, 2015).

- For P-value less than 0.05 (<0.05) indicates statistically significant. It exists strong evidence against the null hypothesis (H0), hence be rejected. Therefore H1 will be accepted.

- For P-value higher than 0.05 (>0.05) means not statistically significant. It exists strong evidence for the null hypothesis (H0), hence H0 can be claimed to be true and the H1 is rejected.

The same interpretation of the P-value was used in all hypotheses testing and the same being followed in the hypothesis tests for this thesis.

3.6.4 Anderson-Darling Test for Normality

The Anderson-Darling normality test is used to determine the normality of the curve which fits a particular data set. This test gives the degree of approximation to which curve would represent a normal curve. The cumulative distribution function for the data set is numerically compared with that for a fitted normal curve. The inference that can be drawn from the Anderson-Darling test is based on the following hypotheses:

- H0: Data follow a normal distribution

- H1: Data do not follow a normal distribution

For H0 to be true, the P-value obtained from the test should be greater than 0.05. This value of P (P>0.05) makes H0 true and denotes the curve follows normal distribution. When P-value is less than 0.05, the H0 becomes invalid and H1 is true, denoting the curve does not follows normal distribution.

The main aim for doing this test is to check the distribution of the test population and compare it with the Swedish population. One another use is to understand the data distribution so that it can be used for statistical analysis that requires the data to be normally distributed.

3.6.5 2-sample T-Test

The 2-sample t-test (classical) is a hypothesis test determining the difference of two population group's data based on the 95% Confidence Interval (CI). The test considers standard deviation (StDev) of the population sample and standard error based on confidence intervals to calculate the t-value.

Based on obtained t-value and CI, the P-value for the hypothesis testing is determined. The test can be used to differentiate two population groups based on mean value of a specific data, e.g. if the two population groups differ based on their body height.

The hypotheses for the 2-sample t-test is:

- H0: µ1-µ2 equal to 0

- H1: µ1-µ2 not equal to 0

Where $\mu 1$ and $\mu 2$ are the mean values of the data pertaining to the two population groups.

For H0 to be true, the P-value obtained from the test should be greater than 0.05. This means that µ1 and µ2 are similar and there is no statistical evidence for the two mean values to be difference. On the other hand, if P<0.05 then H0 becomes invalid and H1 becomes true. This means that the two population groups have statistically different mean values.

However, to be able to run a 2-sample t-test the following stated assumptions need to be true for the tested data.

1. The data are continuous (not discrete).

2. The data follow the normal probability distribution.

3. The variances of the two populations are equal. (If not, the Aspin-Welch Unequal-Variance test should be used.)

4. The two samples are independent. There is no relationship between the individuals in one sample as compared to the other (as there is in the paired t-test).

5. Both samples are simple random samples from their respective populations. Each individual in the population has an equal probability of being selected in the sample.

The data used in this project had satisfied all the assumptions (refer section 7.4.2), except the variances of the two population to be equal. For this, the variances had to be checked before proceeding with classical 2-sample t-test or the Aspin-Welch test should be used. But on default, Minitab-19 uses Aspin-Welch for all 2-sample t-tests for the results. When the assumptions for the classical 2-sample t-test are true, Welch's t-test performs as well or nearly as well as the classical 2-sample t-test (Welch, 1938) (Welch, 1951). Hence, the 2-sample t test using minitab 19 ((*2-sample t-test*, 2017)) provides similar result as classical 2 sample t test and holds good in determining the difference of two population means, without checking the variances of the two population's data.

3.6.6 Pearson Correlation Coefficient

The Bravais–Pearson correlation coefficient, commonly known as the Pearson Cor--relation Coefficient, is a parametric test that can measure the strength and the direction relationship between two variables. These variables are values measured on an interval, ratio, or absolute scale. Pearson denotes the linear correlation between the two variables and cannot be extended to establish non-linear correlations such as quadratic or orthogonal (Spearman's Correlation). It must be noted that the two variables have to be continuous in order to use this test (Mendes, 2007).

In the book *Introduction to Statistics and Data Analysis* (2016) Pearson correlation was explained with the help of scatter plots. With the discussion by the authors, Heumann and Schomaker, upon the coefficient values the inference is summarised in table 3.2.

Table 3.2: The inference for respective Pearson's correlation coefficients

S.No	Pearson's Correlation Coefficient, r	Inference
1	Positive r	Positive and increasing correlation
2	Negative r	Negative and decreasing correlation
3	1	Perfect correlation
4	>0.7	High to very high correlation
5	0.5 - 0.7	Moderate to high correlation
6	<0.5	Low correlation to no correlation

The values in table 3.2 was used to establish the correlation between various variables in this thesis work.

3.6.7 Crobach's Alpha Test

The data collected during the user test were both subjective (VAS scale) and objective (measurement of vertical, diagonal and lateral distance). Reuzel et.al have mentioned that both measures should be considered as approaches and methods used for these measures features its own definition of reliability (Moret, Reuzel, Van Der Wilt, & Grin, 2007).The reliability of using VAS scale to assess the user's perception was not a established method and hence required detailed study. Also, the results of the thesis work was dependent on the user's rating on the VAS scale and hence it was important to understand the reliability in using the VAS scale.

To test the reliability of the test persons' rating of the upper interior space in use of a VAS, the method of Test-Retest was used. Raykov and Marcoulides explain the Test-Retest method as the methodology for reliability testing where the degree of repeatability of the test scores is used. A single form of test is repeated more than one time, to access the repeatability of the test persons (internal consistency) (Raykov & Marcoulides, 2010).

In the same article the authors discuss the use of Cronbach's alpha test in the reliability measurement while using a subjective scale. Hence the Cronbach's alpha test was used as the reliability test to assess the internal consistency while rating the upper interior space on the Visual Analogue Scale.

Cronbach's alpha can be calculated by different methods such as split-half, Pearson correlations, using covariance matrix (Zeller, 2005). Minitab-19 uses the covariance method to arrive at the alpha value and the formula of Cronbach's alpha for all items is calculated as follows:

$$\frac{k}{k-1}\left[1-\frac{\sum_{i=1}^{k} Si^2}{S_T^2}\right] \tag{3.2}$$

where, S are the variances, k is the number of items in the analysis and T is the total scores.

The value of alpha varies from 0 to 1 and from the discussion made by Raykov and Marcoulides, the alpha is an index of the internal consistency, i.e. higher the value of alpha, higher is the internal consistency and higher the reliability (Raykov & Marcoulides, 2010). Zeller mentions in her article (2005) a rule of thumb for the reliability measures based on Cronbach's alpha value which is listed below. But these values do not stress upon the applicability for data extracted from a VAS.

- 0.9 or higher are considered excellent
- 0.8 to 0.9 are adequate
- 0.7 to 0.8 are marginal
- 0.6 to 0.07 are seriously suspect
- less than 0.6 are totally unacceptable

Minitab-19 support had suggested an alpha value of >0,7 to be a benchmark for consistency. Additionally, from the results of the test done on the support website (*Interpret the key results for Item Analysis*, 2019) the values of alpha greater than 0.7 has been accepted to have a good internal consistency. Hence the value of alpha greater than 0.7 was considered the benchmark value to have good internal consistency.

4
Phase 1 - Awareness

The intention for this first phase was to acquire better understanding of the topic and to get a first perception of what parameters affect the perceived interior space. An exploratory study was set up and are described in the method section. A list of identified parameters is presented in the result as an outcome of the study which is followed by a discussion and conclusion determining what parameters to study and control.

4.1 Method

For a better understanding of the topic and to get a first perception of what parameters affect the perceived interior space. Four different cars were utilized to provide awareness and knowledge; a wagon (V90), a sedan (S60) and a small and a big SUV (XC40/XC90). These cars were of different kind in model and the interior spaces were not alike. For example, some had light interior trim and other had dark, some had a panoramic roof and the ones which had were in various sizes.

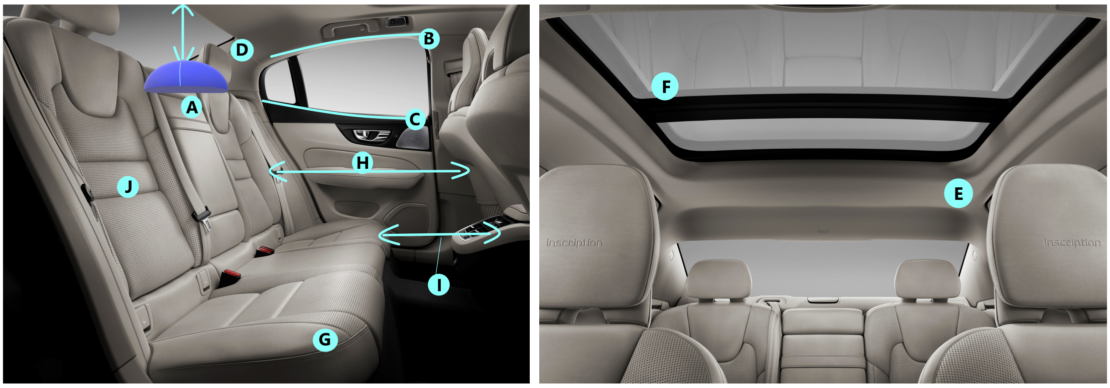
To identify some parameters all the cars were evaluated in roominess and were also compared between each other in an outdoor environment. Fifteen to twenty minutes were spent in every car during the evaluation. By doing this some parameters were concluded to be limited from investigation and as well be fixed. Investigation of noise and other parameters which could disturb and cause variance in results were also studied.

4.2 Result

Four cars (V90/S60/XC40/XC90) from different car segments were evaluated in roominess hence identify parameters which had an influence on the perceived interior space. Following parameters were identified as influential in the rear-outer seat. Some of them was identified as a SAE measurement, which has been described in chapter 2. *Theoretical Framework* and are put in between parentheses. Figure 4.1 helps to identify the parameters inside a car.

- A - Vertical distance to headlining (H35)
- B - Cant rail height and shape (DGO/W35/W38)
- C - Belt line height (H26)
- D - C-pillar position

- E - Roof details (W38)
- F - Panorama roof and size
- G - Interior trim colour
- H - Distance to front seat
- I - Knee roominess
- J - Seating position (A40/Eye location)



(a) Side view on the rear seat of a car **(b)** Front view inside a car

Figure 4.1: Visualizing the listed parameters A-J
Adapted from Volvo Cars Press Material (Volvo Cars, 2020)

4.3 Discussion and Conclusion

Due to already proven data that the presence of a panorama roof (Bentioulis & Forsberg, 2015), as well with a lighter colour of the interior trim have a positive influence on the perceived roominess (Manav & Yener, 1999), these parameters was chosen not to be studied.

To be able to provide reliable data with small variances and focusing on the interesting parameters, the seat position in the rear-outer seat as well the distance from the front seat was set to fixed parameters, in SgRP. Furthermore, for the user tests in this project, indoor environment was recommended hence controllable lightning.

5

Phase 2 - Identification

During the second phase, defined as the Identification phase, a qualitative study was conducted to understand and identify the parameters which affect the upper interior space in a car. Experts from the Customer Experience Center at Volvo Cars were involved to get their opinions and knowledge about what parameters they identify as important. A first assessment about a person's expectation and how it affects the experience was also included in the study. In this chapter the set-up of the study is explained together with the result. But to begin with the exploratory research questions for this phase will be presented.

5.1 Method

To understand and identify the parameters that affect a person's perception and feeling about the interior space in a car, a qualitative study was designed to identify and scrutinize the most affecting parameters. The study was arranged with experts from the Customer Experience Center department to gather qualitative data and information that could reflect upon how they evaluate cars in their daily work. Nine experts took part of the study where all of them went through about the same test procedure.

The main purpose of this study was to identify the most influential parameters which affects the perception of interior space. However, another interesting aspect regarding a person's expectation and preconception where included when designing the study. This was to find out if a person's preconception of a car influence the perceived roominess. For this purpose two types of cars were used. By making the test person to experience two different interior space environments parameters can be compared and generate a comparable analysis of the impact they create.

Four exploratory research questions (ERQ) were generated for this phase that helped to design a suitable user test to provide answers to these questions that follows.

ERQ 2.1: Which are the subjectively perceived parameters?

ERQ 2.2: Which parameters can be measured physically?

ERQ 2.3: Does a person's preconception of the car influence on the perceived interior space (expectation vs experience)?

ERQ 2.4: Which parameters have the largest impact on the perceived upper interior space?

5.1.1 User Study - Identification

For this user study two cars with different interior design were required but with the same interior level and interior trim colour. A XC60 and a S60 were chosen for this test with dark/black interior trim with panorama roof closed. The driver seat (the seat in front of the test person) was set in SgRP (design position) which was a fixed parameter for all participants. The user test took place in an indoor environment with good lightning which could be controlled and set the same for all the participants to create the same condition.

A semi-structured interview approach was conducted. The test was led by two people, one who was leading the study (test leader) and another one who was documenting (assistant). An excel sheet was prepared with questions, answer options and columns for documentation. The documentation sheet can be found in Appendix B. The assistant was seated together with the test person in the rear seat, behind the test leader who was seated in the passenger seat in the front. This was due to attaining a natural position for the test person and not create constrained posture while communicating with the person.

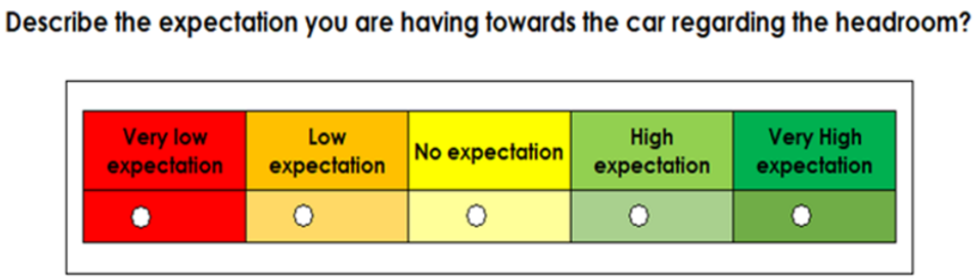
While the test person was seated behind the driver seat in the rear seat a GoPro camera was mounted on the head rest of the driver seat to film the whole study. Additionally, another GoPro was mounted on the opposite side window of the test person to capture his/her sitting posture. Both the cameras' setting was set to video record and took picture in linear view. Furthermore, the test was also recorded to be able to transcript missed information. Consent to document the user test was given from the test person before starting the study by signing a GDPR. For some questions during the user study the test person was asked to select an option from a verbal rating scale (VRS) with five levels and from a mixed scale, between a verbal rating scale (VRS) and a numerical rating scale (NRS), see figure 5.1. These scales were printed out to visualize and aid the selection process.

By the end of the test a mobile application was used to generate a list of relative comparison between two parameters. The method is called paired comparison and was made using the application "Pairwise Comparison", available in Google Playstore.

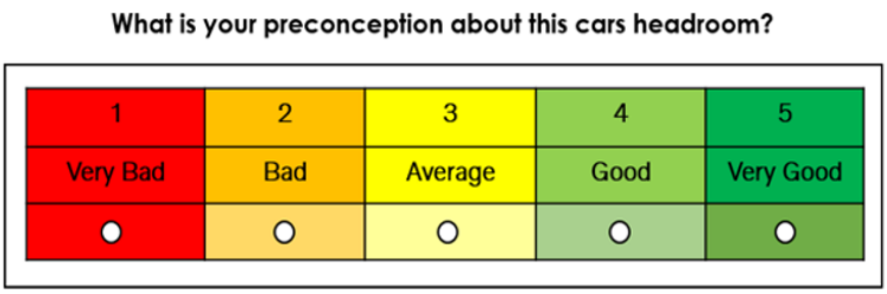
The whole user study took approximately 30 minutes per participant and was divided into two parts; 1. Expectation of the car and 2. Parameters. These are described in the next coming sections.

5.1.2 Expectation of the Car

To understand a person's expectation and later the experience of a product and how the expectation effect changes the dis-confirmation and the emotions it brings with it (Yanagisawa & Miyazaki, 2019), the first part of the qualitative study was designed to understand these factors with the test person. Before entering the cars, S60/XC60, the participant was asked to describe his/her expectation towards the car regarding the upper interior space and what that correspond in roominess. The corresponding answer was given on a five-level VRS where the participant could set their expectation from *"Very low expectation"* to *"Very high expectation"*. Moreover, the preconception about the interior space could be set to be *"Very bad"* to *"Very good"*. The two scales are presented in the figure 5.1.



(a) five level VRS scale



(b) mixed VRS/NRS

Figure 5.1: Visualizing the VRS and NRS scale when assessing the expectation and preconception of the interior space

To understand where the test person's expectation came from, whether it was from previous experiences and interaction with the car or by self-created preconception, the test person was asked if she/he has been seated in the car before, especially in the rear seat. Once entered the car and after been asked to give a general rating of the car's interior space, the test leader asked if his/her expectation was met.

The selection of what car the test person entered first was randomized between the people to be able to tell if the initial experience of a type of car influence the next car's experience of interior space

5.1.3 Parameters

The main focus with this study was to understand which parameters were affecting a person's perception of the upper interior space. Hence used two types of car where the test person experienced two different kind of interior space and compared it with one another, identifying parameters would be easier and noticeable.

Before the investigating the affecting parameters of the upper interior space experience in the cars, the test person was asked to score their general feeling about the interior space. Even here the five-level VRS was used once the test person entered the car and was being seated comfortably by their own choice with the seat belt on. The scale had the levels: *"1. Very bad"*, *"2. Bad"*, *"3. Average"*, *"4. Good"* and lastly *"5. Very good"*. Furthermore, the test person was asked to elaborate upon the given rating and try to identify parameters that has an impact on the perceived upper interior space. When the test person was finished with the analysis the person was once again asked to rate the interior space to see if their initial rating has changed. They could then choose from *"1. Much worse"* to *"5. Much better"* on a five-level scale, where the middle level was *"3. Same"*. Figure 5.2 presents the question and the five-level VRS.

How will you score the head roominess after your evaluation compared to when you first entered the car?

1	2	3	4	5
Much worse	Worse	Same	Better	Much better
○	○	○	○	○

Figure 5.2: The question which is asked in the end of an analysis of a car and the five level VRS

The procedure was performed twice due to two cars. In a final stage the test person used the mobile application "Pairwise Comparison" to rank the parameters accordingly to what they felt had a prominent affect in how they perceived the upper interior space from their experience of the two cars. Hence working with several parameters at the same time a paired comparison method with relative ranking was chosen. By just comparing two parameters at once lessen the confusion in interpreting the result of a subjective judgment of several parameters.

Depending on the number of parameters *(N)* the test person had to work with *N*(N-1)/2* comparisons and choose the parameter which has bigger impact in how the person perceived the upper interior space. The number of parameters were kept around 8 which created 28 comparisons. As an end product a ranked list of the parameters was generated from the application which was needed to get approved by the test person if any changes wish to be made.

5.2 Result

From the study, data was gathered regarding both the parameters and the expectation which was analyzed in a higher level to find answers for the stated exploratory research questions. Nine participants, all experts within the Customer Experience Center, took part of the study; two female and the rest men. All the participants had varying body height going from 1690 mm to 1977 mm and the smallest sitting height was 912 mm to the tallest 1002 mm. The data was summarized in an excel sheet with the test person's anthropometrical measures, ranked parameters as well with their rating. They were sorted in sitting height to be able to find any correlation within a group of sitting heights/percentile. The findings are presented in the next two sections.

5.2.1 Expectation of the Car

In this section the exploratory research question about the expectation was investigated.

ERQ 2.3: Does a person's preconception of the car influence on the perceived interior space (expectation vs experience)?

Observations regarding the expectation and the experience for the two cars are presented separately. Later, a conclusion is presented to answer the research question and if further investigation is needed.

5.2.1.1 XC60

The observations that have been made from how the test persons (TP) have answered regarding their expectation and experience with the XC60 was that the expectation of the upper interior space was between *"High"* and *"Very high"*. Some were based by the car's size and as well the segment it lays within; big SUV car, with good vision out and being spacious. The given grade for the expected interior space altered between *4. "Good"* (6 TP) and *5. "Very good"* (3 TP) and the calculated mean value was 4.3.

Comparing 4.3 with the mean value from the initial rating of the experience it was slightly reduced to 4.1, hence two test persons lowered their score with one step. Moreover, looking at the final rating in expressing agreement or not to the initial score almost everyone agreed with the rating except one. This test person put it to be worse due to the awareness of the C-pillar which affected the perceived interior space to be worse than initially rated.

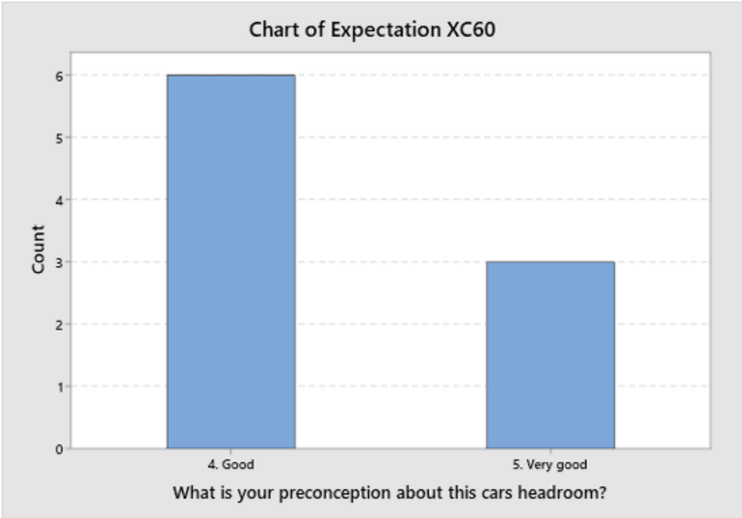


Figure 5.3: Bar chart representing the rating given for the expectation for XC60

5.2.1.2 S60

Looking into the S60, a car in the segment of smaller/sport sedan, the expectation of the interior space was lower and had a wider spread compared to the expectations towards the XC60. The spread was evenly distributed between *"Low expectation"* and *"High expectation"* and one in the middle having *"No expectation"*. Calculating the mean value of the expectation on how the interior space would be before entering the car came to be 2.7. The score was varying between *2. "Bad"* (5 TP), *3. "Average"* (2 TP) and *4. "Good"* (2 TP).

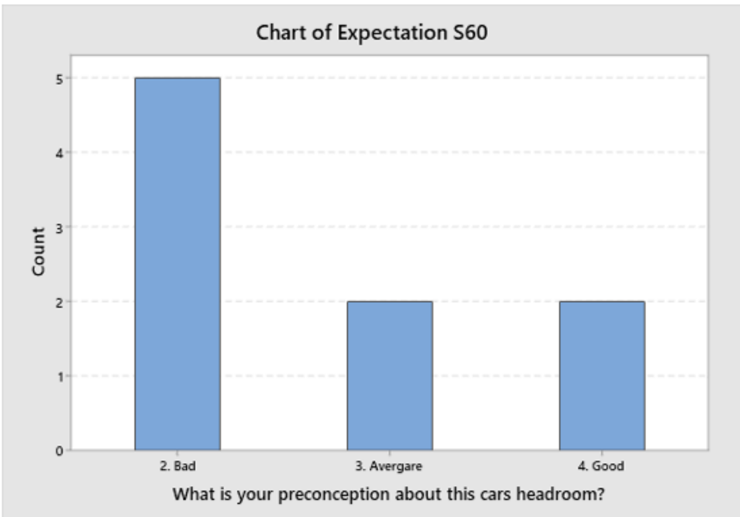


Figure 5.4: Bar Chart representing the rating given for the expectation for S60

Once entered the car, most of the test persons (6 TP) kept the initial rating of the upper interior space to be the same with their expectation. However, two people gave a higher rating and one went down with its rating to *1. "Very bad"*. This score was given from the tallest participant, with a sitting height of 1002 mm, who had the head in the headlining when seated in the natural posture. This gave the initial experience an average of 2.8. But, after a final rating in expressing agreement or not to the initial score, five test persons agreed with initial rating after analyzing the interior space and the rest stated it to be better.

5.2.2 Parameters

In this section about the parameters, the remaining exploratory research questions were studied.

> *ERQ 2.1: Which are the subjectively perceived parameters?*
>
> *ERQ 2.2: Which parameters can be measured physically?*
>
> *ERQ 2.4: Which parameters have the largest impact on the perceived upper interior space?*

In the study the test persons were asked to identify the parameters that was affecting the perceived upper interior space. 23 different parameters where identified related to the car, categorized as Car parameters and 3 parameters categorized as Human factors, a total of 26 parameters. Some of the parameters were identified beforehand in the first phase (Awareness). With help of the study the validity of these parameters was checked. The Car parameters were furthered sorted in sub-levels to get a holistic view of the type of the parameters. Three sub-levels were generated; Vision, Spatial distances and Illumination. Additionally, within Vision two lower levels were distinguished; Visibility out and Enclosure. In table 5.2, all the parameters are listed and sorted in its respective categories.

The parameter “Knee roominess”, listed as a Spatial distance in the Car parameters, was questioned rather if it will have an impact on the sitting posture and consequently affect the upper interior space, before conducting the study (identified in the Awareness phase), hence the parentheses in table 5.2. Due to the fixed position in SgRP of the seat in front of the test person no one had any difficulties with the knee room once seated in their comfortable seating posture. Therefor, not having an impact on the test persons and their perception of space. No further investigation was needed, and the knee roominess was neglected as an affecting parameter. This leaves us with just 25 parameters.

Not all of 25 identified parameters were used when ranking them in the "Pairwise comparison” application. This was because of the limited time of the user test but mainly not needed due to the interest of identifying the most affecting parameters. The parameters were kept to be around 8 parameters (28 comparisons) for every participant but did also exceeded to be done by 9 parameters (36 comparisons). As a result, the application provided a list of the ranked parameters with its respective percentage of importance the parameter had to the perceived upper interior space.

When listing all the ranked parameters and visualizing by a theme-colour the category it belonged to (Vision - blue, Spatial distances - orange and Illumination - yellow) there was a clear pattern among all participants. The Spatial distances had a high influence on the perceived interior space. These parameters where seen as more critical for the test persons who were seated very close to the roof or who were even touching any feature in the headlining, which was concluded from the comments. The table of all participants' ranking of the parameters with the corresponding categorical theme-colour can be found in Appendix A. The test persons were also ordered in an increasing sitting height to be able to spot any trends within specific heights.

Moreover, subtracting the calculated percentage of importance for all nine test persons from the provided list by the "Pairwise comparison" application displayed the next most ranked parameters after Spatial distances. These parameters were the panorama size (Illumination parameter), Belt line, Window divider bar and Cant rail shape/size (all within Vision). Out of the 25 identified parameters only 14 were used as an input in the application "Pairwise comparison". These are listed in the table 5.1. What the table also is providing is the sum of the percentages it received from the participants (*Scores (%)*), as well the number of participants who ranked it (*Count (TP)*).

Table 5.1: Fourteen parameters which were used in the application "Pairwise comparison"

Rank	Parameter	Score (%)	Count (TP)
1	**Vertical distance**	187	9/9
2	**Distance to Cant rail**	146	9/9
3	Rear header	131	7/9
4	Panorama roof size	80	5/9
5	**Belt line height**	70	8/9
6	**Window divider bar**	69	8/9
7	Cant rail shape	57	6/9
8	**C-pillar placement**	56	7/9
9*	Length of rear window	42	2/9
10	Panorama roof lining	32	2/9
11	C-pillar angle	14	1/9
12	C-pillar width	7	1/9
13	**B-pillar placement**	7	6/9
14	B-pillar thickness	3	3/9

The initial plan was to keep the parameters as open as possible to be able to collect the test person's own thought about the affecting parameters of the perceived head roominess. However, after the first three test persons (TP-Q1/Q2/Q7) the given parameters varied a lot. It made it difficult to analyze and compare the data to be able to present concrete result in the end. Therefore, six parameters were decided to be standardized; Vertical distance, Distance to Cant rail, Belt line height, Window divider bar, C-pillar placement and B-pillar placement (marked as bold in table 5.1). This means that the remaining test persons were required to rate these and were given the option to add two or three parameters of their own choice if needed.

The parameter "Length of rear window" (rank 9* in table 5.1) was for example one of the parameters which were identified in the initial phase but was neglected hence including several parameters, i.e. Belt line, Cant rail, C-pillar and B-pillar. In other words, the parameters were more specified afterwards.

Table 5.2: All 26 parameters identified which influence the perceived upper interior space are presented. The parameters are separated in two groups as a high level (Car parameters and Human factors) and in sub-levels within the group

CAR PARAMETERS				HUMAN FACTORS
VISION		***SPATIAL DISTANCES***	***ILLUMINATION***	
Visibility Out	**Enclosure**			
Belt line	C-pillar - angle/width	Vertical distance	Interior trim colour**	Eye position
Window divider bar	B-pillar thickness	Lateral distance	Panarama roof size**	Sitting height
C-pillar placement	B-pillar placement	Distance to rear header		Sitting posture
B-pillar placement	Distance to Cant rail	Distance to Cant rail		Expectation
B-pillar thickness	Headlining	(Knee roominess)		
Cant rail - shape/height	Roof detail	Seat inclination*		
Seat inclination*	Panorama lining *	Seating position*		
Seating position*	Distance to front seat*	Distance to front seat*		

() - check validity
** - fixed position*
*** - left out (proven to have an effect)*

5.3 Discussion and Conclusion

The stated exploratory research questions (ERQ 2.1 - 2.4) are answered in this section. The result will also be discussed together with some interesting aspects that are relevant and conclusive. Like before, the expectation of a car and parameters are discussed separately.

5.3.1 Expectation of the Car

From the observation and the given result, the exploratory research question ERQ 2.3 was answered.

ERQ 2.3: Does a person's preconception of the car influence on the perceived interior space (expectation vs experience)?

The expectation and preconception of a car did influence the perception of the interior space to some degree. When analyzing the test persons' expectation and then the initial rating of the interior space there was a higher risk of getting disappointed if having high expectation. Furthermore, comparing the initial rating after entering the car (where the expectation has a bigger impact on the rating) and the final rating, (which is more influenced by the experience and less by the expectation) the difference was bigger when having low expectation.

With the S60 four out of nine people did rate the upper interior space to be higher (better). While for the XC60 there was one who lowered the score. Another explanation to this result can also be reflected on how frequently the test person has experienced the car beforehand. Less people had been experiencing the S60, or lesser than XC60, which can bring unrealistic assumption with their prior expectation.

A person's expectation and preconception are such a personal matter and needs thorough investigation to understand where they arise and the impact they have in the perception. This was not studied in the next coming study. However, it was evident that the conclusion falls in line with the theory as mentioned in the *Theoretical framework* (chapter 2). Less expectation on the upper interior space based on the size of the car made a positive impact while experiencing it (called *contrast*) and a comparatively higher expectation created a negative impact among the users (called *assimilation*) (Deliza & MacFie, 1996).

A disadvantage with Verbal Rating Scales (VRS) was that it is considered not to be as sensitive to changes compared to VAS and NRS (Roberts, 1997) (Hjermstad et al., 2011). However, it may be argued that the level of sensitivity can be reached depending on the level of category involved in the VRS (Hjermstad et al., 2011). The scale which was used to determine a person's expectation and the experience of the interior space was a mix of both a verbal and numerical rating scale to support the decision process, and had 5 categorical levels. In chapter *Measuring and assessing pain* in the book *Orofacial pain and headache* (2008), the scale would be used for “rough comparisons” due to the few number of categories. The wording which was chosen for the categories were chosen of convenience and were not studied in depth as a pre-study which is required in Thurstone’s scale. This to be able to express descriptive words which reflects a person’s experience, as well to study the scale’s ratio quality. However, due to a first assessment regarding the expectation and experience of the perceived qualities a lighter and rough assessment was seen as a good enough research. Then later decide whether it was needed of a more thorough research in that area. In the end the expectation and experience aspect was decided to be dropped and just focus on researching the parameters.

5.3.2 Parameters

After the analysis of the parameters the exploratory research questions regarding the parameters can now be answered.

ERQ 2.1: Which are the subjectively perceived parameters?

25 parameters which had an impact on how the test person perceived the upper interior space were identified during the Identification phase. Some of them were already identified in the Awareness phase, with help of a qualitative study. These are presented in the table 5.2.

ERQ 2.2: Which parameters can be measured physically?

From the list of parameters (table 5.2) there were three Spatial distances which can be measured easily; Vertical distance, Lateral distance and Diagonal distance to headlining/Cant rail. Regarding the "Shape of the rear header" and distance to it was decided to fall under the Vertical distance. The "Seat inclination" and "Position", as well the "Distance to front seat" was fixed for this study but can as well be measured physically.

ERQ 2.4: Which parameters have the largest impact on the perceived upper interior space?

The top five parameters in the table 5.1 of ranked parameters shows that the Spatial distances Vertical distance, Distance to Cant rail and distance to Rear header had great impact on the perceived upper interior space. Afterwards, Size of the Panorama roof comes as number four and Belt line height as number five.

If considering the rear header being part of the Vertical distance and the limitation of not involving the Panorama roof, the Window divider bar and Cant rail shape came within the top 5 parameters as well. Furthermore, if considering five different areas of importance Vertical distance, Cant rail, Belt line, Window divider bar and C-pillar would be the areas, listed in table 5.3, with the corresponding categorical group defined earlier.

Table 5.3: Top five areas listed as most influential

S.No	Area (Paramter)	Category
1	Vertical distance	Spatial distance
2	Cant rail	Vision
3	Belt line	Vision + Spatial distance
4	Window divider	Vision
5	C-pillar	Vision

Out of this, three angels α, β and θ were generated which were connected to Cant rail, Belt line and C-pillar. These parameters together with the Spatial distances (Vertical/Lateral/Diagonal distance) were studied in the third phase Investigation to understand how the change in α, β and θ affect the perception of upper interior space.

As for the Window divider bar, it was decided to not be studied in detail but instead be noticed and be given some analysis by the test persons who mentions it. Further description about how the angles and the distances were assessed will be presented in the method chapter of *phase 3 – Investigation.* To be able to tell which one of these angels with corresponding parameter has the largest impact on the perceived headroom, more investigation was needed and was brought along to the next phase for further analysis.

In this qualitative study the focus group chose to be the experts within the Customer Experience Center. Their knowledge for the different cars were high due to their work which involves working with the existing cars, evaluating them as well doing benchmarking. Their expertise was taken as an advantage when the need of qualitative knowledge of identifying parameters were fundamental and to get an understanding of what they consider as important parameter to encounter.

However, their expertise can as well be argued to have had a negative impact of the result. Because of the new research area of perceived roominess this might need to consider other parameter then the conventional ones to measure roominess. Then their expertise can rather block the acknowledgment of potential affecting parameters and just focus on the standard parameters. With this risk taken, the experts were still chosen to be the focus group. But, due to the exploratory study of parameters in the Awareness phase potential parameters were seen to already be covered in some degree and were either confirmed or discussed during the user study with the experts. Yet it would have been interesting to investigate if the same parameters would have been identified with another set of test persons to check consistency in findings.

Open-ended questions are mostly referred to qualitative data to enabling personal answer which is not forced/led by the conductor (Boeren, 2015). Majority of the questions asked in the study were open-ended, but to be able to make awareness in some undefined parameters, some questions can be argued to be presuming and leading. However, this was considered necessary to be able to know if the participant would agree or disagree on affecting parameters. Nevertheless, the paired comparison method was utilized for a subjective ranking of the personal identified parameters (most important ones) where the raking was not influenced by any others' opinions than the test person him/herself.

6

Hypothesis and Research Questions

The following phase Investigation, chapter 7. *Phase 3 - Investigation*, contains the main study and essential findings. This chapter was then encouraged to bring clarity in what was studied and answered during the investigation of all the 6 parameters; Vision parameters and Spatial parameters. To start, 6 hypothesis (H) are presented which were based on the knowledge obtained from the results of phase 2, Identification. Answering the hypotheses provided supporting evidence for the results obtained from that phase. The hypotheses are followed by five exploratory research questions (ERQ) which the user study in phase 3 was designed after. They provide more of a holistic understanding of the analyses. Further, to aid the statistical analyses of the data the ERQ were elaborated into what will be the 13 research questions (RQ). All the hypotheses, exploratory research questions and research questions are presented below.

6.1 Hypothesis

After the investigation of the second phase, while identifying the parameters, the following six hypotheses (H1-H6) were created and studied in the third phase.

H1: Users can be consistent in their rating assessment of perception of interior spaces.

H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space.

H3: Tall group of people are more sensitive to changes in Cant rail position while assessing the upper interior space.

H4: Short group of people are more sensitive to changes in Belt line position while assessing the upper interior space.

H5: Position of C-pillar has an equal effect on the Short and Tall group while assessing the upper interior space.

H6: The test persons have similar critical angle to the parameters.

6.2 Exploratory Research Questions

Five exploratory research questions (ERQ) were designed to lead and structure the user study in phase 3. Because these questions brought more of a holistic analysis of parameters and discussions to them, thus were addressed in a comparative aspect between the analysed parameters in chapter 8. *Compared analysis*.

> *ERQ 3.1: Which parameters have the largest impact on the perceived upper interior space?*
>
> *ERQ 3.2: Is there a trend between the body dimension (Short/Tall group) and the most influential parameters?*
>
> *ERQ 3.3: Is there a correlation between the Spacial parameters and the subjective perception of roominess?*
>
> *ERQ 3.4: Is there a correlation between the body dimension and the subjective perception of roominess?*
>
> *ERQ 3.5: Are there any critical measures for the most influential parameters?*

6.3 Research Questions

As mentioned in the introduction chapter (section 1.5) the thirteen research questions (RQ1-RQ13) are presented in this chapter. Because these were mainly related and formulated to fit the statistical analyses in the third phase it became more naturally to present these here. To understand how the RQs were evolved from the ERQ, the correlated ERQ are put in brackets afterwards. The answers for all the RQs are attained in phase 3 and discussed in the sections pertaining to the parameter.

> *RQ1: How is the position of Cant rail influencing the VAS rating on perceived upper interior space? (ERQ 3.1/3.2)*
>
> *RQ2: How is the position of Belt line influencing the VAS rating on the perceived upper interior space? (ERQ 3.1/3.2)*
>
> *RQ3: How is the position of C- pillar influencing the VAS rating on the perceived upper interior space? (ERQ 3.1/3.2)*
>
> *RQ4: How is the Vertical distance influencing the VAS rating on the perceived upper interior space? (ERQ 3.3)*
>
> *RQ5: Is there a difference in rating the nominal Vertical distance and after the vertical change? (ERQ 3.3)*
>
> *RQ6: Is there a trend of how the test persons' ranking the parameters in Short and Tall group? (ERQ 3.2)*

RQ7: Is there a correlation between the VAS rating of nominal state and the Vertical distance? (ERQ 3.3)

RQ8: Is there a correlation between the VAS rating of nominal state and the Lateral distance? (ERQ 3.3)

RQ9: Is there a correlation between the VAS rating of nominal state and the Diagonal distance? (ERQ 3.3)

RQ10: Is there a correlation between a person's Z-position of eye coordinate and the VAS rating? (ERQ 3.4)

RQ11: Is there a correlation between a person's X-position of eye coordinate and the VAS rating? (ERQ 3.4)

RQ12: Is there a trend between the sitting posture (X-coordinate) and the VAS rating? (ERQ 3.4)

RQ13: Does the borderline for every parameter reflect upon a range of an angle for a specific parameter? (ERQ 3.5)

7
Phase 3 - Investigation

7.1 Method

This chapter is intended to provide information about the set-up of the user study for the Investigation phase. In the user study section (7.1.1), explanations are given about the environment in which the user study took place, the modifications made in the chosen car, the tools that were used, and interview approach to obtain the required data from the test persons. The following section, 7.1.2. *Analysis Methodology*, contains information about the method that was used to handle the data. Furthermore, the methods that were incorporated to derive new data that were not obtained directly from the user test are explained in 7.1.2 as well. These data were used in various analysis to answer the research questions of this phase. Additionally, a brief introduction are given to the software that was used for the purpose of data analyses.

7.1.1 User Study - Investigation

The user study was designed in three stages, following a structured data form, where the participant rated and ranked the cars upper interior space in the first stage. In the second stage the parameters were changed in different levels to observe how it affected the perception of the upper interior space. In the last stage the test person's Spatial distances were documented; Vertical/Lateral/Diagonal distance. The user test took approximately thirty minutes per test person (TP), plus some additional time for measuring body and sitting height. The next coming subsections will describe how the study was prepared and conducted.

7.1.1.1 Set-up of User Study

A big SUV, XC90, was utilized hence largest interior room to do modification and use as design space to manipulate some design features. Due to the limitation of cars for extensive period of booking a XC90 with panoramic roof was accepted even though the study was limited from investigation in that area. The driver seat was set in SgRP position as well for the seat where the test person was seated to create the same conditions and environment for every test person (set as a fixed/controlled parameter). For easier access of this seat installation a car with memory seat was chosen. The interior was chosen to be light due to more distinctive/contrasting pictures of object. Even in this study the user study took place in an indoor environment with good lightning which could be controlled and set the same for all the participants to create the same conditions, see figure 7.1.

Figure 7.1: The indoor environment of the user study

During the first stage called “Rate and Rank” a physical Visual Analogue Scale (VAS) was utilized for all rating in the second stage as well. The VAS was a 100 mm long straight line with two anchoring words on each end of the line, *“Very narrow”* at the left-most end and *“Very spacious”* at the right-most end. The VAS that was used in the user test can be seen in the figure 7.2

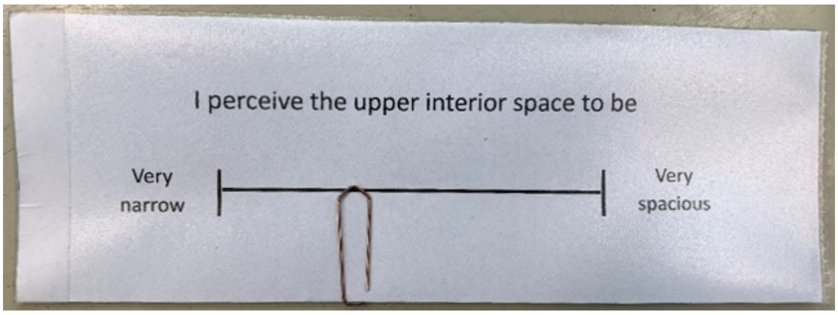


Figure 7.2: The Visual Analog Scale used in the user study of phase 3

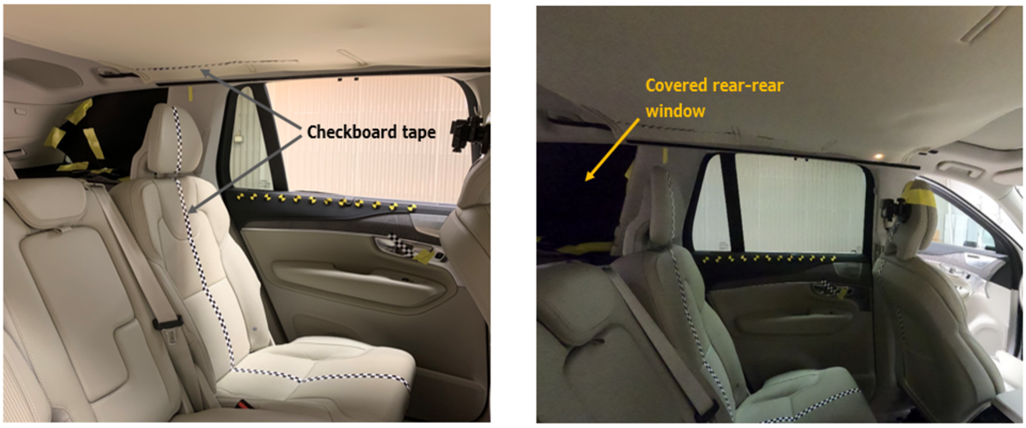
The VAS was used to answer how the test person perceived the upper interior space, and with a marker to place it on the line indicating the amount of space the person was perceiving. A numeric representation was then read with help of a ruler from the left anchor to the mark. Once again the application “Pairwise comparison” was used to rank some predefined parameters with the paired comparison as method.

Due to the circumstances of the Covid-19, all equipment that was in use were sanitized after every participant. This was for example done to the VAS scale and the mobile phone.

For the second stage, called "Manipulation", extensive work was needed to prepare the different manipulations of the Vision parameters and one manipulation for the Vertical distance. Inside the car was the panoramic roof covered by a similar fabric with the same texture but with a different nuance. However, this was just done for the rear seat, from the rear seats' head rest to the front seats' head rest. The fabric was prepared with Velcro on the back side for fastening. The panoramic roof was then closed underneath the textile. A Kapa-board (foam-board) with approximately the same size as the covering fabric was cut and covered with the same textile for manipulation in vertical height.

To be able to tell how the test person was seated and to centralize the participant in the seat, the rear seat together with headlining as well the back of the seat in front had a checkboard tape pasted on to distinguish the central line in the seat, see figure 7.3 (a).

For not having the test person distracted by other parameters during manipulation, the rear-rear window behind the test person, on the left side, was covered throughout the whole study, see figure 7.3 (b).



(a) The position of the checkboard tapes

(b) The rear-rear window covered with black material

Figure 7.3: Test set-up inside the test car showing the checkboard tapes and covered rear-rear window

In terms of the manipulation of Vision parameters, for , α - Cant rail and β - Belt line, thicker paper in black was mounted on the car exterior with a sliding feature to be able to address different levels of changes. A paper ruler was attached on each side of the black-sliding papers to acknowledge the level of change. Regarding the angle θ – C-pillar placement, a smaller Kapa-board was also covered in black paper. To be able to move the board with the same angle as the C-pillar forward angle, a perpendicular line was attached on to the car with an additional paper ruler, see figure 7.4.

Two GoPro cameras were mounted for documentation of seating posture; one in front of the test person on the head rest of the driver seat (see figure 7.3), and the other one for a profile picture mounted on the left rear window. Both cameras' setting were set to take picture in a linear view.

Figure 7.4: Test setup on the left rear window to manipulate the parameters

Furthermore, in this stage three measurable distances were taken. To access them a thread was used to be able to capture smaller distances, e.g. the vertical distance to headlining. The thread was afterwards measured to get the numbers.

All documentation was done in excel where every test person's comments and rating were carefully noted. With the same approach as the qualitative study there was one test leader leading the study and was asking the questions, and one assistant documenting and assisting if needed. The test leader was always in the car with the participant giving direction and the assistant documenting from outside the car. The documentation sheet can be found in Appendix C. To get the most out of the participant the study was adapted to the language the test person was comfortable communicating/expressing feelings in, either Swedish or English.

The three stages, "Rate and Rank", "Manipulation" and "Measure", will be described in detail in the next coming passage.

7.1.1.2 First Stage - Rate and Rank

In this initial stage subjective data of the test person's perception of the upper interior space of the XC90 was collected, before gathering any objective data. Once the test person entered the car and got seated comfortably in the left rear seat, centralized in a posture of their own choice and with the seat belt on, the person was asked to tell how he/she perceived the interior space to be. The focus was on the roominess around their upper body (from chest above), hence described as upper interior space. The participant was not allowed to do any physical measuring with hands when seated inside the car to judge the roominess, thus focusing on the perception.

A Visual Analogue Scale (VAS) was given to the test person to rate the upper interior space. One the linear scale *"Very narrow"* was the descriptive word anchoring the left-end side and *"Very spacious"* on the right-end side. A marker was then moved by the test person from its starting position outside the scale area to somewhere on the line corresponding the feeling she/he had towards the car's upper interior space. For documentation the test person was also asked to elaborate upon the given rating. The VAS was handed over to the assistant to be measured and documented in the excel file (Appendix C). The marker on the VAS was then replaced to its original position outside the line.

(a) Side view showing the Vision parameters

(b) Front view showing the Spatial distances

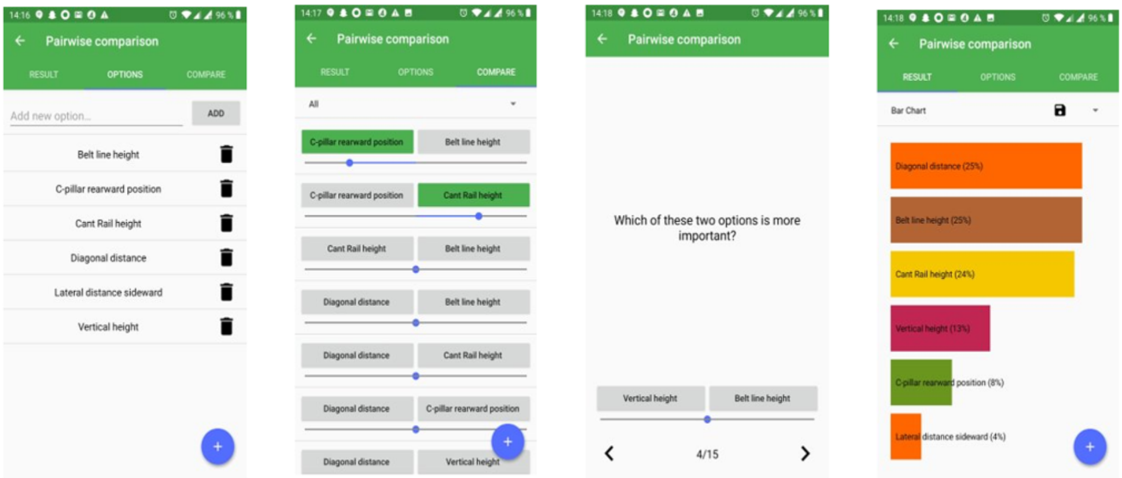
Figure 7.5: Interior of XC90 showing the 6 parameters in the outer-rear seat of a XC90

After the rating a set of predefined parameters (3 Vision and 3 Spatial parameters) were ranked in order of influence by the test person with the help of the mobile application 'Pairwise Comparison'. This was done to identify the test person subject--ive opinion about what parameters was affecting his/her perception of the upper interior space the most (in a negative way) in that specific car. All the predefined parameters was the outcome form the previous phase Identification of the most influential parameters (table 5.3). However, in this study the parameters were translated to a more specific form. Moreover, three of them was identified as Spatial distances and the other as Vision parameters. In figure 7.5 the Spatial and Vision parameters are visualized. The six parameters for ranking was:

- Belt line height (Vision parameter)
- Cant rail height (Vision parameter)
- C-pillar rearward position (Vision parameter)
- Vertical distance between head and headlining (Spatial distance)
- Lateral distance sideward (Spatial distance)

- Diagonal distance from head to closest feature in the headlining (Spatial distance)

The test leader who was sitting in the car together with the test person, but on the right side, was presenting these parameters on the car for the person to understand and to relate to them before handing over the phone. If further clarification was needed the test leader was there to help. After comparing 15 paired comparisons *(N*(N-1)/2, N=6)* a list of the 6 parameters in a ranked order was generated. After the generated list either the test person agreed with it or changes was made by consent. Figure 7.6 is visualizing how the application looks like and how a generated list might look.



(a) Listing the 6 parameters

(b) Generating 15 paired comparisons

(c) Test person need to choose one of the options

(d) Ranked order is generated in the end for the parameters

Figure 7.6: Pairwise comparison application

7.1.1.3 Second Stage - Manipulation

In the second stage the Vision parameters Belt line height, Cant rail height and C-pillar rearward position, was manipulated to study their effect on perceived roomi--ness using the Visual Analog Scale (VAS) for rating. The three parameters was changed between three pre-set steps for each of them. The difference in height between two step where 40 mm, a total range of 120 mm, for Belt line and Cant rail. While for C-pillar there was a bigger step of 70 mm between two steps with a total manipulation range of 240 mm. To understand the procedure of the manipulation the figure below provides a visual understanding. In the figure 7.7, the nominal state of the car and the extreme position of the parameter manipulation are available. In Appendix D contains images of all the manipulations of the parameters.

(a) Nominal state of the car

(b) Cant rail extreme position (A3)

(c) Belt line extreme position (B3)

(d) C-pillar extreme position (C3)

Figure 7.7: Manipulation of the Vision parameters in the extreme position (A3/B3/C3) in reference to the nominal state

In figure 7.8, the angles α, β and θ which are correlated to the different Vision parameters are presented from the mid-eye centroid point. The angels are unique for every participant because their relativeness to the test person's eye position as well with the changing parameters. These angels were determined during the analysis of the result when the eye position was calculated in CATIA V5 (section 7.1.2.3).

Three parameters with three steps each generated nine manipulation. Furthermore, three additional set-up were added into this stage where the test person rated the original car with no changes made (the nominal position) with the purpose to tell if the person was consistent in its rating. Additionally, one more parametrical change were done; change in vertical height. This test provided knowledge about how the Vertical distance (Spatial distance) affected the perception of upper interior space, and once again was the VAS used for rating.

During change in vertical height and the Vision parameters, the other parameters were set to the original position to make the changes independent. Change in vertical height was designed to place a flat mock-up roof on a position where the headlining will be lowered 62 mm from the original position, in line with the SgRP point. This manipulation is visualized in the figure 7.9. In total thirteen manipulations were prepared, but not all participants took part of the change of Vertical distance due to ocular judgement from test leader that the test person had the head above the mock-up headlining.

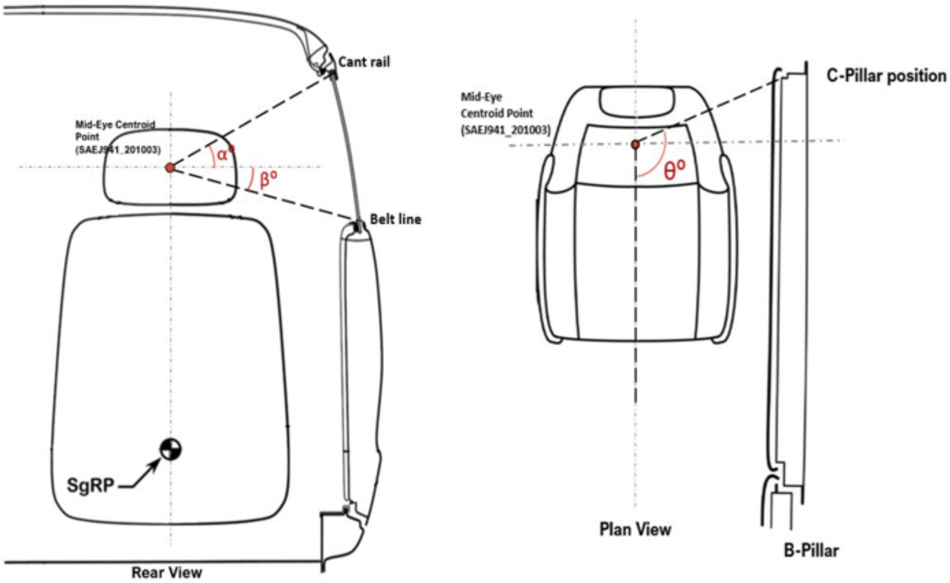


Figure 7.8: Visualizing how α, β and θ are determined

Figure 7.9: Visualizing the vertical distance manipulation with flat mock-up roof

In order to avoid rating bias the order of parametrical change was randomized to some level. The three nominal position were spread out during the manipulation stage for not occurring too close upon one another. Furthermore, the manipulation order was designed to not have the same parameter changed as a next step to create a set-up where the different parameters were compared between each of them.

The test person who was seated in the car was not informed of what kind of change was to be performed. For the test person not to see the direct change he/she was asked to close their eyes or look away. Once the manipulation was done the test person was asked to rate their subjective feeling of how they perceive the upper interior space to be on the VAS where *"Very narrow"* was anchored on left-end side and *"Very spacious"* on the other end. During the evaluation the test person was asked to think out loud and elaborate upon their rating. Before moving on to the next change the test person was also asked to judge if the scenario of that particular change in that set-up was acceptable or not. After a given answer the next change was prepared and a new VAS was provided to the test person. The procedure repeated itself for thirteen times (twelve times without the change in vertical height).

7.1.1.4 Third Stage - Measure

In the third and last stage was where the objective data of measurements was collected, the three Spatial distances. The Vertical distance was measured from the top of the head to headlining, Diagonal distance from top side part of the head to closest feature on the headlining diagonally, and Lateral distance sideward was measured from a point close to the ear in line with the eyes horizontally out to the closest object, see figure 7.5). A thread with the diameter of 3 mm was used as a measuring tool to access shorter distances which was measured with a ruler to get the values. As a last thing the test person's sitting posture was captured with help of the mounted GoPro cameras, one in front of the test person and the other one on the side window for a profile view.

7.1.1.5 Measure Test Person

For all participants two anthropometrical measures were taken; body height and sitting height. For measuring the body height, a measure was determined from a vertical measurement from the floor to the top of the head. The person was standing erected, looking straight ahead with his/her arms hanging along the bodyside. The person was also measured without shoes. While assessing the sitting height the person was asked to sit erected, with the thighs horizontally with the floor. The arms were placed on the lap, and the head was positioned so that the person was looking straight ahead. When assessing the measure, the hair needed to be compressed hence taking the accurate measure from top of the head. Specific tools at the department were utilized to make it easier to assess these measurements.

7.1.2 Analysis Methodology

The *Data Analysis Methodology* described in the section 3.6 was used as a guideline when analysing the user study's data. The results obtained by following this method--ology did not need not be in the same order as presented in the table 3.1 in chapter 3. As a final step in this methodology the results were required to be presented in the appropriate way to create conclusions. Some of the steps presented in the original methodology were not required for the scope of the thesis and have been skipped. In table 7.1, different steps are described together with the analysis which has been applied in this research. It can be noted that step 5 and 6 are not included as it were not required to address the research questions of the study.

Table 7.1: The data analysis steps with the respective analysis done for each step

Step Number	Step	Analysis done
1	Identification	Distribution analysis (histogram), Cluster analysis to check for identical data clusters and outliers were identified and addressed.
2	Error Checking	Errors in data entry and change in units of measurement, deviation of test population from the Swedish population.
3	Modification	Eye positions were arrived using which the vision angles were calculated (section 7.1.2.3), sitting posture data set arrived.
4	Comparison	Comparison graphs of scatter plots, box plots, line plots for the purpose to address the research questions.
7	What-If analysis	Exploratory analysis for certain data sets like extending linear correlation to non-linear. However, they did not yield results that were interesting to be investigated further.
8	Interpretation	2-sample t-tests to investigate box plots, Anderson normality test for distribution analysis and Pearson correlation to quantify scatter plots.
9	Presentation of Conclusion	The results of the above mentioned analysis are presented in the section 7.2 in a chronological order of the parameters that were studied.

For the analyses new data sets were required, for example eye position and vision angles. The method used to derive these data sets are introduced later in this chapter, and the software with which the analyses were generated with.

7.1.2.1 Data Arrangement

After the data collection from all 34 participants, the data was arranged and handled in an excel sheet to be able to get an overview of the data. All the participant's anthropometrics data (body height, percentile of body height and sitting height) and given answers from the user study were summarized in tables for data retrieval and for data analysis. Additional analysis of eye position, sitting posture and angles (α, β and θ) were also documented in this data sheet.

7.1.2.2 Determination of Eye Position

By determining the eye coordinate of the test person further analysis of vision angles (α, β, θ) were done. These angles were calculated in CATIA V5, a computer aided design (CAD) software, where the car's design specifications were visualized in 3D. To convert the test person's eye position in a real environment to a coordinate point in a three-dimensional room where the vehicle product was designed in, a checkboard with two reference points was printed out to act as a reference plane. The checkboard was cut to follow the contour of a XC90's seat in the second row, set in SgRP, in the XZ-plane. The mid-eye centroid point and the SgRP point for the rear seat were marked on the board to act as reference point when determining the eye coordinates later.

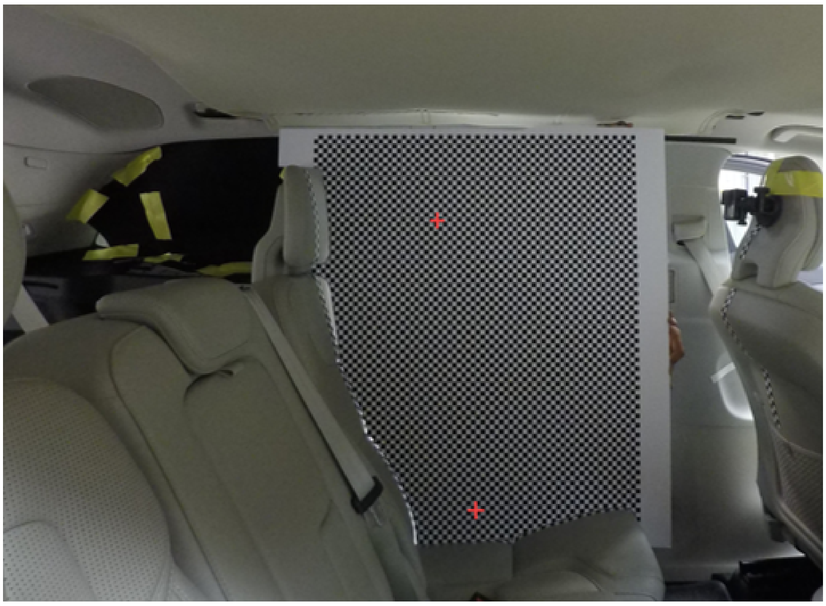


Figure 7.10: The checkboard positioned inside the XC90. The upper red marker represent the mid-eye centorid point and the lower the SgRP point

After placing the customized checkboard in the real environment inside the XC90 a side picture was taken. This picture did later act as a reference picture to follow when editing the side picture for all participants. It was changed in colour to a light orange colour set for easier handling when layering pictures on top of each other. By layering the pictures and making one transparent the side picture with the test person was easily moved to match the reference picture. Once having the pictures arranged, test person's eye point was marked, as in the figure 7.11. The next step was then to calculate the distance and identifying the direction to where the eye point was marked from the mid-eye centroid point. By having every square piece to be 10 mm in the checkboard made the distance approximation accessible.

Hence working in two dimensions (XZ-plane) the Y-coordinate was kept in a fixed position while X and Z were determined for every test person. All documentation was done in a excel sheet and the calculation of the eye coordinate was determined by a formula where either the approximated difference was subtracted or added to the reference coordinate due to the direction.

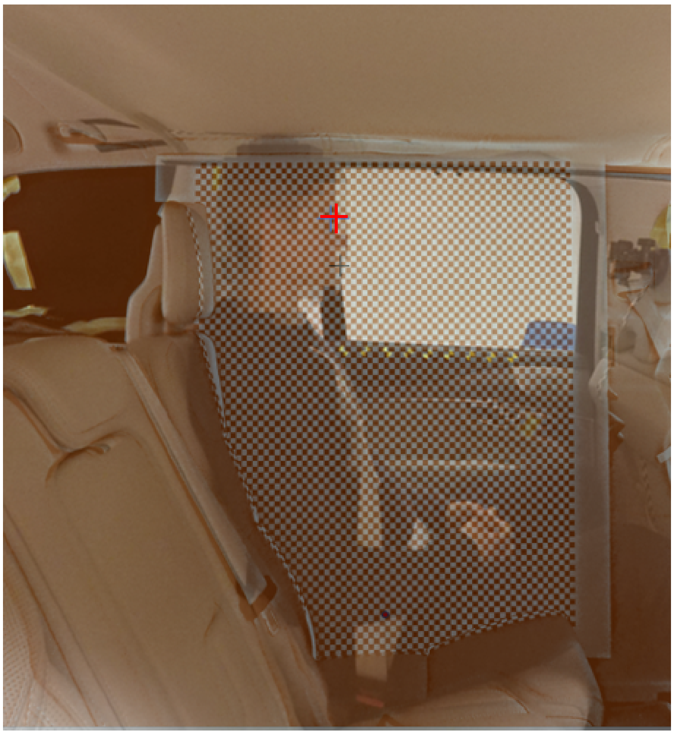


Figure 7.11: Two images are overlaying each other; reference picture and the test person side picture. By having the upper layer transparent it is possible to match the images and determine the difference in eye position from the reference point

7.1.2.3 Determination of Vision Angles

The Vision parameters α, β and θ which were connected with the Cant rail, Belt line and C-pillar, were determined for every test person and their eye coordinate. This has been done in CATIA V5 where the car's specification was presented together with participants' eye coordinates which have been added into the CAD file afterwards. By translating all the three pre-set steps during the manipulation for Cant rail, Belt line and C-pillar in the CAD file and creating design lines and boundaries which were linked to a coordinate, calculating all the angles for a specific eye point can quickly be determined at the same time without putting too much effort.

The trickier part here was to have all the features linked to a point so when updating that point to a new one, all the connected lines and features were automatically updated to be linked to this new point. Furthermore, creating parameters in the CAD file, the desired angle related to α, β or θ were presented in what was called the *Process Product Resources specification tree* which was available on the home screen. The figure below is presenting how all the vision angles were determined. All the coloured lines that were coincided at an eye point were creating a vision angle. The upper blue lines were presenting the α angles in a nominal state as well for the three pre-set levels. The bright purple lines were presenting the θ angles in a same manner as described for α, and in the bottom blue lines were presenting the β angles. In the same figure to the left side, the specification tree were displayed. Furthest up the *"Parameters"* were shown and below it all the angles were presented.

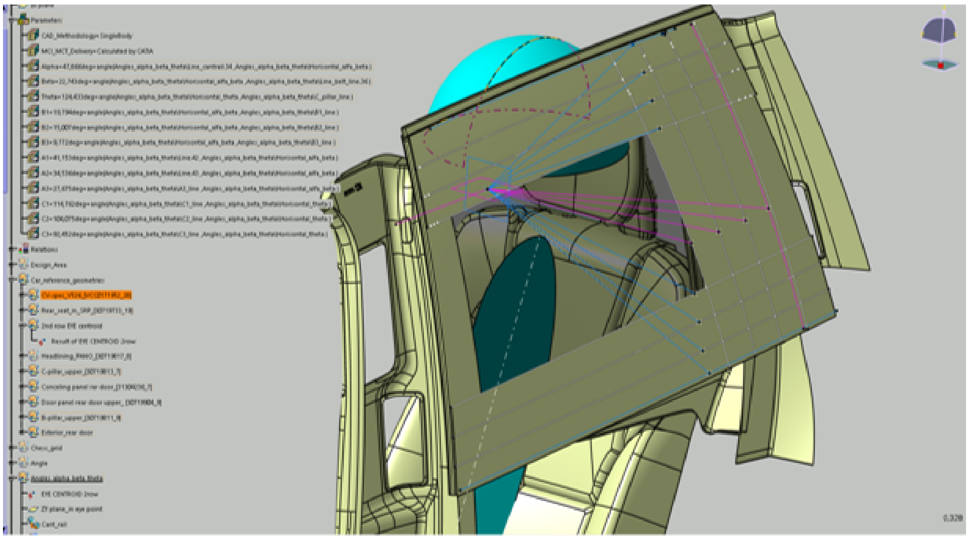


Figure 7.12: Presenting all the vision angles and how they were determined in a CAD file

7.1.2.4 Determination of Sitting Posture

An investigation was placed to understand if the sitting posture was affecting how the test person perceived the interior space. When categorizing test persons' sitting posture the focus was on where the head was in relation to the head rest. Four different sitting posture were defined with the help and inspiration from previous study (presented in the *Theoretical framework* (2.2)); 'a' head on head rest, 'b' head off and body in a upright/natural sitting posture, 'c' head positioned far forward from head rest and 'd' sitting in an extreme/awkward posture. All the test persons were analysed from their sitting posture and if that had an impact on how the interior space was perceived. The sitting postures are presented in the figure 7.13.

Figure 7.13: Presenting the four sitting posture categorizes used in this study. 'a' head on head rest, 'b' head off and body in a upright/natural posture, 'c' head positioned far forward and 'd' sitting in an extreme/awkward posture

7.1.2.5 Statistical Analysis - Minitab

The Minitab-19 software was used for the purpose of data analysis. The advantage of using the Minitab-19 was the ease of importing data from excel, as data was stored and summarized in excel and the ease for exporting the analysis results as tables and images to office packages such as excel and power point. The summarized data was stacked up in excel for the purpose of use in Minitab-19. The analysis results and charts presented in the *Results* section (7.3 - 7.9) are exported from the Minitab-19. The plots and graphs that are presented were arrived using *Graph* tab from the Minitab-19. The required graphs and the appropriate data were selected to get the desired graphs. The required tests like 2-sample t-test, correlation analysis and furthermore, were done using the *Stat* tab in Minitab-19. These test yields the appropriate results with pertaining graph, for example a box plot in case of 2-sample t-test.

7.2 Disposition of Results

This sub-chapter provides an overview of the disposition of the results from the analysis of phase 3. The following sub-chapters covers the result of 13 manipulations for four parameters (Cant rail, Belt line, C-pillar and Vertical height) with 34 participants, with additional parameters analysed as well (Spatial distances, eye position and sitting posture). The chapters are divided into these parameters, where pertaining analyses are presented with the methodology adopted from Huber (Huber, 2012).

To start with, results from analysis of the *Quality of data* are presented that enables to understand the data sets (section 7.4). This follows by the *Analysis of Ranking Trend* which helped in understanding the thoughts of the test persons before the manipulations were done (section 7.5). This is followed by the results obtained from the Vision parameters (section 7.6), Spatial distances (7.7), eye position (7.8) and sitting posture (7.9). In the *Discussion and Conclusion* parts, the findings are discussed and concluded by answering the relative research questions (RQ1-13). All the research questions require analysis from the whole test group but as well from two groups defined as Short and Tall. These two data sets are presented in the next section *Data grouping – Short and Tall* (section 7.3).

7.3 Data Grouping - Short and Tall

The test persons were divided into two groups, Short and Tall, based on their sitting height, for the purpose of comparative studies. The anthropometric data table (table 7.2) for the Swedish population was carried out from Lars Hanson's study (Hanson et al., 2009).

Table 7.2: Anthropometric data for the Swedish population

	Sitting Height (mm)				
	Min	**5th %-ile**	**50th %-ile**	**95th %-ile**	**Max**
Female	773	832	892	949	993
Male	841	883	946	1006	1029

Since only two groups were required, the mean of the 50th percentile (%-ile) was decided as the differentiating line where the gender was not accounted during the grouping. The 50th %-ile sitting height for male was 946 mm and for female was 892 mm. The mean of these two values was 919 mm and was considered to be the differentiating sitting height for the two groups. All test persons below 919 mm in sitting height were grouped in the Short group and there were 19 test persons in total; 13 females and 6 males. Test persons who had a sitting height at 919 mm or above were grouped in the Tall group and there were 15 test persons; 5 females and 10 males.

Some additional analyses were done for what was described as the extreme groups based on the sitting height. For this purpose, two new groups, Shortest and Tallest were formed. Based on the Swedish anthropometric data table 7.2, 5th %-ile and 95th %-ile were used for this differentiation. The 5th %-ile sitting height for male was 883 mm and female was 832 mm, and test persons below this value was grouped as Shortest and had 8 test persons. The 95th %-ile sitting height for male was 1006 mm and female was 949 mm and test persons above this value were grouped as Tallest and had 4 test persons in total. The analysis for the extreme groups are not presented in the report, however is placed in the Appendix E as additional analyses for the presented results in the report.

7.4 Quality of Data

In this section the results of the analysis pertaining to the quality of the data are presented. The data quality was analyzed on the grounds of data distribution based on sitting height, differentiation of the Short and Tall group, cluster analysis to identify similar data sets and item analysis to check for internal consistency in data. The inference from these data analysis are presented individually in the respective *Discussion and Conclusion* part.

7.4.1 Distribution Study and Normality Test

The distribution was studied based on the sitting height for the complete population of the test persons, the Short and the Tall groups. Histogram graph with a distribution curve line was simulated. The normal spread of data was evident from the obtained graphs. Figure 7.14 is visualizing the result of the distribution study obtained for the complete population of the test persons; 34 participants whereas 18 were females and 16 were male. Seen in the graph, the distribution was concentrated from a sitting height of 860 mm to 960 mm. These values were identified as the lower (Q1) and upper (Q3) quartile. Studying the mean value and the median they were calculated on a similar sitting height, a mean on 906 mm and a median on 907 mm. For a 95% confidence level the P-value for the Anderson-Darling Normality was 0.970. This means that the test persons were normally distributed based on their sitting height, hence a P-value lager than 0.05. Statistical analysis that require data to be normally distributed can be made valid.

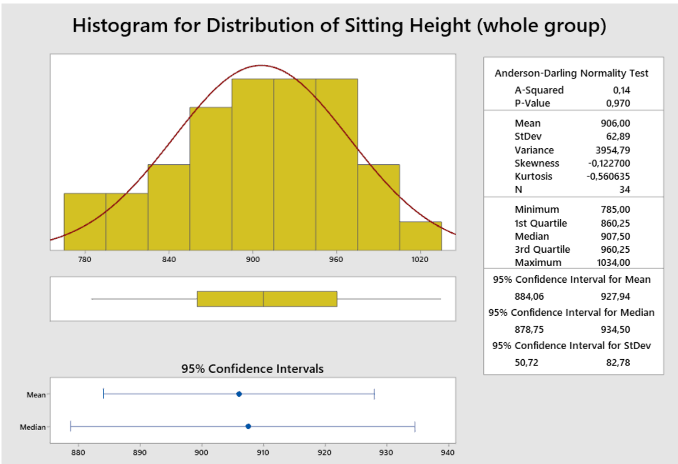
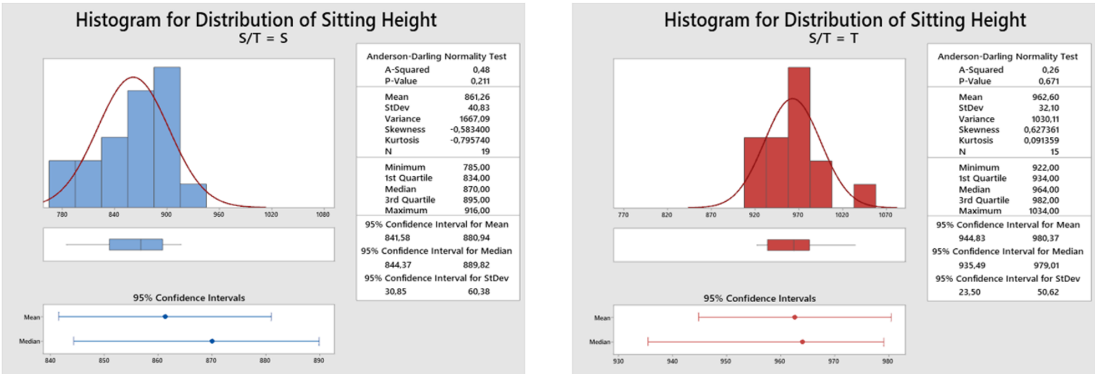


Figure 7.14: Histogram plot showing the distribution of whole group based on sitting height. Contains results from Anderson Normality test

The normality test was done for the Short and Tall group as well. Studying the Short group the density of the participants' sitting height laid between 834 mm and 895 mm. The median was 870 but the mean value was 861 mm. Looking at the graphs in figure 7.15 (a), it can be seen that most of the Short test people on the upper half of the range (Q2-Q3) were concentrated within a smaller range of sitting height compared to the lower range which was having a bigger spread. This was reflected upon the mean value which was higher than the median. The data distribution was still consider to be normal distributed due to a P-value lager than 0.05, in this case 0.22.

While studying the Tall group, it can be seen that the normal distribution was better, hence higher P-value (0.67). The mean value and the median fell approximately on the same value, having the mean at 963 mm and the median 964 mm. As seen in the graph in figure 7.15 (b), most of the participants had a sitting height between 934 mm and 982 mm.



(a) Short group

(b) Tall group

Figure 7.15: Histogram graphs showing the distribution of Short and Tall group based on sitting height. Contains results from Anderson Normality test

In this study the focus was to not do any distinction between the female and male, rather just accounting the sitting height. However, to understand if the collected data were reflecting a Swedish population's anthropometric data some analysis have been emphasised separating the data in gender; female (f) and male (m).

In the figure 7.16 a histogram with a fitted curve is illustrating the distribution of 18 female participants' sitting height. With a P-value above 0.05 the distribution was normal distributed. The mean value and the median was determined at approximately at the same value 874 mm.

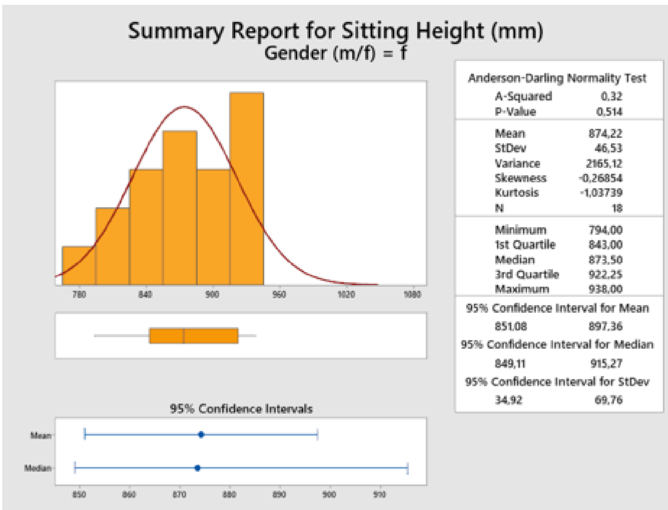


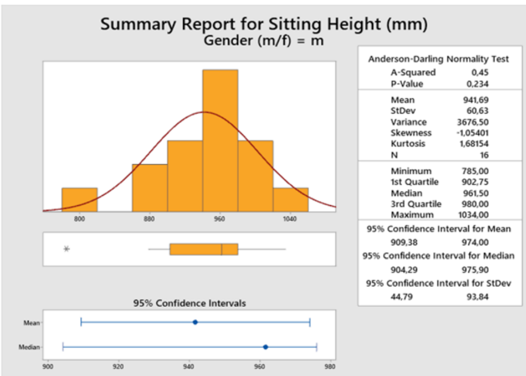
Figure 7.16: Histogram showing female test persons' distribution in sitting height

However, comparing Hanson's anthropometric data on the Swedish female population the collected data did not have the same property as Hanson's data, which can be studied in table 7.3. In general all the numbers of the collected data fell below the documented percentile value respectively. If studying the range between the 5th %-ile and the 95th %-ile the calculated difference was 27 mm longer for the collected data from this user study. In the same table 7.3, it is also possible to assess the calculated difference between the collected data's values and the documented Swedish sitting height, making it more evident of the differences between the values.

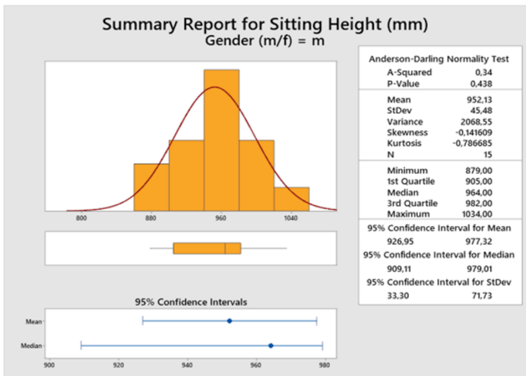
Table 7.3: Sitting heights values for the Swedish female population (Swe) and the 18 female test persons (TP). The row called *"Difference"* is the calculated difference between the data sets

	Sitting Height		
	5th %-ile	**50th %-ile**	**95th %-ile**
Female (Swe)	832	892	949
Female (TP)	794	873.5	938
Difference	-38	-18.5	-11

Furthermore, studying the 16 male participants' sitting height values, again it was determined to be normal distributed hence P-value>0.05 (0.23). An outlier was identified at a sitting height of 785 mm (see figure 7.17 (a)). A decision was taken to remove this participants during the analysis of the gender to get a result which can better represent the collected data. After the removal a new graph was generated with additional information seen in figure 7.16 (b). A mean value was calculated at 952 mm and the median was determined at a higher value at 964 mm. This can be understood with help of the box plot underneath the histogram where the spread was larger from Q1-Q2 (905-964 mm), compared to Q2-Q3 where the sitting heights were accumulated in the range of 964-982 mm.



(a) Histogram with outlier



(b) Histogram after removed outlier

Figure 7.17: Histogram showing male test persons' distribution in sitting height

Comparing the collected data with Hanson's anthropometric data about the Swedish population from the 50th %-ile and up, the collected data were laying above the Swedish data, and below it when studying the 5th %-ile value. Studying the range from the 5th %-ile and 95th %-ile the calculated difference was 32 mm, hence the collected data had a larger range. The row with the descriptive name *"Male (Swe)"* in table 7.4 are numbers taken from Hanson's study, representing the Swedish male population and the other row called *"Male (15)"* are values taken from the participants in the user test, not including the outlier hence 15 participants and not 16. In the row called *"Difference"* are the calculated differences in values between the collected data and the Swedish data.

Table 7.4: Sitting height values for the Swedish male population and 15 males participating the user test, excluding one outlier

	Sitting Height		
	5th %-ile	**50th %-ile**	**95th %-ile**
Male (Swe)	883	946	1006
Male (TP)	879	961.5	1034
Difference	-4	+15.5	+28

If then studying the whole test population with all 34 participants with the mean values from the Swedish females' and males' anthropometric data, which were used to divide the Short and Tall group there were differences in values. All of the data is presented in the table 7.5; *"Set-up (mean)"* is presenting the calculated mean values of the Swedish female and male values, and *"Test (34)"* is presenting the collected data. Moreover, a calculated difference from the desired mean value and the collected data is presented in the row called *"Difference"*. With a vast difference at the 5th %-ile the gap decreased at the 50th %-ile but later increased again and even went above the 95th %-ile value. This results in a much greater sitting height range from the 5th %-ile to the 95th %-ile of the collected data with a range of 203 mm, 83 mm longer than the Swedish data range.

Table 7.5: Sitting height values of the calculated mean compared to the collected data of 34 participants

	Sitting Height		
	5th %-ile	**50th %-ile**	**95th %-ile**
Set-up (mean)	857.5	919	977.5
Test (34)	799	908	1002
Difference	-58.5	-11	+24.5

Discussion and Conclusion

The results for all of the groups did show the same type of distribution which was normal distribution. The P-value for all the Anderson-Darling Normality Test showed above 0.05, which indicates that the null hypothesis (H0) became true; the data follow a normal distribution.

When comparing the test population's anthropometric data with the Swedish pop--ulation's there were some differences comparing the 5th/50th/95th %-ile values in sitting height. After some analyses of the collected data as a whole group, as well separated in female and male groups, the collected data did not match the Swedish population completely.

Looking at the 5th %-ile value for all the collected data, it is under representing the Swedish data and went below the desired value for all groups. A consequence for this is that the extreme group Shortest will then be below the average within that class compare to the Swedish population. Because majority of the participants in the extreme group Shortest were females (4 out of 5 TP), the results pertaining this group might be applicable for a sitting height 30 mm below the 5th %-ile in sitting height for Swedish females. While studying the 95th %-ile values might have the opposite problem, representing above the average of tall Swedish people in the extreme group Tallest, thus all test persons (4 TP) in the Tallest group were male.

By having a normal distribution for all groups, the values around 50th %-ile were dominantly represented in the test result. Because having a lower sitting height value for the 50th %-ile than the Swedish anthropometric data, except for the male group, the results are representing a population being around 10 to 20 mm shorter than the Swedes when studying the whole test population. However, the gap might be even bigger when just studying the Short group hence people had shorter sitting heights. Moreover, Tall group is represent a taller population than the Swedes. The table 7.6 is a summarized table with previous presented data.

Table 7.6: Summarized anthropometric data representing Swedish population and the collected data

	Sitting Height		
	5th %-ile	**50th %-ile**	**95th %-ile**
Female (Swe)	832	892	949
Female (18)	794	873.5	938
Male (Swe)	883	946	1006
Male (15)	879	964	1034
Set-up (mean)	857.5	919	977.5
Test (34)	799	908	1002

Covid-19 had partly an impact on this by making it harder to gather test persons, hence uncontrollable selection of test persons to a desired spread in sitting height. By having an even spread would provide stronger correlation analysis, but on the contrary it might be more difficult to find trends and patterns. This was furthered discussed and mentioned when analysing the parameters. It was a societal aspect to have an even distribution in gender and the same was planned during the user study. It was impossible to execute as there were restrictions in time and conducting user test during the Covid-19 period. A gender equality in test population was not achieved and it was decided to eliminate the parameter of gender from the analysis. Though it was a downfall on the societal aspects side, the trade-off decision was taken on ethical basis complete the thesis in the provided time frame.

7.4.2 Test for Differentiation

In order to check if the two groups (Short and Tall) represent two significantly different groups based on their sitting height, the test for differentiation was done. The assumptions of the 2-sample t-test was checked and are listed below from 1-5, before proceeding with the test in Minitab-19.

1. Sitting height is a numerical continuous data.
2. From the result of distribution study, the sitting height for Short and Tall group follows normal distribution.
3. The variances were not checked as Minitab 19 follows Aspin-Welch test as discussed in section 3.6.5.
4. The two samples are independent and there exists no relationship between the test person sitting height in one group to the other.
5. The whole test population was considered as sample and hence all have equal chances of getting selected in sample.

The P-value was found to be 0 which refers to statistically significant and the null hypothesis (H0) becomes invalid and was rejected. This means that the alternative hypothesis (H1) becomes true. Thus, can be concluded that the two groups were significantly differentiable based on their sitting height. The results for the 2-sample t-test can be seen in the figure 7.18.

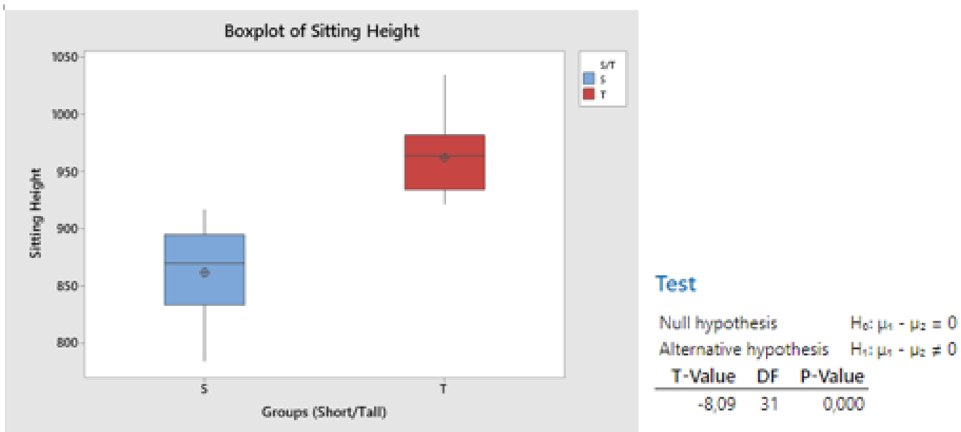


Figure 7.18: 2 sample t-test with boxplot for Short (blue box) and Tall (red box) group based on sitting height

Discussion and Conclusion

The two groups Short and Tall were then proved to be two significantly different groups with the 2-Sample t-test. It provides evidence that the groups represent significantly different groups based on their sitting height. This makes it possible to compare the data sets between the groups and conclude behaviors and trends that are distinctive for a specific group. This also makes provision to study the parameters based on the groups and establish results that can be valid only to one group in specific.

7.4.3 Cluster Analysis

The cluster analysis was done in order to understand the similarity between all the variables that were obtained from the user study against the response variable of the rating in the VAS; body height, sitting height, eye position in X- and Z-coordinate (EX/EZ), Vertical distance, Lateral distance and Diagonal distance, and the Vision parameters α, β and θ. In total 10 variables were studied that were described as available variables.

By doing this cluster analysis, the variables that have similar correlation with the response variable can be identified as clusters. By this knowledge, the further correlation tests and analysis can be planned, thus removing correlation tests of two similar variables. Figure 7.19 is the dendrogram obtained from the cluster analysis of all the available variables. The Y-axis of the graph is the measure of the similarity and the variables are listed along the X-axis. The horizontal lines represent the similarity measure and join the variables to form clusters.

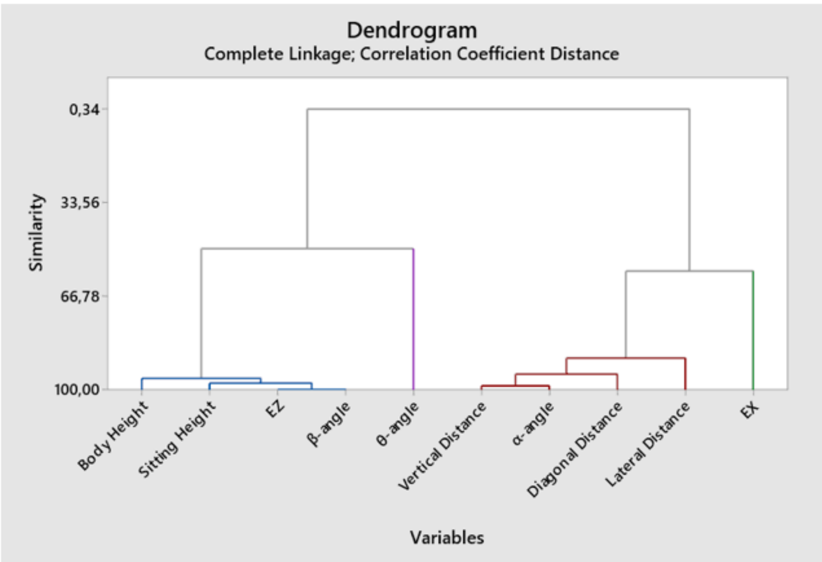


Figure 7.19: Dendrogram (initial) with all parameters showing clusters and similarity between the parameters

Fig 7.20, is the finally arrived dendrogram that represents the similarity between some distinct variables. In order to arrive to this dendrogram, the similar variables were removed for the next iteration of the cluster analysis. For example, in the cluster between EZ and β-angle, β-angle was decided to be removed based on the decision that it is studied specifically against the VAS rating (as per RQ2). Another similar decision was to remove body height from the cluster, as the Spatial distances

(Vertical/Lateral/Diagonal) are based on the sitting height. The sitting height and EZ (Z-coordinate of the eye position) formed a cluster and had a very high similarity about 95. Vertical and Diagonal distance formed a cluster with high similarity and this cluster indeed formed a cluster with Lateral distance of similarity 85. It can be seen that the EX (X-coordinate in eye position) was distinct from the other variables and did not have any correlation between other variables.

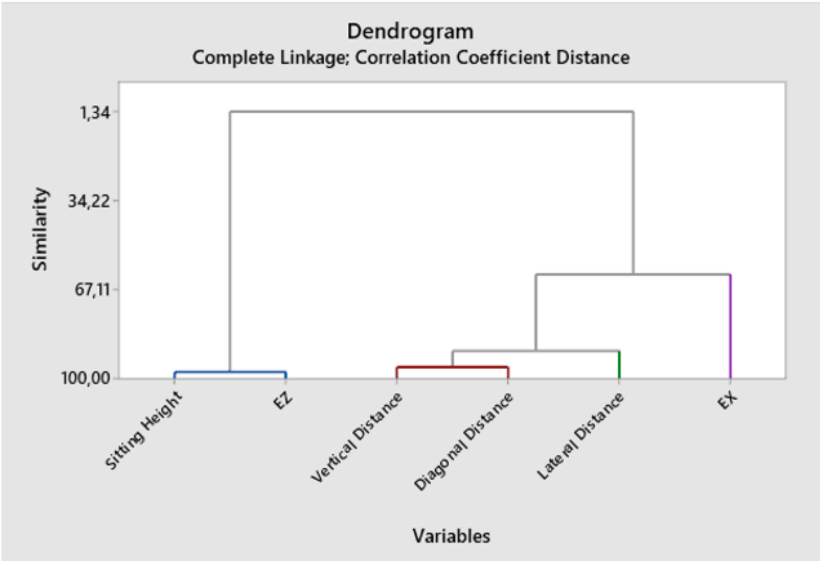


Figure 7.20: Dendrogram with six parameters showing the cluster and similarity between the parameters

Discussion and Conclusion

From the cluster analysis, clusters with very high similarity in the predictor variables existed. The non-correlated variation in the X-coordinate of the eye position (EX) might be due to some other factors regarding the sitting posture. These analyses are presented later in chapter 7.9.

One important conclusion is that while designing future experiments to study upper interior space in rear seat, just one of the predictor variable from identical cluster should be chosen due to reflection on similar or same statistical result. Either the sitting height of the test person or the Z-coordinate of the eye position needs to be reclaimed and analysed. However, the choice of predictor variable is highly subjective to the type of study and experiment. But a person's sitting height is much more easily assessed compared to the Z-coordinate of the eyes. Two other predictor variables with high similarity were the Vertical distance and Diagonal distance. In other words, one variable can be neglected for analysis of the same sort. With the observation from user study, it is seen that measuring the diagonal distance was more difficult than the vertical distance and hence can be avoided. Again, this decision is subjective to the type of study, experiment or the required results.

7.4.4 Internal Consistency

The perception of the upper interior space of the test persons was assessed using a Visual Analogue Scale (VAS). The reliability in the use of a VAS for studying perception of head roominess was checked by studying the consistency of the indivi--dual test person's ability to give the same subjective rating for the same judgement several times during a period of time. During the user study, the test persons had to rate the nominal state of the car four times in random instances. These four ratings were used to study the consistency of the users in rating the perception of upper interior space (internal consistency).

The item analysis to check for internal consistency was done to arrive at a Cronbach's Alpha value. The ratings of the four different manipulation instances when the test person's rated the upper interior space were used as variables for the item analysis. The Cronbach's Alpha value was found to be 0.978 which is greater than the benchmark value of 0.7. This value of Cronbach's Alpha was said to have 'excellent' reliability in internal consistency. Hence, it can be inferred that the test persons were highly consistent in rating their perception of the upper interior space by using a VAS scale.

Discussion and Conclusion

The VAS was proven to be reliable in measurement of pain by various authors including (Eliav & Gracely, 2008), but there were very less or no evidence that VAS could be used a reliable scale to assess the upper interior space in car. Hence it was necessary to study its reliability to use in the assessment of the upper interior space. As a result of the Cronbach's Alpha test, for an alpha 0.964 it can be said that users were consistent in rating the upper interior space. This proves the following hypothesis to be true.

H1: Users can be consistent in their rating assessment of perception of interior spaces.

The advantage of using a VAS to arrive at objective values for the perception can be harvested to perform statistical analysis. With this internal consistency the response variable from the VAS can be compared between different parameters and be interpreted in a comparative way. This comparison can be perception of upper interior space between cars, or different position in cars or different set-ups in the same position of the car.

7.5 Analysis of Ranking Trend

In the beginning of the user study six pre-defined parameters (Belt line height, Cant rail height, C-pillar rearward position, Vertical distance, Lateral distance and Diagonal distance) were ranked in a paired comparison method with help of a mobile application called "Pairwise comparison". In total fifteen paired comparison were created and a list of ranked parameters were generated. In this section it is discussed if a trend was found on how the parameters were ranked for the Short and Tall group, and if it differs between the groups. Two perspective are analysed where one is where all percentages are summarized for respective parameter, and the other analysis is focusing on the top three ranked parameters for all participants in the respective groups; Short and Tall.

7.5.1 Sum of Percentage

While the app was generating a ranked order of the parameters, a percentage was also calculated referring to how much the concerning parameter was influencing the person's perception regarding the upper interior space, which was used when ranking the parameter. All the determined percentages for the six parameters for all 34 participants were summarized in the Short and Tall group, and the result is presented in figure 7.21.

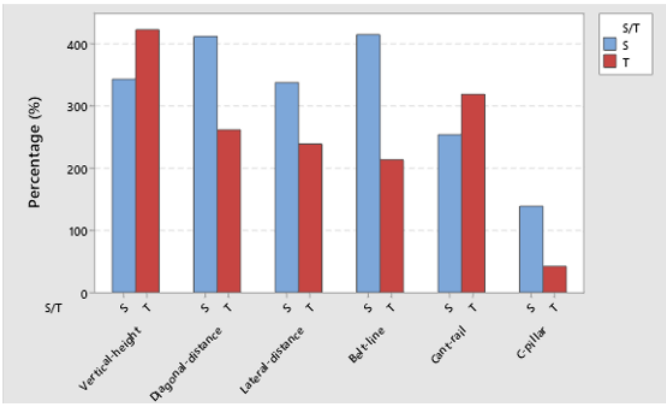


Figure 7.21: Histogram presenting the summarized percentage for respective parameter in Short (S) and Tall (T) group

Table 7.7: All the ranked percentages added together and summarized in Short and Tall group for respective parameter

	Sum of Percentage					
	Vertical	**Diagonal**	**Lateral**	**Belt line**	**Cant rail**	**C-pillar**
Short	343	412	338	415	254	139
Tall	423	262	239	214	319	42

In this graph (figure 7.21) it is possible to see a general understanding of how the distribution of the percentages been allocated between the 6 parameters in the different groups. Table 7.7 has summarized all the percentage values in Short and Tall group. For the Tall group (red staples) Vertical height (Vertical distance) has got the highest sum of percentages (423 %) and can be concluded as the most affecting parameter in how the test persons will perceive the upper interior space. C-pillar got the lowest percentage at 42% and will be concluded to have least impact on the perceived roominess in the XC90. If arranging the parameter in a falling order the Vertical height will come first, followed by Cant rail, Diagonal distance, Lateral distance, then Belt line and lastly C-pillar.

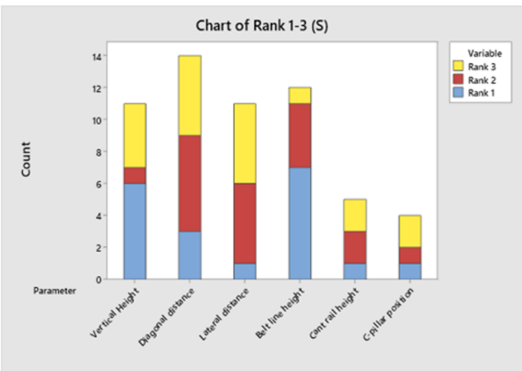
When checking the ranking trend for the Short group, they have ranked Belt line and Diagonal distance in a similar way as highly affecting parameters of how they perceive the upper interior space in the XC90. C-pillar was once again ranked as the least influential parameter. Arranging the parameters in a falling order of importance will have the following sequence: Belt line, Diagonal distance, Vertical distance, Lateral distance, Cant rail and C-pillar in the end. Together with the Tall group's ranking order the arrangement are presented in the table 7.8.

Table 7.8: Presenting Short and Tall group's sequence of parameters that are affecting them the most in a falling order

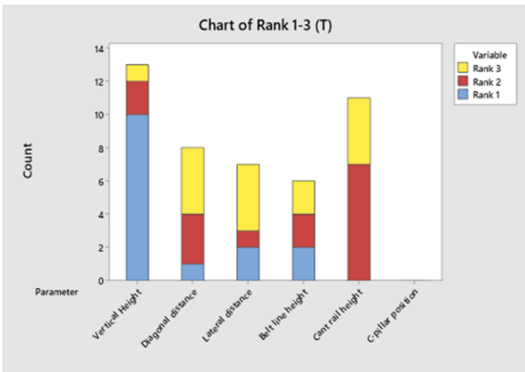
Falling Order	**1**	**2**	**3**	**4**	**5**	**6**
Short	Belt Line	Diagonal	Vertical	Lateral	Cant rail	C-pillar
Tall	Vertical	Cant rail	Diagonal	Lateral	Belt line	C-pillar

7.5.2 Top 3 Parameters

Because the values from the analysis *Sum of percentage* is more reflecting a general perspective of how the parameters have been ranked in Short and Tall group. The ranking trend showing in table 7.8, was compared against a ranking order generated by the count of picking a parameter as the top 3 parameters of importance, by mean having a great impact of how the roominess was perceived.



(a) Short group



(b) Tall group

Figure 7.22: Presenting the amount of times a specific parameter has been ranked as either 1, 2 or 3 as the most influential parameter, where 1 indicates the highest rank

The histogram seen in the figure 7.22, are presenting how many times a specific parameter has been picked as one of the top 3 parameters. It is even distinguished in a colour code how many times the parameter has been chosen for a specific ranking; rank 1 (blue), rank 2 (red), rank 3 (yellow). If then arranging the parameters once again in a falling order of the count by how many times the parameter have been picked as a top 3 most influential parameter, then the sequence looks a bit different from the previous created table 7.8. The new order is presented in table 7.9.

Table 7.9: The order of most affecting parameter in a falling arrangement from the count as a top 3 parameter

Falling Order	**1**	**2**	**3**	**4**	**5**	**6**
Short	Diagonal	Belt line	Vertical	Lateral	Cant rail	C-pillar
Tall	Vertical	Cant rail	Diagonal	Lateral	Belt line	C-pillar

When comparing the order in table 7.9 with the previous order generated in *Sum of Percentage* it is not much that are differentiating the two tables. The blue marked words (1 & 2) are indicating a change. Compared to the previous arrangement Belt line height and Diagonal distance have swooped their place with each other for the Short group. When looking into the graphs for the Short group both Vertical distance and Lateral distance were at the same level with a total count of 11. Vertical distance was still chosen to have a higher rank than Lateral distance due to a higher ratio of being ranked as number 1 (marked as blue in the staples in figure 7.22 (a)).

7.6 Analysis of Vision Parameters

The results from the analysis of Vision parameters; Cant Rail, Belt line and C-pillar, are presented in this section. All results include for the whole group and then for the Short/Tall group. First, the distribution of the VAS rating for the parameter positions are presented using box plot. This is followed by the pattern analysis using line plots to understand the trend in the VAS ratings. Discussion about the comments from the user study are presented followed by the correlation analysis of the angle to the parameters and then arriving at the discussion about the acceptance angles. The research questions pertaining to the specific parameters are answered in the *Discussion and Conclusion* section of every parameter analysis.

7.6.1 Cant Rail

The position of the Cant rail was studied against its influence in the perception of the upper interior space in the rear seat. With the VAS ratings of the upper interior space from the test persons, graphs and interpretations were made based on the research questions and the data analysis methodology. The answer for all the relative research questions and hypotheses are given in the end. For the different graphs, the alphabet 'A' denotes the Cant rail followed by its respective positions 1, 2 and 3.

The hypotheses and research question this section answers are:

> *H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space.*

H3: Tall group of people are more sensitive to changes in Cant rail position while assessing the upper interior space.

H6: The test persons have similar critical angle to the parameters.

RQ 1. How is the position of Cant rail influencing the Visual Analogue Scale (VAS) rating of perceived upper interior space?

7.6.1.1 VAS Rating and Position

In order to study the distribution of the VAS ratings for the different Cant rail positions box plot graphs were simulated. Figure 7.23 shows the distribution of the ratings for the various Cant rail positions; nominal state, A1, A2 and A3, based on the whole group of test persons.

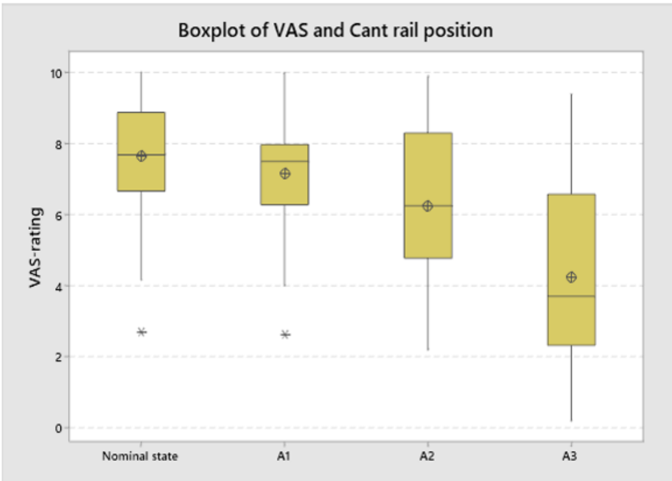


Figure 7.23: Boxplot showing the distribution of VAS rating for the various positions of Cant rail (nominal state, A1,A2 and A3)

The interquartiles defined by the upper and lower quartile of the VAS rating, represented by the range boxes in figure 7.23, are summarized in table 7.10. The mean value of the VAS-rating for the different levels are also presented in the table, visualized as a crossed circle in the figure 7.23. What the numbers can tell is that the range became bigger with the higher level of change of the Cant rail. Furthermore, the lower the Cant rail was moved a lower VAS mean was determined.

Table 7.10: Summarized Q1, Q3 and mean values for the various position of Cant rail

	Nominal state	**A1**	**A2**	**A3**
Q1	6.7	6.3	4.8	2.3
Q3	8.9	9.0	8.3	6.6
Mean	7.7	7.2	6.3	4.2

The visible outliers in the nominal state and A1, marked as a star in table 7.23, pertain to a test person who will be referred as TPx25 in this report. The test person was the tallest in the population and had the most constrained Spatial headroom. Since the rating was acceptable, it was decided not to remove the test person from further analysis.

The box plot was interpreted by using 2-sample t-test to check the difference between the levels in VAS rating to understand if a difference was perceived compared to the previous level. The P-values are summarized in the table 7.11. As a reminder, a P-value higher than 0.05 means that the H0 will be accepted which signify similarity between the data sets. In the table 7.11 it is evident that the test persons have perceived the nominal state and A1 to be similar and then A1 and A2 to be similar in their perception.

Table 7.11: Summarized P-values of the whole group for the comparing levels of VAS-rating

Comparing levels	**Nominal - A1**	**Nominal - A2**	**Nominal - A3**	**A1 - A2**	**A2 - A3**	**A1 - A3**
P-value	0.240	0.003	0.000	0.050	0.000	0.000

The same analysis was done but for the Short and Tall group to compare the result between them. Figure 7.24 is a similar box plot analysis as previously for the whole group. It was interpreted in a similar way regarding the distribution of the rating on the VAS. A lower VAS rating was given as the Cant rail was manipulated further down. A bigger interqurtile range was also determined for A3 compared to the other levels, especially for the Tall group. The Q1, Q3 and mean value of VAS for the different levels are summarized in table 7.12.

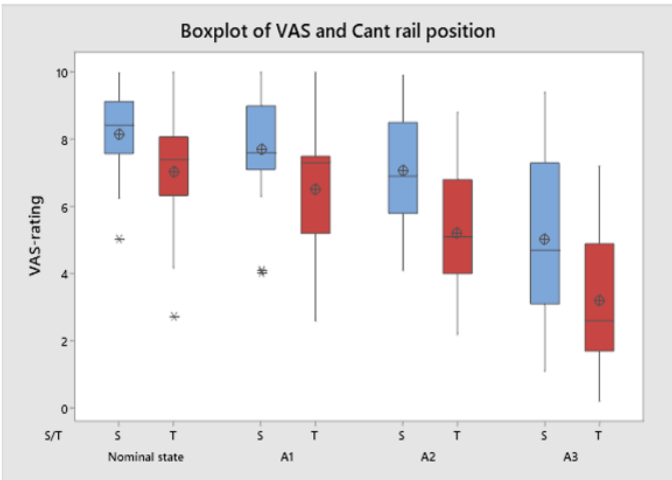


Figure 7.24: Box plot showing the distribution of VAS rating for the various positions of Cant rail (nominal state, A1, A2 and A3) between Short and Tall group

The outliers in the Tall group for nominal state pertains to the same test person as previously, TPx25. For the Short group two test persons, named TPx04 and TPx24, were identified as outliers. Studying their data, TPx04, an outlier in A1, has just been given a low rating in general. While for TPx24, an outlier in the nominal state as well in the A1, the expectation exceeded the experience of how spacious the car would be in vertical distance, hence disappointment arose with a low VAS rating.

By both looking at the figure 7.24 and the values in table 7.12, the Short group has consistently a higher mean value than the Tall group. This can be interpret as the Short group not being as negatively affected by the change in Cant rail than the Tall group.

Table 7.12: Summarized Q1, Q3 and mean values for the various position of Cant rail for Short and Tall group

	Nominal		**A1**		**A2**		**A3**	
	S	**T**	**S**	**T**	**S**	**T**	**S**	**T**
Q1	7.6	6.3	7.1	5.2	5.8	4.0	3.1	1.7
Q2	9.1	8.1	9.0	7.5	8.5	6.8	7.3	4.9
Mean	8.2	7.0	7.7	6.5	7.1	5.2	5.0	3.2

In order to understand if there was any significant difference in the VAS rating between the Short and Tall group for the different positions of the Cant rail, a 2-sample t-test was used. With the P-values summarized in table 7.13, the positions A2 and A3 had a significant difference in the VAS-rating for the Short and Tall group. The P-value was less than 0.05 meaning that the alternative hypothesis was retained. While for the nominal state and A1 the given VAS rate were similar for both of them.

Table 7.13: P-value presented from the 2-sample t-test between the Short and Tall group for the Cant rail positions

Comparing levels	**Nominal State (S-T)**	**A1 (S-T)**	**A2 (S-T)**	**A3 (S-T)**
P-value	0.066	0.060	0.008	0.025

Further, it was interesting to study the influence of the change in the position of the Cant rail on the perception of the upper interior space. For this purpose, line plots were made to see the rating difference between the changing levels between the groups. In the figure 7.25 the rating of the different levels are compared to the mean of the VAS rating of the nominal state. The rating of the nominal state was then placed at 0. The position A1 had a less and equal impact on both the Short and Tall group. Both groups had a similar trend with the positions A2 and A3. However, Tall group had a greater influence in the VAS ratings with change in positions of the Cant rail by having the red line under the blue line which is representing the Short group. Additional analysis was done where the VAS rating difference was studied from the previous change, and not compared to the nominal state, see figure 7.26. Visualized in the figure, it is evident that the Tall group (red line) was equally impacted for every change in Cant rail. However, the position A3 had the greatest impact on the Short group which is reflected by a greater negative change from A2 to A3.

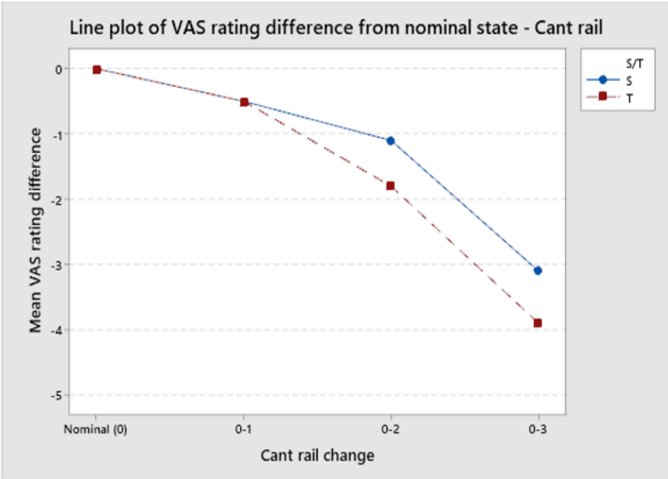


Figure 7.25: Line plot visualizing the difference in VAS rating compared to the given rating in nominal state of the Cant rail. The blue coloured dots and lines represent the Short group and red coloured marks represent the Tall group

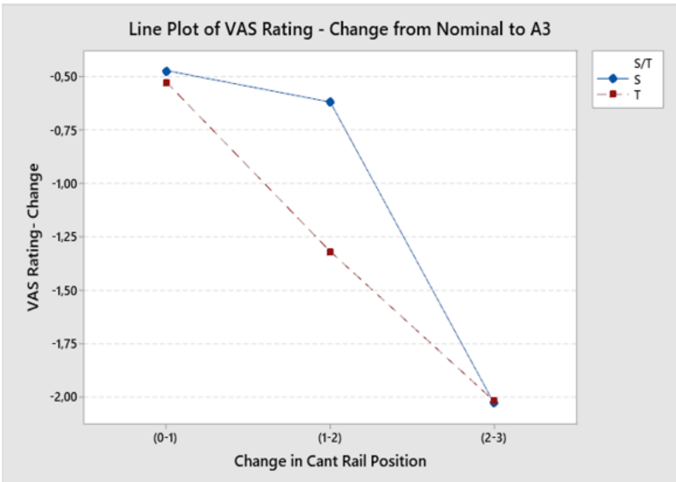


Figure 7.26: Line plot showing the difference in VAS rating compared to previous change of Cant rail. The blue coloured dots and lines represent the Short group and red coloured marks represent the Tall group

7.6.1.2 Comments from Test Persons

During the manipulation of the Cant rail comments providing complementing information about how the change affects the person were documented. Those comments are summarized as statements with the amount of test person who also had mentioned/observed the same thing, divided in groups (S/T). Following table 7.14 presents the commonly mentioned aspects regarding the change in Cant rail.

Table 7.14: Commonly mentioned comments as description and the respective counts for Short and Tall group

Comments from test persons (Description)	Short (Count)	Tall (Count)
Reminds of a sun visor	0	3
Getting darker	2	1
Not affecting upper interior space	2	3
Reducing the visibility	3	5
Not acceptable for XC90	2	1

7.6.1.3 VAS Rating and Angle

To study if there was any correlation between the α-angle and the respective VAS rating, a Person correlation coefficient test was done. The generated scatterplot is presented in figure 7.27 with a fitted regression line. 136 points were included into the plot, which represent all the determined α-angles for the whole test group and all Cant rail changes. The determined correlation coefficient was 0.676 which can be stated as a moderate to high correlation. The regression line can be interpreted as that with increase in α-angle, the VAS rating increased which in turn means that it improves the spacious feeling of the upper interior space.

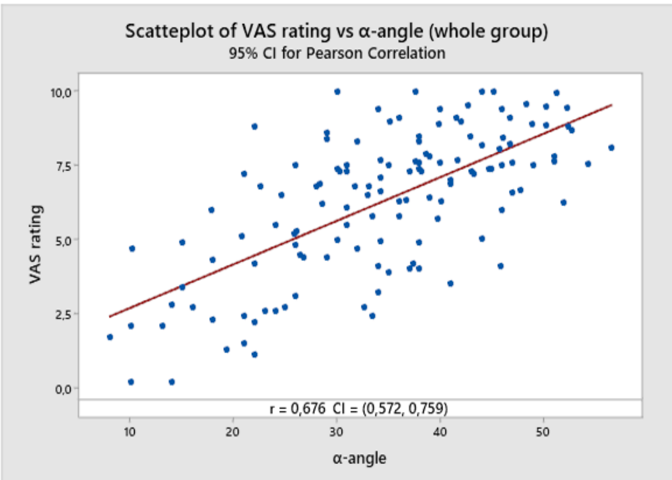


Figure 7.27: Scatterplot of α-angle and VAS rating for all the determined Cant rail changes

Further, the similar correlation studies was extended for the Short and Tall group (go to Appendix F for Scatterplots). The correlation coefficient for the Short group was 0.559 which was a moderate correlation. However for the Tall group it was 0.700 which can be stated as high correlation. The Tall group had a much higher correlation to the α-angle than the Short group.

7.6.1.4 Last Acceptable Angle

During the user study the question of acceptance for every manipulation were asked and was used to identify the last acceptable level for every parameter. In the table 7.15, the last acceptable level is presented in the groups of Short and Tall. The last acceptable level for the Short group was evenly spread on A2 and A3, while for the Tall group majority of the people accepted A2.

The pertaining angle to these levels for every test person was derived and named as acceptance angles which were studied for the whole population and within the groups. The distribution of the acceptance angle for the total test group and the Short and Tall group was studied using histogram and the Anderson-Darling normality test.

Table 7.15: The count of the identified last acceptable level for Short and Tall group

Level	Short (count)	Tall (count)
Nominal	0	1
A1	0	2
A2	10	8
A3	9	4

Seen in the histogram (figure 7.28), regarding all test persons, it can be seen that the P-value for Anderson-Darling normality test was calculated to be 0.280, which implies that the acceptance angle for the Cant rail follows a normal distribution. The mean value of the acceptance angle was 29 degrees and the values lies between 13-46 degrees. However, majority of the test person chose the last acceptable angle to be between 23 to 34 degree, determined from Q1 and Q3.

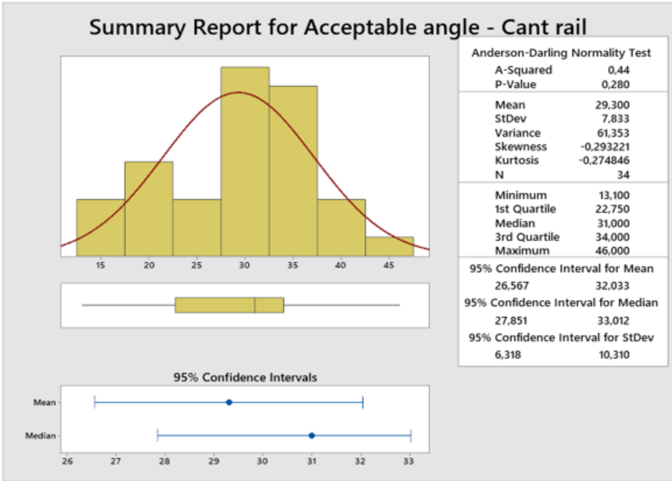
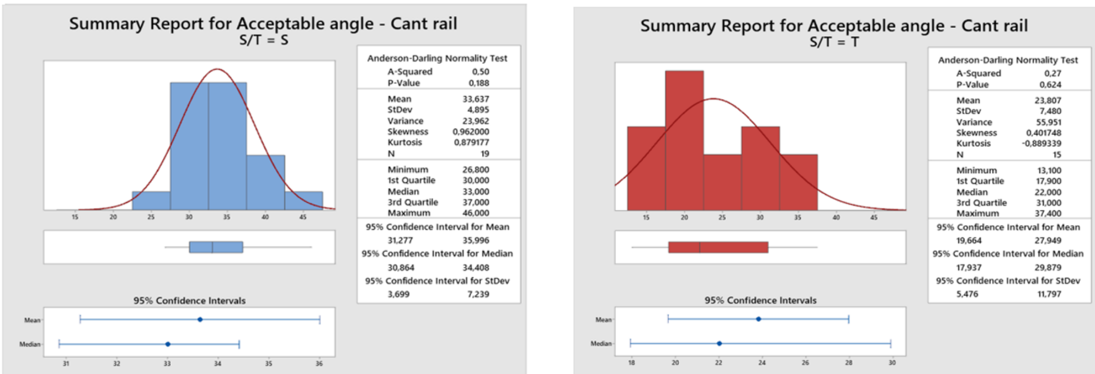


Figure 7.28: Histogram with a distribution fit for the whole test group

Similar normality test was done for the Short and Tall group, see figure 7.29. The P-values were greater than 0.05 and denoted that the values were normally distributed. For the Short group the mean value was 34 degrees and the range was between 27-46 degrees. The lower quartile (Q1) and upper quartile (Q3) were identified as 30 and 37 degree. For the Tall group the mean value was 24 degrees and the range was between 13-37 degrees, with Q1 as 18 and Q3 as 31.



(a) Short group (b) Tall group

Figure 7.29: Histogram with a distribution fit for acceptance angle

A 2-sample t-test (Appendix G) was performed to test the differentiation between the Short and Tall group for the acceptance angle to the Cant rail. The calculated P-value was 0.00, which implies that the null hypothesis falls invalid and the alternative hypothesis becomes true. In other words, the two groups had significantly different acceptance angles for the Cant rail.

7.6.1.5 Discussion and Conclusion

From the established result presented in the section VAS rating and position of the Cant rail, the Tall people have been rating the perception of head roominess lower than the Short group. This is true when studying the mean and upper/lower quartile in the table 7.12, when comparing the Short and Tall group. As a result from the 2-sample t-test and what can as well be seen in figure 7.25, the Tall group did provide a lower rating on the VAS for position A2 and A3 than the Short group. With help of these results, the hypothesis H3 can be answered.

H3: Tall group of people are more sensitive to changes in Cant rail position while assessing the upper interior space. - True

This was evaluated true. The visibility upward-outward restricted by the position of Cant Rail had affected the Tall group more than the Short group. However, the nominal state and A1 was perceived similar for both the groups, meaning a difference was first seen in A2 and A3. When studying the whole group, the nominal state of the car and A1 was perceived similarly. This means, by moving the Cant rail to position A1 did not have significant influence in the VAS rating of the perception of upper interior space. Described in the method 7.1.1.3), the position of Cant rail was moved 40 mm for each manipulation along the curvature of the outer body of the car. For every participant every change of 40 mm was also converted to an angle determined form their eye point, to understand if every change was of similar character. The calculated mean from one level change in degrees, from all participant, is resumed in the table 7.16.

Table 7.16: Cant rail change presented in degrees, determined by the mean from all 34 participants

Manipulation of cant rail position	**Nominal-A1**	**A1-A2**	**A2-A3**
Mean of change in degrees from eye position	7.0	6.9	7.1

Seen from the table 7.16, every 40 mm change means an angle change of approximately 7 degrees. One reason to explain the similarities in VAS rating between the nominal state and A1 can be due to the reason that the change was not that noticeable to affect the perception of head roominess. The initial starting point of the Cant rail should then be moved further down, because a difference was achieved from A1-A2 and A2-A3. From this inference, future experiments should be designed by pursue a significantly different perception for every manipulation. By having a starting point from A1 instead and going 7 degrees further down than A3, might be a better design of the experiment.

When studying the alpha angles and their correlation to the VAS rating, a moderate to high correlation was found for the whole test group at 0.68, and as well for the Tall group at 0.70. This falls in line with the result from the Identification phase that the Tall group was more sensitive or affected by the changes in the position of the Cant rail (H3). By knowing that the Tall people were more affected and as well having a strong correlation, they should be the group to involve in studies regarding the Cant rail and be considered when taking design decisions.

From the results of the acceptance angle study, it was evident that the Tall people had a smaller acceptance α-angle of 18-31 (Q1-Q3). While the Short group had a larger acceptance α-angle of 30-37. A reason why a lower acceptance angle for the Tall group might be reflected on the comments they provided during the user study. Comment like *"reminds of a sun visor"* and *"not affecting the upper interior space"* either reflects a positive feeling for the Cant rail change or a neutral attitude, thus accepting lower changes. Another argument might as well be that the taller people exhibit compensatory behaviour as they are used to be exposed to a more constrained space in a car. Because the XC90 might have provided more space than what they were used to a lower acceptance angle were accepted.

While for the Short group comments like *"it is getting darker"* and *"not acceptable for XC90"* reflects on more negative subjective feelings and might have had been reflected on their choice of the last acceptable angle. This proves that the Short and Tall people have different critical angle towards the Cant rail in their perception of what is acceptable in terms of the interior space in a XC90. The hypothesis H6 can then partly be answered, in regards to the Cant rail to be false.

H6: The test persons have similar critical angle to the parameters. - False

By studying the received comments, reduced visibility was stated 8 times during the manipulation of the Cant rail. This makes it also tangible with hypothesis H2.

H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space. - True

The Cant rail was restricting the visibility upward-outwards. Together with the earlier conclusions that the changes in Cant rail was affecting the perceived roominess, there exist a linkage between the visibility and the perceived roominess and H2 can be stated to be true, in regards to the Cant rail.

With these discussions and conclusions, the following RQ can be answered with a summary of this chapter.

RQ 1. How is the position of Cant rail influencing the Visual Analogue Scale (VAS) rating of perceived upper interior space?

The position of Cant Rail had affected the perception of upper interior space seen in all the analysis done with the VAS. Tall group was however more sensitive to the changes than the Short group, and should be considered to be the group to do design related evaluation regarding the Cant rail. However, even if the Tall group was more affected by the change they were also accepting smaller angles for the last acceptable α angle. By this mean, the Short group should be taken into consideration for this aspect. There exists a moderate correlation with α-angle and VAS rating for the whole group (0.68) and the Tall group exhibiting a high correlation (0.70).

7.6.2 Belt line

Belt line was studied against its influence in the perception of the upper interior space in the rear seat of the XC90. With the VAS ratings, graphs and interpretations were made based on the research questions and the data analysis methodology. The alphabet 'B' denotes the Belt line in the graphs followed by its respective positions 1, 2 and 3. All the relative research questions and hypothesis for the Belt line are discussed in the *Discussion and Conclusion* part.

The hypotheses and research question this section answers are:

> *H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space.*
>
> *H4: Short group of people are more sensitive to changes in Belt Line position while assessing the upper interior space.*
>
> *H6: The test persons have similar critical angle to the parameters.*
>
> *RQ 2. How is the position of Belt line influencing the VAS rating of the perceived upper interior space?*

7.6.2.1 VAS Rating and Position

The box plot chart was made to study distribution of the VAS ratings for the different Belt line positions. Figure 7.30, shows the distribution of the ratings for the various Belt line positions; nominal state, B1, B2 and B3, based on the whole test group.

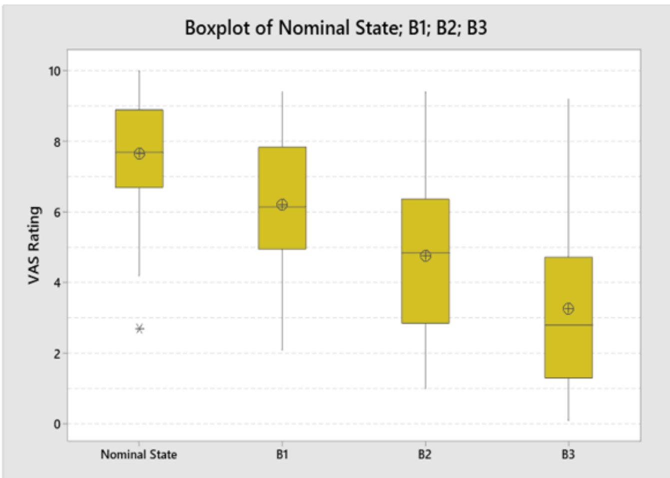


Figure 7.30: Box plot showing the distribution of VAS rating for the various positions of Belt line (nominal state, B1,B2 and B3)

The range the boxes in the figure 7.30 are bounded by are the upper and lower quartiles (interquartile) of the VAS rating. The interquartile and the mean values (represented as circle with cross in figure 7.30) are summarized in the table 7.17. It is evident from the mean values that the VAS rating was lowered with every change in the position of Belt line. Also, the range becomes larger with higher position of the Belt line.

Table 7.17: Summarized Q1, Q3 and mean values for the various position of Belt Line.

	Nominal state	B1	B2	B3
Q1	6.7	5.0	2.9	1.3
Q3	8.9	7.9	6.4	4.7
Mean	7.7	6.2	4.8	3.3

The visible outlier in the nominal state pertain to the test person TPx25 and as discussed earlier. The reason is that being the tallest test person and the user had to be squeezed into the constrained space. 2-sample t-test was used to interpret the box plot to study the difference between the levels in VAS rating to understand if a difference was perceived compared to the previous level. The P-values are summarized in the table 7.18. All the P-values were found to be less than 0.05. It can be interpret as when comparing the changed levels to the nominal state, they have all been rated differently. 2-sample t-test was used to interpret the box plot and the results are summarized in the table 7.18.

Table 7.18: Summarized P-values of the whole group for the comparing Belt line's levels of VAS rating

Comparing levels	Nominal - B1	Nominal - B2	Nominal - B3	B1 - B2	B2 - B3	B1 - B3
P-value	0.001	0.000	0.000	0.004	0.007	0.000

The distribution analysis of the VAS rating for the Short and Tall group for the various positions of the Belt line are presented in a box plot, see figure 7.31. It was interpreted in a similar way regarding the distribution of the rating on the VAS for whole group. A lower VAS rating was given as the Belt line was manipulated further up. For the Short group, the interquartile range became bigger along with a higher positioned Belt line, compared to the Tall group. This can be interpret by a heterogeneous rating and that the Short group was experiencing mixed feelings regarding how the B3 was affecting the upper interior space. The Q1, Q3 and mean value of VAS for the different levels are summarized in table 7.19.

The outliers in the Tall and Short group for the nominal position pertains to the test person TPx25 and TPx24 for the Short group. These test persons have been identified earlier, where the TPx25 is the very tall person and TPx24 expected better roominess for the XC90 .

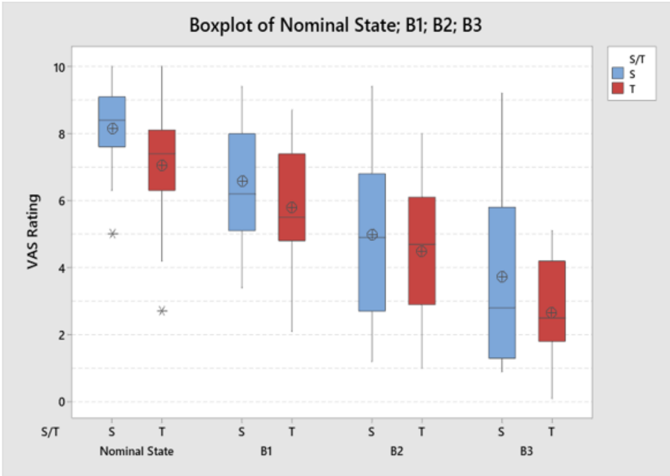


Figure 7.31: Box plot showing the distribution of VAS rating for the various positions of Belt line (nominal state, A1, A2 and A3) between the Short (blue marked) and Tall group (red marked)

Table 7.19: Summarized Q1, Q3 and mean values for the various position of Belt line for Short and Tall group

	Nominal		**B1**		**B2**		**B3**	
	S	**T**	**S**	**T**	**S**	**T**	**S**	**T**
Q1	7.6	6.3	5.1	4.8	2.7	2.9	1.3	1.8
Q2	9.1	8.1	8.0	7.4	6.8	6.1	5.8	4.2
Mean	8.2	7.0	6.6	5.8	5.0	4.5	3.7	2.6

If just studying the mean value for the Short and Tall group (marked as the crossed circle in figure 7.31) the Short group's mean was constantly calculated higher than the Tall group's. This is going against the hypothesis believing that the Short group would be more negatively affected than the Tall group. However, by doing a 2-sample t-test the differences of the VAS rating between the Short and Tall were determined with respect to the standard division and variations of the sample. In table 7.20, all the P-values for from the 2-sample t-test are tabulated. All the P-values were found to be above 0.05 meaning the groups did not differentiate from each other between the two groups. Thus, it can be said that every position of the Belt line had similar influence on the Short and Tall group.

Table 7.20: P-value presented from the 2-sample t-test between the Short and Tall group for the Belt line positions

Comparing levels	**Nominal State (S-T)**	**B1 (S-T)**	**B2 (S-T)**	**B3 (S-T)**
P-value	0.066	0.228	0.510	0.150

Further, line charts were simulated to study the influence of the change in the position of the Belt line on the perception of the upper interior space. In the figures

7.32 and 7.33, Y-axis represents the change in VAS rating from the nominal state (0) and the X-axis represents the different change in positions of the Belt line from the nominal state. Analyzing the pattern from the line plot 7.32, all the positions of the Belt line had equal impact on the Short and Tall group with a steady decreasing trend. Observed in figure, the blue line is below the red line indicating a larger difference, hence influence from the nominal state for the Short group. However, known form the 2-sample t-test, there was no difference in how the Short and Tall group perceive the changes in Belt line.

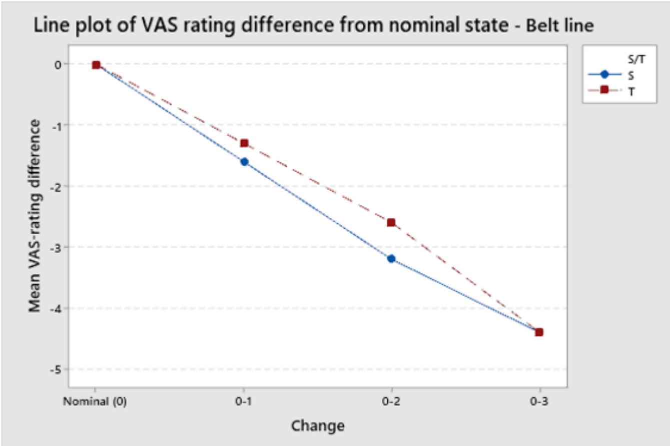


Figure 7.32: Line plot visualizing the difference in VAS rating for the different Belt line positions, compared to the mean of the nominal state. Blue represent Short group, Red represent Tall group

Figure 7.33 is the line plot for analyzing the change in the VAS rating from the previous positions of the Belt line. X-axis represents the change in positions and Y-axis is the corresponding change in VAS rating. Looking upon the pattern, it was interpreted that for Tall group (red line) change from B2 to B3 had a comparatively high impact denoted by the steep decline than change from B1 to B2. For short group (blue line), the change from B2-B3 had a comparatively lesser impact than change from B1 to B2 which was denoted by steep increase. This trend was inverse to what is seen for the Tall group, as the line goes in the opposite direction for change B2-B3.

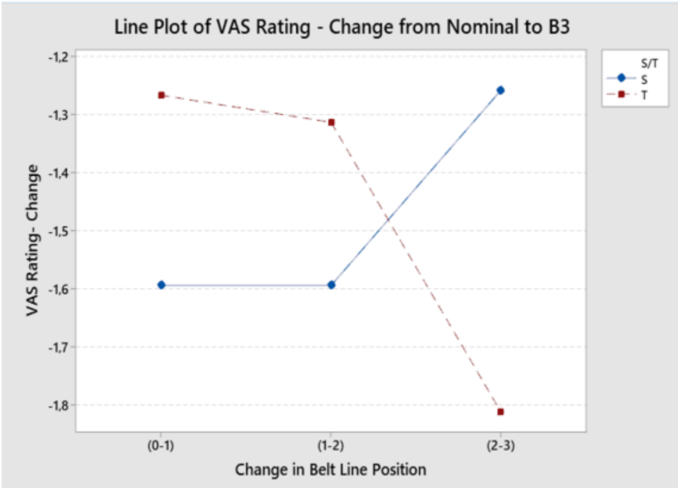


Figure 7.33: Line plot visualizing the difference in VAS rating for the changes in the position of Belt line. Redline represents the Tall group and the blue line represents the Short group

7.6.2.2 Comments from Test Person

During the manipulation of the Belt line comments providing complementing information about how the change affected the person were documented. Those comments were summarized as statements with the amount of test person who also had mentioned/observed the same thing, divided in the groups (S/T). Following table 7.21 presents the commonly mentioned aspects regarding the change in Belt line.

Table 7.21: Commonly mentioned comments as description and the respective counts for Short and Tall group

Comments from test persons (Description)	Short (Count)	Tall (Count)
Motion sickness	2	2
Affecting the roof	1	1
Not affecting upper interior space	4	1
Reducing the visibility	7	3
Not acceptable for XC90	2	1

7.6.2.3 VAS Rating and Angle

To study if there was any correlation between the β-angle and the respective VAS rating, a Pearson correlation coefficient test was done. Figure 7.34 presents the generated scatterplot, the X-axis represents β-angle and the Y-axis is the corresponding VAS ratings with a fitted regression line. 136 points were obtained of all the β-angles for every position of the Belt line for the whole test group. From the scatterplot, it is seen that the points are highly dispersed with no specific trend or clusters hence a low r-value at 0.2 concluding no correlation for the whole test group.

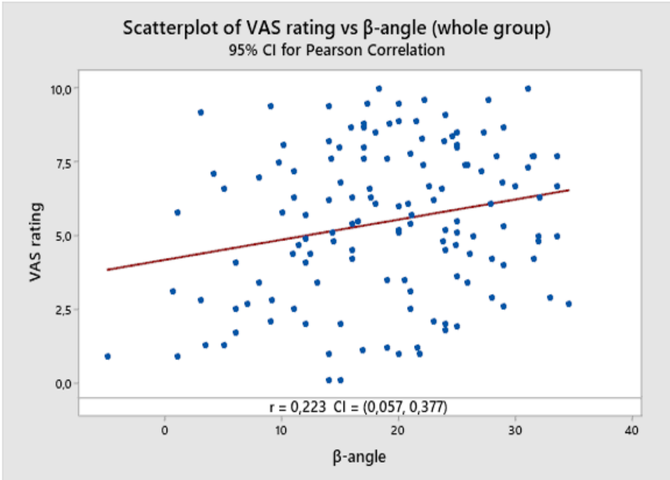


Figure 7.34: Scatterplot of β angle and VAS rating for all the determined Belt line changes

Further, the similar correlation study was extended for the Short and Tall group (the scatter plots are presented in Appendix F). The correlation coefficient for the Short group was 0.447 and 0.427 for the Tall group. The values reflected a better correlation between the VAS and β angle, however it is still indicating a low correlation.
Studying the regression line, it can be interpreted as that with increase in β-angle (Belt line positioned low) there is an increase in VAS rating. This means increasing the β-angle can increase the spacious feeling of the upper interior space.

7.6.2.4 Last Acceptable Angle

Similar to the manipulations of the Cant rail, acceptance for the position of the Belt line was documented and was used to identify the last acceptable level. In the table 7.22, the last acceptable level are presented in the groups of Short and Tall. For the Short group majority of the people just accepted the first two levels (B1/B2). While for the Tall group the higher levels were also accepted.

Table 7.22: The count of the identified last acceptable level for Short and Tall group, regarding Belt line positions (nominal, B1-B3)

Level	**Short (count)**	**Tall (count)**
Nominal	4	2
B1	7	3
B2	5	6
B3	3	4

The pertaining β angles to these levels for every test person was derived and named as acceptance angles which were studied for the whole population and within the groups. The distribution of the acceptance angle for the total test group and the

Short and Tall group was studied using histogram and the Anderson normality test. In figure 7.35, regarding all test persons, it can be seen that the P-value for the normality test was 0.530. This implies that the acceptance angle for the Belt line followed a normal distribution. The mean value of the acceptance angle was 19 degrees, the values lies between 1-32 degrees. However, majority of the test person lies between 14 to 25 degrees, determined from Q1 and Q3.

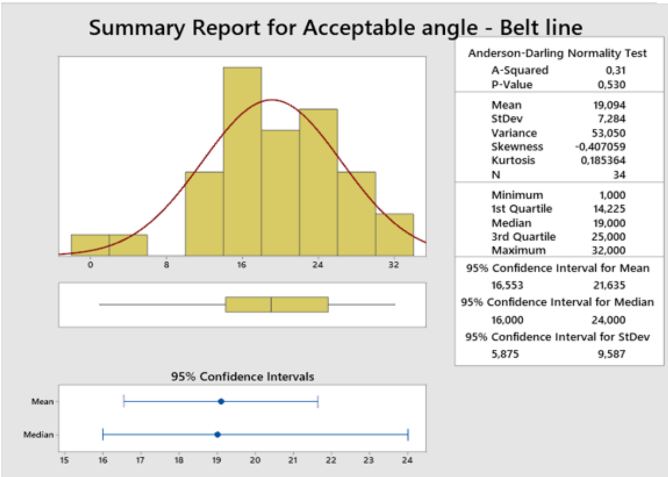
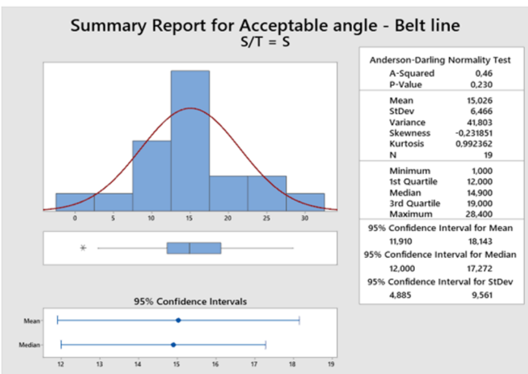
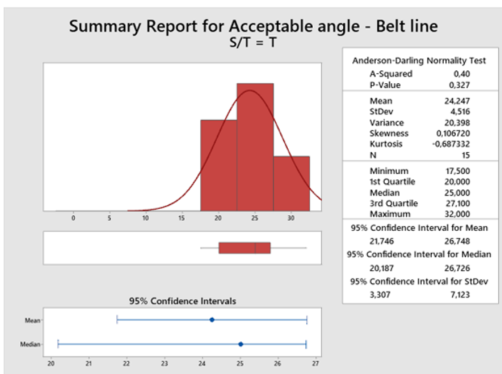


Figure 7.35: Histogram with a distribution fit for the whole test group of Belt line's acceptance angles

Similar normality test was done for the Short and Tall group. The P-values were greater than 0.05 and denoted that the values were normally distributed. For the Short group the mean value was 15 degrees and the range laid between 1-28 degrees where the lower quartile (Q1) and upper quartile (Q3) were identified as 12 and 19 degrees. For the Tall group the mean value was 24 degrees and the range was between 18-32 degrees, with Q1 as 20 and Q3 as 27. This information can be visualized in the figure 7.36.



(a) Short group



(b) Tall group

Figure 7.36: Histogram with a distribution fit for acceptance angle

The arrived acceptance angle for the Short and Tall group were tested for differentiation. The P-value was found to be 0.00 by the 2-sample t-test (presented in Appendix G), it can be stated that the acceptance β angle was significantly different for the two groups.

7.6.2.5 Discussion and Conclusion

When studying the VAS rating for the Belt line positions for the whole group, it was concluded from the 2-sample t-test that every position was perceived differently. There existed a decreasing rating trend for the interior space along with a higher position for the Belt line. One of the entering hypothesis for phase 3 was that the Short group would be more affected by the change. However, this was concluded not to be true after comparing the VAS rating of the various positions between Short and Tall. The two groups were equally affected by the change. The following hypothesis will then be stated false.

H4: Short group of people are more sensitive to changes in Belt line position while assessing the upper interior space. – False

The similar trend was also identified analysing the line plot for VAS rating change from the nominal position, see figure 7.32. Thus, it can be stated that the visibility downward-outward restricted by the position of Belt line had similar influence on the Short and Tall group. Strengthen by the comments received during the change of Belt line, 10 test persons (7 Short and 3 Tall) mentioned that the change did restrict the vision out, which in turn affected their perception of roominess. This inference answers hypothesis H2 to be true.

H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space, – True

When studying the β-angles and their correlation with the VAS rating, just low correlation was established for all of the groups. Recognized during the study the Belt line did not just influence on the aspects regarding the visibility out and the perceived roominess. It was revealed to be a much more complex than the other Vision parameters where the question of safety and perceived security contradicts the roominess aspect. As the position of Belt line was moved upward, some test persons reported that it created a feeling of safety. Even if it was on the down fall for the perceived roominess, the change did still create a positive experience due to perceived protection. On the other hand, some test persons, especially from the Short group, was dissatisfied with the position of Belt line already in the nominal state and stated that it was too high up and created a feeling of enclosure and compared it with sitting in a bath tub. Some other people said it did not affect the perceived roominess at all and other stated that with the restriction of sight might cause motion sickness. Two interesting comments was on how the roof was perceived after the change in Belt line. One did perceive the roof to be higher and perceived the space to be more spacious and another perceived it to be the opposite, that the roof got lowered hence space perceived narrower.

These contradicting outcomes and a disorder in how to interpret the positions of Belt line can be the reason that the test persons did not establish a high correlation with the β-angle and the VAS rating. Further investigation and studies on the Belt line are encouraged to understand the emotions Belt line provokes and give rise to. Also, which ones to prioritize in regard to design. Furthermore, the study of acceptance angles have shown that the acceptance angle for Belt line for Short group (12-19) and Tall group (20-27) were significantly different from each other. This means that the critical position of the Belt line was different for the groups. This answers the following hypotheses to be false.

H6: The test persons have similar critical angle to the parameters. – False

On a concluding note to summarize the discussions about the study of the Belt line, the following RQ is answered.

RQ 2. How is the position of Belt line influencing the VAS rating of the perceived upper interior space?

The position of Belt line had affected the perception of upper interior space which is evident from all the analysis done with the VAS rating. Both the groups were affected similarly by the manipulation of Belt line. On the other hand, both the groups had dissimilar acceptance angles of β; the Short group accepted smaller β-angles than the Tall group. Due to the complexity the Belt line brings in terms of evoking various feelings in different aspects (visibility, roominess, safety), there was no statistical correlation established between the β-angle and the VAS rating for the whole test group nor Short/Tall group.

7.6.3 C-pillar

In line with the analysis done for Cant rail and Belt line, the results of the analysis of C-pillar are presented in the same chronological order. The letter 'C' represents the C-pillar in the graphs and numbers 1, 2, 3 represents its position. All the relative research questions and hypothesis for the C-pillar are discussed in the *Discussion and Conclusion* part.

The hypotheses and research question this section answers are:

H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space.

H5: Position of C-pillar has an equal effect on the Short and Tall group while assessing the upper interior space.

H6: The test persons have similar critical angle to the parameters.

RQ3: How is the position of C-pillar influencing the VAS rating on the perceived upper interior space?

7.6.3.1 VAS Rating and Position

The whole test groups's distribution of the VAS ratings for the different positions was studied in box plots, see figure 7.37. The boxes represent the interquartile that were bounded by the upper (Q3) and lower quartile (Q1). The mean was represented by the circles with cross line. The quartiles along with the mean are summarized in the table 7.23.

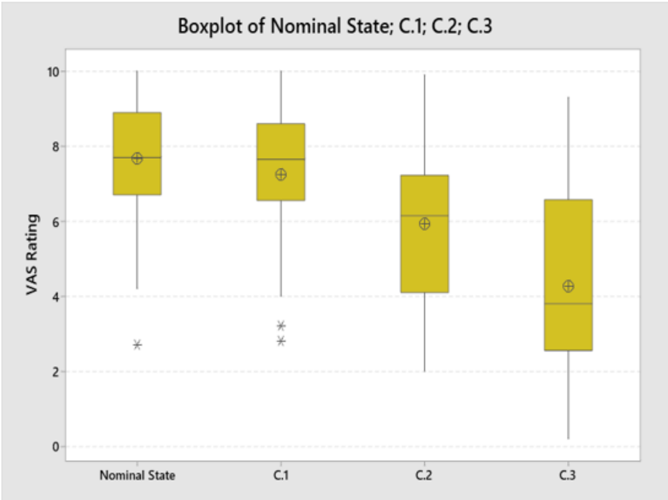


Figure 7.37: Box plot showing the distribution of VAS rating for the various positions of C-pillar (nominal state, C1, C2 and C3)

Table 7.23: Summarized Q1, Q3 and mean values for the various position of C-pillar

	Nominal state	C1	C2	C3
Q1	6.7	6.6	4.1	2.6
Q3	8.9	8.6	7.2	6.6
Mean	7.7	7.2	5.9	4.3

It is seen that nominal state and C1 had similar interquartile denoting that the two positions were perceived in a similar way. For positions C2 and C3 the range became larger and there was a decrease in the mean of the VAS rating of the perceived upper interior space, see figure 7.37. The visible outlier in the nominal state and A1 pertain to a test person who is referred as TPx25 in this report. The test person was the tallest in the population and had the most constrained Spatial headroom. The TP had provided a similar VAS rating for nominal state and C1. Another outlier in position C1, corresponds to TPX15. The test person had mentioned that the lower ratings were due to the reason that the roominess was not acceptable to the XC90 (SUV) car.

To be able to interpret if the VAS rating for the manipulated levels were perceived differently in comparison with the other levels a 2-sample t-test was used. The results are summarized in the table 7.23. With a P-value greater than 0.05, position C1 was perceived similar to the nominal state. C2 and C3 had significant difference from nominal state and between them as well.

Table 7.24: Summarized P-values of the whole group for the comparing C-pillar's levels of VAS rating

Comparing levels	Nominal - C1	Nominal - C2	Nominal - C3	C1 - C2	C2 - C3	C1 - C3
P-value	0.307	0.000	0.000	0.008	0.003	0.000

The similar distribution analysis was done for the Short and Tall group for the various positions of the C-pillar, see figure 7.38. The box represents the interquartile (Q1 and Q3) and mean values is represented by the circles with cross line. These values are summarized in the table 7.25. The calculated mean of the VAS rating was decreasing along with a more forward position with the C-pillar, for both groups (S/T). While studying the Short group's interquartile, C3 had a much larger range compared to the other C-pillar positions. In comparison to the Short group, the Tall group had much larger ranges, due to diversified VAS rating within the group.

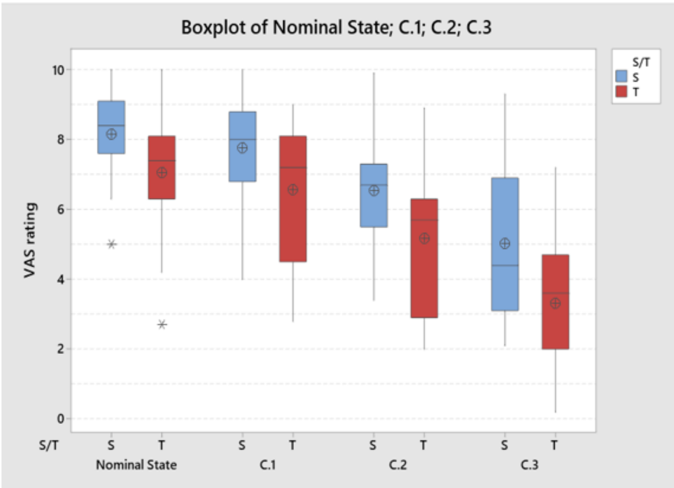


Figure 7.38: Box plot for VAS rating distribution for Short and Tall group

The box plots changed independently from each other for the Short and Tall group. Meaning that the positions C1, C2 and C3 had varied from the nominal state in terms of influencing for both the Short and Tall group. The outliers in the Tall group for nominal state pertains to the same test person as previously, TPx25. While the outlier in Short group pertains to TPx24, where the expectation exceeded the experience of how spacious the car would be in the vertical distance, hence disappointment arose with a low VAS rating. With the figure 7.38 and table 7.25, the VAS rating had a decreasing mean value for change in C-pillar position for both the Short and Tall group. Also, the Tall group have been consistent with low mean VAS rating than the Short group. This means that the Tall group were more negatively influenced by change in C-pillar than Short group.

Table 7.25: Summarized Q1, Q3 and mean values for the various position of C-pillar for Short and Tall group

	Nominal		C1		C2		C3	
	S	T	S	T	S	T	S	T
Q1	7.6	6.3	6.8	4.5	5.5	2.9	3.1	2.0
Q2	9.1	8.1	8.8	8.1	7.3	6.3	6.9	4.7
Mean	8.2	7.0	7.8	6.6	6.5	5.2	5.0	3.3

The difference in the VAS rating between the Short and Tall group for the different positions of C-pillar was studied by interpreting the box plot using 2-sample t-test. The P-values are tabulated in table 7.26. Positions C1 and C2 had a P-value greater than 0.05, indicating no significant difference between the Short and Tall group in the VAS rating. Position C3 have a P-value less than 0.05 denoting there was a significant difference in the VAS rating and thus a different perception between Short and Tall group. Despite a shown difference of the mean value in table 7.26, for the nominal, C1 and C2, the perceived upper interior space was identified to be similar between the Short and Tall group, except for C3.

Table 7.26: P-value presented from the 2-sample t-test between the Short and Tall group for the C-pillar positions

Comparing levels	Nominal State (S-T)	C1 (S-T)	C2 (S-T)	C3 (S-T)
P-value	0.066	0.070	0.060	0.030

In order to study the influence of the change in positions of C-pillar on the perception of the upper interior space, line plots were plotted for change in positions against the change in VAS rating, see figure 7.39. The X-axis represents the change in position of C-pillar from nominal state (0) and Y-axis is the change in the VAS rating.

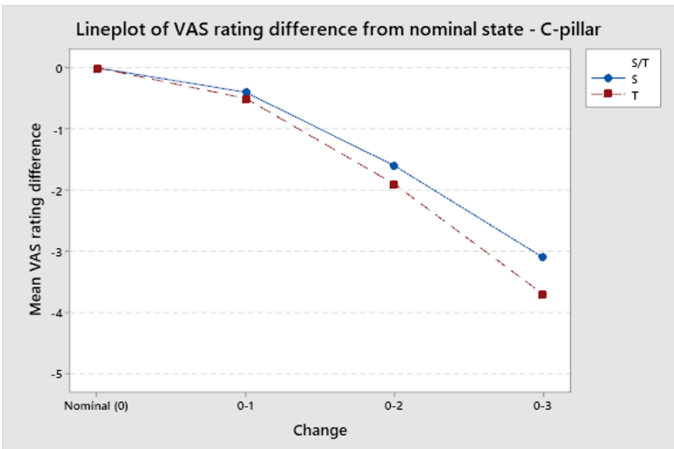


Figure 7.39: Line plot visualizing the difference in VAS rating for the changes in the position of C-pillar from nominal state. Red line represents the Tall group and the blue line represents the Short group

Blue line represents the Short group and the red line represents the Tall group. From the line plots, the various positions of C-pillar were affecting the perception of the upper interior space for both the Short and Tall group in a similar way. However, the position of C3 had more influence on the Tall group than the Short group. This may be due to the upward inclination of the C-pillar (inclined angle) thus making it more evident for the Tall group. Figure 7.40 is the line plot for change in VAS rating against the change in position of C-pillar from the previous position. In this plot it is more explicitly understood of how the change in VAS rating changes with every change. For Short and Tall group, the change from C1 to C2 had more influence on their perception than change from C2 to C3. This pattern requires further investigation and may be due to the angle in which the C-pillar was inclined and the presence of the window divider obstructing the view laterally out.

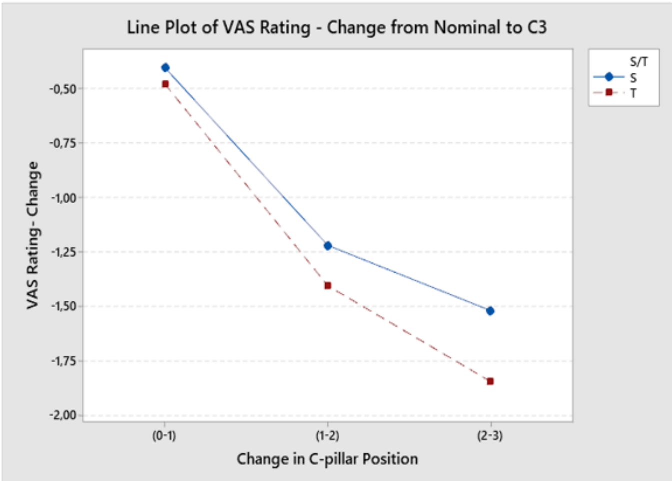


Figure 7.40: Line plot visualizing the difference in VAS rating for the changes in the position of C-pillar . Red line represents the tall group and the blue line represents the short group

7.6.3.2 Comments from Test Persons

During the manipulation of the C-pillar comments providing complementing information about how the change affects the person were documented. Those comments are summarized as statements with the amount of test person who also had mentioned/observed the same thing, divided in groups (S/T). Following table 7.27 presents the commonly mentioned aspects regarding the change in C-pillar.

The comment about *"feeling prolonged"* was mentioned twice from participants in the Short group. The meaning of "prolonged" was interpreted as the feeling of sitting further back, similar to be sitting in a limousine for example, due to a restricted view to the side caused by the C-pillar change.

Table 7.27: Commonly mentioned comments as description and the respective counts for Short and Tall group

Comments from test persons (Description)	Short (Count)	Tall (Count)
Not affecting space	5	0
Restricting Vision	5	5
Not acceptable in a XC90	2	0
Feeling prolonged	2	0

7.6.3.3 VAS Rating and Angle

Correlation analysis was done to study the relationship between the θ-angle and perception of upper interior space based on the VAS rating. Pearson correlation test was done and the resulting scatterplot is presented in figure 7.41. The X-axis represents the θ-angle and the Y-axis is the VAS rating. The regression line is represented by the red line, witnessing an improved VAS rating for larger θ-angles. 136 points were plotted for all the determined θ-angles for the whole group. The Pearson correlation coefficient was found to be 0.512 which just about indicates a moderate correlation.

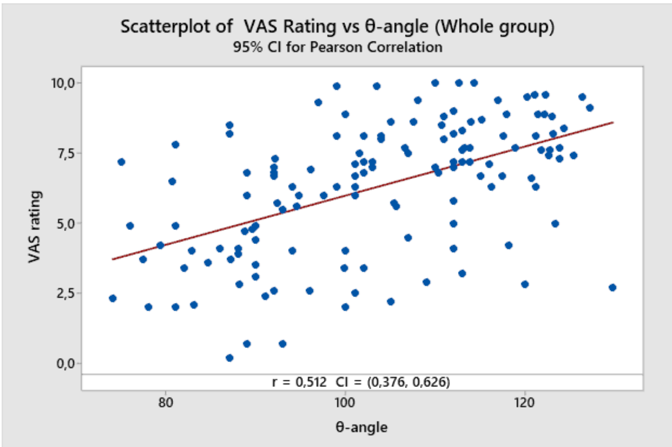


Figure 7.41: Scatterplot of θ-angle and VAS rating for all the determined C-pillar changes

The similar correlation study was extended to Short and Tall group (scatterplots presented in Appendix F) The Pearson correlation coefficient was found to be 0.641 for Short group which is a moderate correlation and 0.400 for Tall group which reveals no correlation between the θ-angle and VAS rating.

7.6.3.4 Last Acceptance Angle

In line with the last acceptable angle for α and β-angle, the θ-angle was also studied. The last acceptable level for the position of C-pillar is summarized in the table below (table 7.28). The choice of last acceptable level was widely spread across the levels for both Short and Tall group, and no specific level did stand out to be the most chosen one.

Table 7.28: The count of the identified last acceptable level for Short and Tall group, regarding Belt line positions (nominal, C1-C3)

Level	Short (count)	Tall (count)
Nominal	0	1
C1	5	5
C2	6	4
C3	8	5

The pertaining angle to these levels for every test person was derived and named as acceptance angles which were studied for the whole population and within the groups. The distribution of the acceptance angles for the whole test group and the Short and Tall group was studied using histogram and the Anderson normality test. The P-value was found to be 0.25 hence the angle was normally distributed for the whole test group. The mean value was determined to 98 degrees with value lying between 76 and 118 degrees. Additionally, the quartiles laid between 90 and 105 degrees. This information can be extracted from figure 7.37.

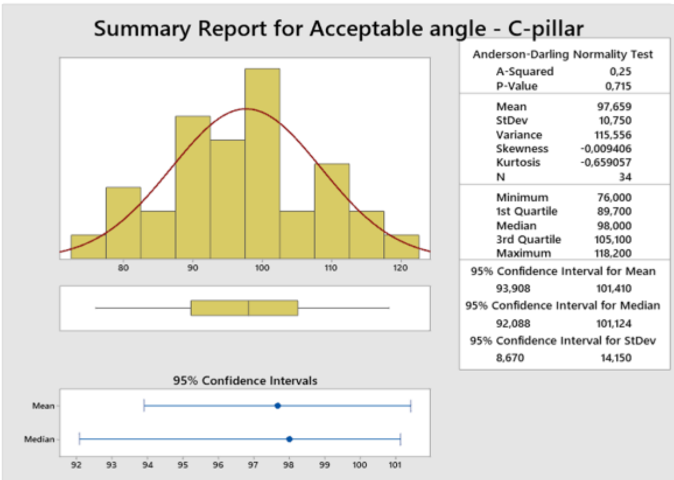
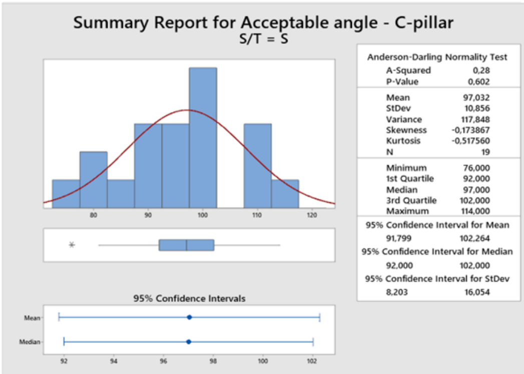
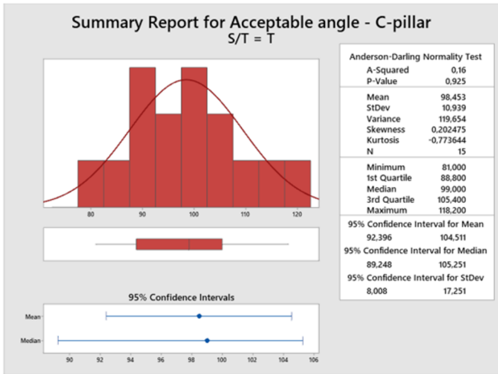


Figure 7.42: Histogram with a distribution fit for the whole test group of C-pillar's acceptance angles

Similar normality test was determined for the Short and Tall group, see figure 7.43. The P-values were all greater than 0.05 which as per Anderson normality test follows normal distribution. The calculated mean values for the Short and Tall group was 97 and 98 respectively, which falls at the same value as the determined mean for the whole group. The Q1 and Q3 were identified as 92 and 102 degree for the Short group, and 89 and 105 for the Tall group.



(a) Short group



(b) Tall group

Figure 7.43: Histogram with a distribution fit for acceptance angle in S/T

A 2-sample t-test was done (presented in Appendix G) to study the differentiation of the acceptance θ-angle between the Short and Tall group. The P-value was found to be 0.708, which means that the Short and Tall group have similar acceptance angle for the θ-angle. In contrast to the other identified acceptance angle, it is calculated to be the same for both Short and Tall group regarding the C-pillar.

7.6.3.5 Discussion and Conclusion

From the results of the analysis of VAS rating and position of C-pillar, a decreasing VAS rating was given with a further forward manipulated C-pillar. However, it was first after C1 a decrease was identified, meaning that the change to C1 from the nominal state did not affect the perceived roominess. The upper interior space was perceived similarly between the Short and Tall group for most of the levels except for C3 where the Tall group was influenced much more by the change than the Short group. In table 7.29, the mean θ-angle value were calculated for every manipulation level for C-pillar in the respective Short and Tall group. By studying the θ-angle for every level a better understanding was comprehended for why Short and Tall group perceive the change differently in C3.

Table 7.29: Mean θ-angle determined for every C-pillar level, separated in S/T group

θ angle	Nominal	C1	C2	C3
Short	120	110	99	87
Tall	120	109	97	84

With the help of the table 7.29, it is clearly seen that the Tall group as a smaller θ-angle in comparison to the Short groups mean value. Due to the angled C-pillar, inclining forward towards the front in the upper end of the pillar, a smaller theta angle will be identified for the same change for the Tall group than for the Short group, seen in the table 7.29. Furthermore, referring back to a similar VAS rating of the nominal state and the C1 change can be due to the large θ-angle. The C-pillar might not be in the peripheral vision until after C1, resulting in unawareness of the first change, if not the test person is rotating the upper body or head to see the change.

By analyzing the comments from the user test, where only the Short people have been stating that the C-pillar change did not affecting the space makes it also evident that the Short group was less affected by the C-pillar.

The observation from the Identification phase was that the influence of C-pillar in affecting the perception of head roominess would be similar to the Short and Tall group. This is coinciding with the results where the Short and Tall group have been rating the C-pillar positions of C1 and C2 similarly. However, the Tall group was more affected by the C3. The following hypothesis would then to be partly true.

H5: Position of C-pillar has an equal effect on the short and tall group while assessing the upper interior space. – True (C1/C2)

The dissimilarity only in position C3 has given an opportunity to further investigate the position of C-pillar with respect to presence of the window divider in the peripheral view of the users. The presence of window divider with respect to the eye position was analyzed and the results are discussed in the section 7.7.3.2.

The similarity in perception was also evident from the acceptance θ-angle for the Short and Tall group. Irrespective of the group, the acceptance angle was found to be similar with a mean of 98 degrees. This make the below mentioned hypothesis to be true only for C-pillar.

H6: The test persons have similar critical angle to the parameters. – True for C-pillar.

The Pearson correlation value between the θ-angle and the corresponding VAS rating was found to be 0.51 for the whole group. This denotes a moderate correlation between them. Therefore, it exists a linear relationship between θ-angle and the perception of the upper interior space based on the VAS ratings. The Short group exhibit a near to high; moderate correlation (0.64) with the θ-angle and the Tall group has no correlation (0.40) with θ-angle. Thus, with all these discussions it can be concluded that the position of C-pillar did affect the perception of head roominess. By studying the comments of test person that 10 TP's have mentioned *"Restricting vision"* during manipulation of C-pillar, it was concluded that restricting the vision had affected the perception of upper interior space. By changing the C-pillar position to the outer levels (C2/C3) the side vision out was for some people directly affected. Otherwise the peripheral vision was affected and even so it affected the perception of roominess. This answers the following hypothesis H2 to be true.

H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space. – True

On a concluding note, with these discussions made about the C-pillar, the following RQ was answered.

RQ 3. How is the position of C- pillar influencing the VAS rating on the perceived upper interior space?

The position of C-pillar has affected the perception of upper interior space from all the analysis of VAS. The Short and Tall group had similar acceptance angle of 98 degrees for the C-pillar position. Though the Short and Tall group had similar perception to changes in the C-pillar the contradiction for position C3 had provided space for further investigations. There exists a moderate correlation (0.64) for θ-angle with VAS rating for the Short group and no correlation (0.40) for the Tall group.

7.7 Analysis of Spatial Distances

In the end of the user study, during the third stage, the Vertical, Diagonal and Lateral distances were possessed from every test person. These measured distances were studied against VAS rating to identify relationships or noticeable patterns. All the relative research questions for the Spatial distances are discussed in the *Discussion and Conclusion* part.

The hypotheses and research question this section answers are:

RQ4: How is the Vertical distance influencing the VAS rating on the perceived upper interior space?

RQ5: Is there a difference in rating the nominal Vertical distance and after the vertical change?

RQ7: Is there a correlation between the VAS rating of nominal state and the Vertical distance?

RQ8: Is there a correlation between the VAS rating of nominal state and the Lateral distance?

RQ9: Is there a correlation between the VAS rating of nominal state and the Diagonal distance?

7.7.1 Vertical Distance

The Vertical distance was measured vertically from the top of the test person's head to the headlining. This measure was taken twice for those who also did the change in the vertical height by adding an additional mock-up roof 62 mm lower down. Together with this data and the VAS rating the correlation was determined and if the change in Vertical distance had an equal effect on the Short group as the Tall group experienced it. Commonly mentioned comment will also be presented in this chapter.

7.7.1.1 VAS Rating and Distance

To determine the correlation between the Vertical distance and the VAS rating, the measured distance in the nominal state was plotted against the given VAS rating. The calculated r-value was found to be 0.49 which is a low correlation. Studying the figure 7.45, the dots are widely spread in the scatterplot which indicate a spread opinion about how much the Vertical distance influencing on how the person was perceiving the upper interior space.

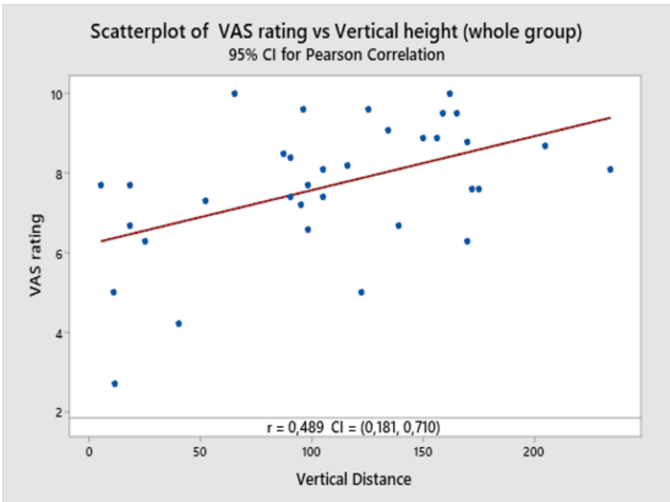
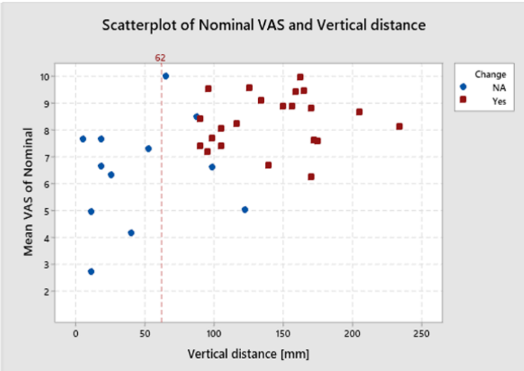


Figure 7.44: Scatterplot for the whole group determining the correlation between the VAS rating and the Vertical distance. The regression line is presented as well with a r-value at 0.49

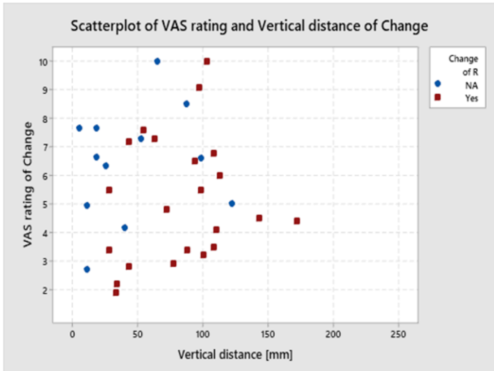
The study was extended to the Short and Tall group to see if a better correlation could be found. For the Tall group a better correlation was calculated at 0.55 meaning that there exists a moderate correlation. For the Short group a worse correlation, almost no existing one, was determined at 0.20. The scatterplot for the Short and Tall group can be found in Appendix H. When studying the regression line for all groups, it had a positive inclination meaning that the roominess was perceived to be more spacious when the person had a bigger vertical distance to the headlining.

7.7.1.2 Change in Vertical Distance

By lowering the roof of the car for some of the participants it was possible to do studies regarding if the Short and Tall group had different tolerance and acceptance to the vertical height in regard to how they perceive the upper interior space. Once again was the VAS rating was plotted against the measured vertical distance obtained from this manipulation. The before and after scenario of the manipulation was studied to observe how the general change of the VAS rating was influenced by lowering the roof.



(a) Scatterplot of Vertical distance and VAS rating



(b) Scatterplot of VAS rating given during the manipulation against the new calculated vertical distance

Figure 7.45: Scatterplot of Vertical distance vs VAS rating, with differentiation of having the vertical change done (red dots) or not (blue dots)

Figure 7.45 to the left (a) is similar to the previous scatterplot (figure 7.44) for the nominal state. However, in figure 7.45 the test persons have been differentiated based on if the roof was lowered or not. Red dots represent the VAS rating provided by the test persons who were subjected to this manipulation and blue dots did not go through with the manipulation. Another difference is that a red vertical line is indicating where the mock-up was placed and how the test persons had their heads in regard to this. The scatterplot to the right (b) represents the VAS rating given during the manipulation against the new calculated vertical distance. The blue plots did not go through any changes and are the same in 7.45(a) and 7.45(b).

When comparing the figures to each other (nominal (a) vs change (b)), most of the test persons have given a lowered rating. It is also evident that for a range of vertical distance the red dots were mostly below the blue dots. This can be explained as the Tall group has a much higher acceptance towards the Vertical distance compared to the Short group. This is usually a parameter they need to compromise on quite often when they need to fit themselves into a car. Because the user study used a bigger car, a SUV, the comments received from the Tall people were positive hence to more vertical height than what they might be used to.

For the Vertical change a total of 22 test persons had the vertical distance changed; 17 people from the Short group and 5 people from the Tall group. By comparing the mean value of the VAS rating of the nominal state and the mean of the VAS rating after the change for those who were decided to go through with the vertical manipulation, the mean had changed to a much lower value. The Short group went from 8.16 to 5.62 and the Tall group from 7.04 to 5.56.

The Short group had a bigger drop than the Tall group, even if they had bigger distances to the headlining. If studying the upper quartile (Q3) which represent 75 percent of the given VAS rating after the change, the Tall group had a bigger value than Short group; 6.80 (S)/7.65 (T). While studying the Q3 of the nominal state the Short group laid above the Tall group; 9.13 (S)/8.08 (T). In table 7.30 the values are summarized for the Short and Tall group.

Table 7.30: Summarized the mean and Q3 values in respective groups; Short and Tall. The parenthesis under the row description of *"Count"* in *"VAS rating of changed vertical height"* indicate how many went through with the change

	VAS rating in nominal state			**VAS rating of changed Vertical distance**		
	Count	Mean	Q3	Count	Mean	Q3
Short	19	8.16	9.13	19(17)	5.62	6.80
Tall	15	7.04	6.3	15(5)	5.56	7.65

This can also be interpret as people who are used to have large vertical distance are rating the roominess lower than people who are used to have small distances in vertical distance. In this case, the Short group was more negatively influenced by the change in vertical height.

7.7.1.3 Comments from Test Person

During the change in vertical distance by adding the mock-up roof, comments providing complementing information about how the change affects the person were documented. Those comments are summarized as statements with the amount of test person who also had mentioned/observed the same thing, divided in groups; Short (S) and Tall (T). Following table 7.31 presents the mentioned aspects regarding the vertical change.

One of the interesting comments was the *"Affects more while looking towards the other side"*, which was just mentioned within the Tall group. This was explained as while the test person was looking straight ahead or out though the closest window not much of a difference were noticed. However, putting the change into a perspective view by looking diagonally across to the other side of the car the change was more noticeable.

Table 7.31: Commonly mentioned comments as description and the respective counts for Short and Tall group

Comments from test persons (Description)	Short (Count)	Tall (Count)
Took notice of no curvature in the headlining	0	1
Affects more while looking through the other side	0	3
Does not affect the space	2	1
Not acceptable in a XC90	3	0
Sporty feeling	1	0

7.7.2 Diagonal Distance

The Diagonal distance was measured from the top side part of the head to the closest feature on the headlining diagonally. With this measure together with the VAS rating the RQ9 can be answered by determine the r-value. This will be described below.

7.7.2.1 VAS Rating and Distance

With the similar approach as the Vertical distance was studied, the correlation between the Diagonal distance and the VAS rating was determined for the whole test group as well in the Short and Tall groups. The Pearson correlation coefficients was calculated respectively and are summarized in table 7.32. The Tall group established the highest r-value at 0.67, which is near a high correlation at 0.7. While for the Short group they had nearly no correlation to the Diagonal distance with a correlation coefficient of 0.16. For the whole group with a value close to 0.5 the correlation between the VAS rating and Diagonal distance can be determined to be moderate, see figure 7.46. The scatterplot for the Short and Tall group are placed in Appendix H.

Table 7.32: Summarized r-values for the VAS rating and the Diagonal distance in a nominal state for the whole group, Short and Tall group

Correlation Analysis of VAS rating vs Diagonal distance			
	Whole group	**Short group**	**Tall group**
Pearson correlation Coefficient (r)	0.48	0.16	0.67

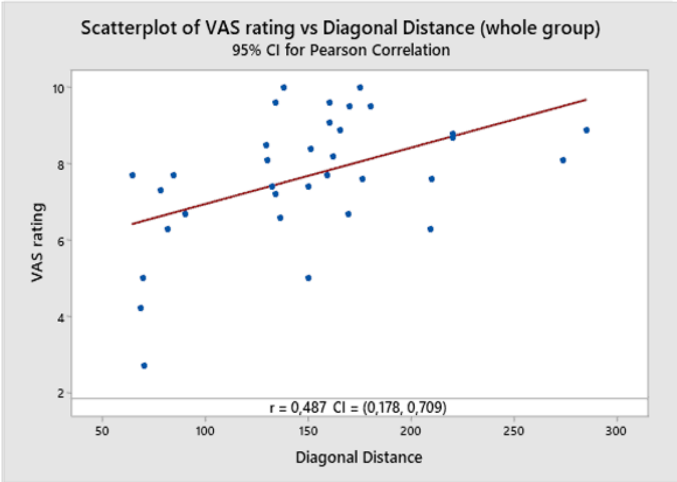


Figure 7.46: Scatterplot for the whole group where the VAS rating is plotted against the Diagonal distance, the regression line is visualized as well with a r-value at 0.48

7.7.3 Lateral Distance

The lateral distance sideward was taken from a point close to the ear, in line with the eyes, horizontally out to the closest object. The same correlation analysis was done between the lateral distance and the VAS rating in the nominal state of the car. In this section some attention was also drawn towards the window divider bar hence been mentioned by some test persons that it had affected the perceived lateral space.

7.7.3.1 VAS Rating and Distance

To check the correlation between the Lateral distance and the VAS rating, the Pearson correlation coefficient was calculated and a scatterplot was plotted with a regression line. The r-value for the whole test group was determined to be 0.41 which indicate a low correlation. When doing the same analysis for the Short and Tall group, a better correlation was found with the Tall group at 0.46 (moderate), while for the Short group no correlation was found, -0.05. The table 7.33 is summarizing the r-values for the groups.

Table 7.33: The calculated Pearson correlation coefficient for the Lateral distance and VAS rating in the nominal state of the car

Correlation Analysis of VAS rating vs Lateral distance			
	Whole group	**Short group**	**Tall group**
Pearson correlation Coefficient (r)	0.40	-0.05	0.46

Regarding the Short groups r-value, even though the strength of correlation was of no significance, the negative direction is something against the theories of roominess, see figure 7.47. The other scatterplots for the whole group and Tall group can be found in Appendix H.

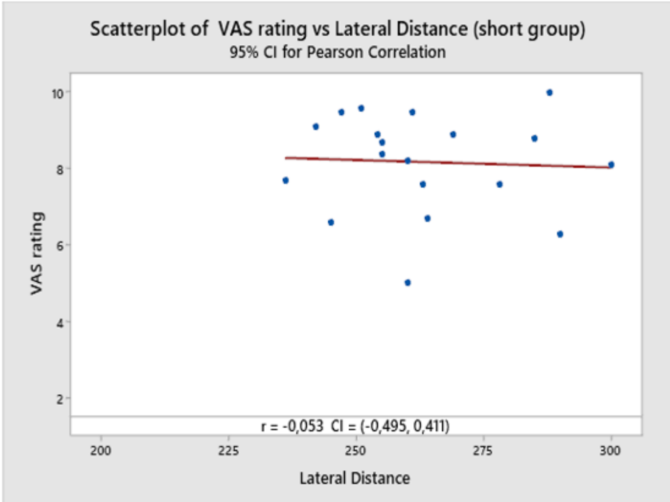


Figure 7.47: Short group's scatterplot of the Lateral distance and the VAS rating, plotted with the regression line

7.7.3.2 Window Divider Bar

During the user test, some participants mentioned that the window divider bar intruded on their space and had a negative impact on how they perceive the upper interior space. Because of this observation a study was done to understand if there was a trend of rating the perceived upper interior space lower if having the eyes parallel to the window divider bar. By having the eye's parallel to the bar it created loss in the peripheral vision, and the question was if this has a big enough impact to find a trend in the rating.

By study the side pictures taken during the user test, it was possible to identify who was sitting parallel to the window divider bar. These people were marked as a red dot when plotted the mean of the VAS rating against the Lateral distance, and the other test persons with a blue dot, see figure 7.48. In total there were 17 people sitting with their eyes parallel to the window divider bar, 10 Short test persons and 7 Tall test persons. It is noticeable that the red points are scattered without correlation, similar to the blue dots. Since there were no clusters or pattern observed, it can be interpreted that the presence of the window divider bar in the peripheral vision did not influence the perception of the upper interior space in regards to the lateral distance.

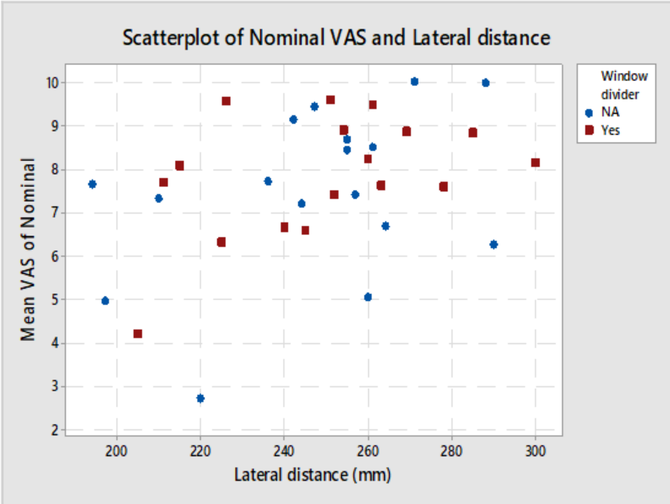


Figure 7.48: Scatterplot where the VAS rating is plotted against the Lateral distance, with identified people sitting parallel to the window divider bar (red dots)

7.7.4 Discussion and Conclusion

The table 7.34 is summarizing the Pearson correlation coefficient for the whole test group, Short and Tall group. The following four research questions can be addressed and answered after the analysis of the correlation between the Spatial distances and VAS rating:

> *RQ4. How is the Vertical distance influencing the VAS rating on the perceived upper interior space?*
>
> *RQ7. Is there a correlation between the VAS rating of nominal state and the Vertical distance?*
>
> *RQ8. Is there a correlation between the VAS rating of nominal state and the Lateral distance?*
>
> *RQ9: Is there a correlation between the VAS rating of nominal state and the Diagonal distance?*

By having an r-value above 0.7 is statistically proven to be a high correlation. None of the determined r-values were above 0.7 so just low and moderate correlation have been identified. When studying the whole group the r-values for all of the Spatial distances lay between 0.40-0.49 which indicates a low correlation. However, looking at the correlations separately in the Short and Tall group big differences were presented when comparing the r-values with each other.

In general, the Tall group had established a better correlation values when compared to the other groups. Especially, for the Diagonal distance where the Tall group had a moderate correlation at 0.67. The r-values for the Spatial distances lay between 0.46-0.67, which indicates a low to moderate to almost high correlation for the

Spatial distances and VAS rating respectively.

The Short group had constantly less correlation values which lay between (-)0.05-0.20, which indicating almost non-existing correlation. This can be due to the reason that the measured enclosures (Vertical, Diagonal and Lateral distance) were identified far away from what could be an influential region for the Short group. The Tall people were sitting closer to the enclosures and physical objects, thus a lesser distance. This can also be true for the Lateral distance as a curvature was observed in the door and window, thus reducing the lateral distance if sitting closer to the headlining.

Table 7.34: Summarized all the calculated correlation coefficient for the Spatial distances for Short, Tall and the whole group

Pearson's Correlation Co-efficient			
	Whole group	**Short group**	**Tall group**
Vertical Distance	0.48	0.20	0.55
Diagonal Distance	0.48	0.15	0.66
Lateral Distance	0.40	-0.05	0.46

The provided overview tells that the Tall group have been influenced more by the Spatial distances than the Short group. In a XC90's set-up, the Short group were far away from the enclosures in order to influence their perception of space in terms of roominess. On a conclusive note, in order to establish correlations between the parameters of Spatial distances and the perception of upper interior space, the distances should be manipulated to create a narrower space.

When discussing the results from the vertical change in height both the Short and Tall group had a massive drop in mean value of the VAS rating from the nominal state of the car to the VAS rating with a changed vertical distance. Even if the Short group did not experience the smaller vertical distances as the Tall group, an equivalent low mean value of the VAS rating at 5.62 was provided from the Short group compared to the Tall group's mean at 5.56. A linkage can be drawn between the Short group's low VAS value to one comment received only from the Short group which was that the change in vertical distance was not acceptable for XC90, a big SUV car. This comment involves expectation towards the type of car they were experiencing, and with this vertical change disappointment of the interior space might have occurred and assimilation evolved *(chapter 2.4. Perceived interior space)*. However, the study upon the expectation was withdrawn from this research but no assurance can be given that the VAS ratings were not influenced by the expectation effects contrast and assimilation. The following research question can then be answered.

RQ5. Is there a difference in rating the nominal Vertical distance and after the vertical change?

Yes, a difference was identified between the Short and Tall group. In the nominal state the Short group provided a higher mean value than the Tall group at 8.16, and the Tall group had 7.04. But then after the vertical change the mean value dropped to an equal level at 5.6 instead, for both groups. When observing the scatterplot in figure 7.45 where the VAS was plotted against the Vertical distance and the 62 mm borderline was presented. According to this plot, three or maybe four potential test persons could have gone through the vertical change (one test person had the head very close to the placement of the mock-up). Two of them were from the Short group and 1, maybe 2, were from the Tall group. Due to ocular judgment of the procedure on the vertical change the left out of the four candidates where not intended. However, the sitting posture could have caused the judgement of not proceeding with the change. Because the Vertical distance was measured in the end a more relaxed and lowered sitting posture might have occurred compared to the beginning of the user study. It would be assumed if including these participants that a lower mean would be determined for both the groups, and in that case all the people in the Short group would have gone through with the vertical change and for the Tall group approximately half of the people.

7.8 Analysis of Eye Position

Once the participant's eye points were determined and translated into a CAD file contained with the car's specification, further analysis was carried out. With the analysis done in this chapter, where the eye coordinates were studied against the VAS. All the eye points were also compared with the position of the mid-eye centroid point. But to begin with, the eyellipse for the Short, Tall and the whole group will be described. The following RQ's are answered in this section.

> *RQ10. Is there a correlation between a person's Z-position of eye coordinate and the VAS rating?*

> *RQ11. Is there a correlation between a person's X-position of eye coordinate and the VAS rating?*

7.8.1 Eyellipse

To be able to calculate the vision angles (α, β, θ) the test persons' eye position were saved into the CAD file. They were visualized and coloured with respect to the belonging group; Short group were coloured blue and Tall red. The green point represent the mid-eye centroid point. Three eyellipses in colour yellow, blue and purple were created from the collected eye points; one for all of the 34 participants (yellow), one for the Short group (blue) and one for the Tall group (purple). All ellipses were designed to fit 90 percent of the eye-points, meaning that the 95th and 5th %-ile of the eye points were operating as restriction points. A rectangular was drawn to make sure that the ellipse was designed within its limits by constraining the corners of the rectangular to coincide at the restriction points, see figure 7.49.

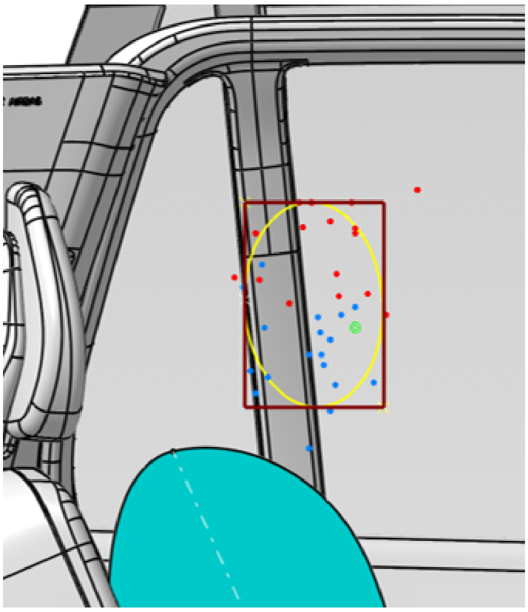


Figure 7.49: The whole group's eyellipse is fitted within the restricting rectangular by having its corners coincide to the 95th and 5th %-ile of eye point

To be able to design a well fitted ellipse the angle of the ellipse was determined in a regression analysis of the eye position in X and Z. The tilting angle was calculated by using trigonometry on the linear regression model for all of the analyses. What needs to be reminded when studying the analysis is that the direction of X was reversed in CAD which means that the angle will be angled differently. All of the eyellipses are presented in figure 7.50. The specification for the three eyellipses are summarized in table 7.35.

Table 7.35: Specification of the eyellipses

	Major radius (mm)	**Minor radius (mm)**	**Angle (degree)**
Yellow ellipse(34)	55.4	82.0	3.3
Blue ellipse (S)	53.7	62.6	-4.6
Purple ellipse (T)	66.3	42.7	-173(6.9)

7.8.1.1 Mid-eye Centroid Point

When all the participants' eye positions were plotted, the eye points were compared to the mid-eye centroid point, to understand where the eye positions were located. As seen in figure 7.50 majority of the test persons were sitting behind the mid-eye centroid point. However, the mid-eye point could still be found inside the yellow eyellipse. If studying the Z-coordinate in reference to the mid-eye point for all the people with respect to the Short/Tall group, the mid-eye point was located within the upper part of the eyellipse for the Short group but still far below the Tall group's eyellipse. For a closer look at the eye points and where the mid-eye centroid point is located in reference to the other see figure 7.51. Be aware of the direction of the X-coordiante, in CAD it was reversed.

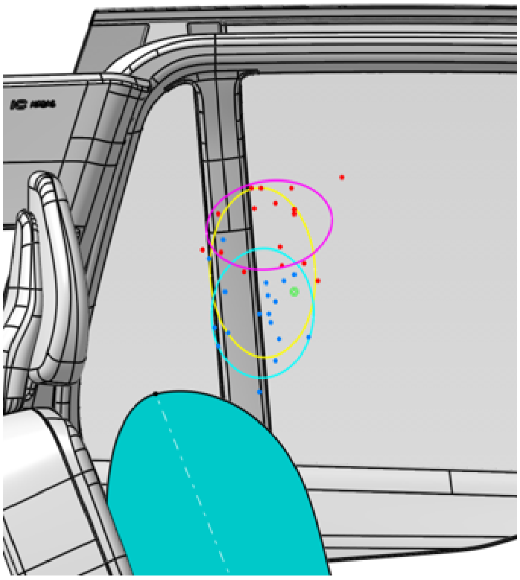


Figure 7.50: The eyellipses; yellow represent the whole group, blue the Short group and purple the Tall group

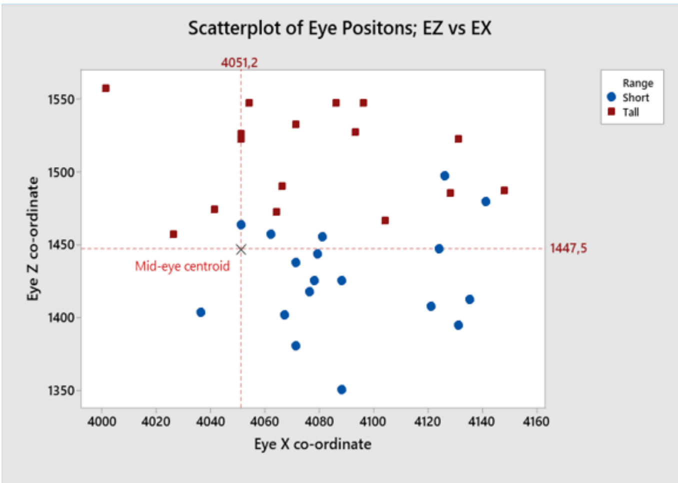


Figure 7.51: 2D presentation of the test persons' eye points, colour marked in Short/Tall group, in correlation to the mid-eye centroid point

7.8.1.2 VAS Rating and X-coordinate of Eye Position

To check if the eye position in X direction (fore and aft) had an impact on the VAS rating of the nominal state, a correlation analysis was designed. The X-coordinate of eye position (X-axis) was plotted against the corresponding VAS rating (Y-axis). In figure 7.52 the plotted graph is illustrated with the determined linear regression line drawn in red with an almost unexciting inclination. By being almost horizontal indicate a small r-value. The Pearson correlation coefficient was found to be 0.15 meaning that a linear correlation does not exist. The vertical red dotted line in figure 7.52 represents the X-coordinate of the mid-eye centroid point. This line was used as a reference line to understand where the eye points were located.

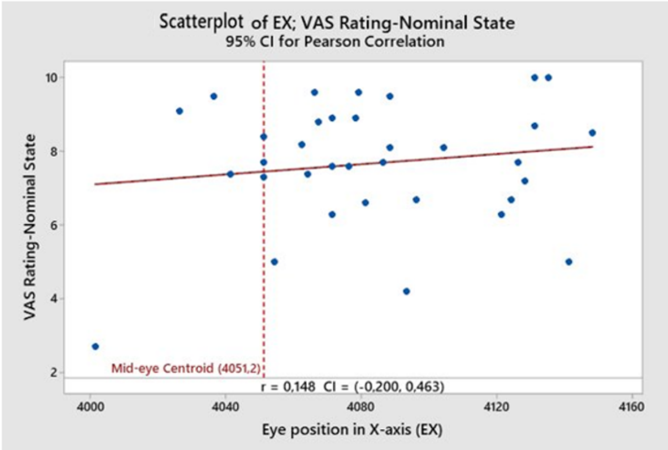
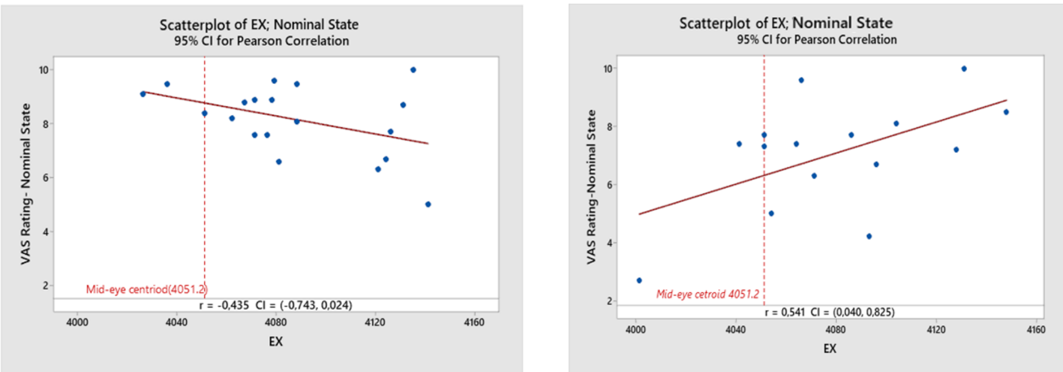


Figure 7.52: Correlation analysis with the linear correlation visualized for the X-coordinate of the eye point and VAS rating of the nominal state of the car

The same analysis was done for the Short and Tall group. In figure 7.53 a the generated scatterplot with its regression line is presented, showing a negative slope denoting that while the X-coordinate of the eye position increases (moving backwards the head rest) the VAS rating of the nominal state decreases. The r-value was determined at -0.44 which denotes a low correlation.



(a) Short group's Pearson Correlation Coefficient analysis resulting in a scatterplot with a given r-value at -0,44

(b) Tall group's Pearson Correlation Coefficient analysis resulting in a scatterplot with a given r-value at 0,54

Figure 7.53: Scatterplot of X-coordinate of eye position(EX) vs VAS rating

For the Tall group the r-value was calculated at 0.54 which indicates a moderate correlation. Studying the scatterplot, the regression line has a positive slope, opposite to the Short group, see figure 7.53(b). This was interpreted that a lower VAS rating were provided when having the eye position further backwards towards head rest.

7.8.1.3 VAS Rating and Z-coordinate of Eye Position

The correlation was also studied between the eye position Z-coordinate and the VAS rating of the nominal state. The analysis was done for the whole group and separately in the groups. The r-value for all the groups are summarized in the table 7.36. The direction was the same for all of them which means that the VAS rating decreases with the increasing height.

Table 7.36: Pearson correlation coefficient calculated for the 3 groups

	Whole group(34)	Short group(19)	Tall group(15)
Pearson's Correlation Coefficient	-0.48	-0.26	-0.53

The Short group has the lowest value on the r (no correlation) while the Tall group got the strongest correlation between (moderate) the VAS rating the Z-coordinate. For the whole group the correlation was graded low at the -0.48. In the generated scatterplots the mid-eye centroid's Z-coordinate point was marked out with a vertical line for reference, see figure 7.54.

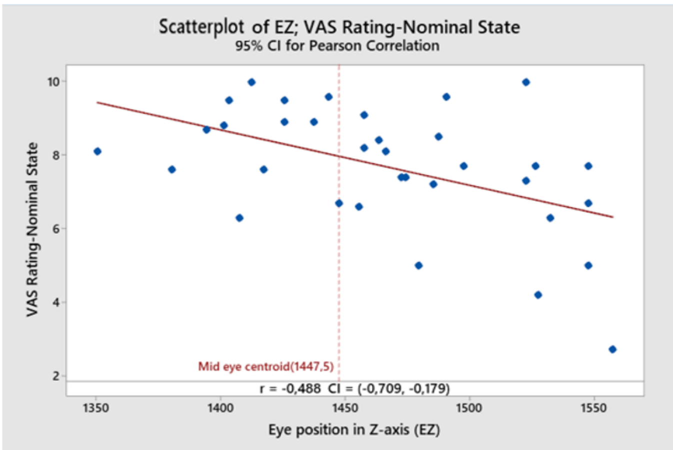


Figure 7.54: The whole group's Pearson Correlation Coefficient analysis resulting in a scatterplot with a given r-value at -0,53

7.8.1.4 Discussion and Conclusion

An interesting observation was that when studying all the eye points of the participants they were not located around the mid-eye centroid point but behind it, closer to the head rest. From the literature study the eyellipse are used to determine placement of different object to ensure adequate vision for the passenger. In this case, when the mid-eye centroid point was not determined to be in the middle of the yellow eyellipse the original eyellipse in the specification might need to be recalculated to check if the placement of the previous designed eyellipse is accurate for the passenger in the rear seat.

Because the process of identifying and determining the eye position of all the participant were done manually by overlapping and matching images the accuracy might be a bit off by +/- 10 mm. However, when comparing the location of the mid-eye centroid point in the CAD specification with the placement it got from the placed reference plane (checkboard), it was still positioned in front of the window divider bar as it was in the specification. Nine test persons had their eye points in front of the window divider bar, which still leaves us with having majority of the people behind the reference point.

There might be a possibility that the pre-set seat was not set in the SgRP, due to an uncontrolled environment with no high accuracy tools in use. However, this might still not be the problem, hence both the participants and the reference plane were analysed from the same position of the seat and were referred to each other.

Looking at the Z-coordinate in regard to the Short and Tall group, there is an intersecting part if studying the eyellipses for the groups. Short group had some participants above the mid-eye centroid point while the Tall group had all of the test persons above the Z-coordinate of the mid-eye centroid point.

Table 7.37: Summarized r-value between the VAS rating and the x/z-coordinates

Pearson's Correlation Coefficient			
	Whole group	**Short group**	**Tall group**
VAS rating vs X-coordinate	0.14	-0.43	0.54
VAS rating vs Z-coordinate	-0.48	-0.26	-0.53

While studying the results of the eye position from the Pearson correlation coefficient analysis, summarized in table 7.37, the following research questions RQ10 and RQ11 can be answered.

RQ10. Is there a correlation between a person's Z-position of eye coordinate and the VAS rating?

RQ11. Is there a correlation between a person's X-position of eye coordinate and the VAS rating?

Due to not having an r-value >0.7 there were no strong correlation between the X and Z-coordinates and the VAS rating. While studying every group individually the Tall group had a much higher correlation with the coordinates and the VAS rating if comparing the r-value with the Short and the whole group. For the analysis with the X-coordinate the whole group's r-value was the lowest at 0.14 and studying the Z-coordinate the Short group had the smallest r-value at -0.26. As an additional information, the VAS rating was plotted against the relative positions of eye in the X and Z coordinates. The resulting contour is presented in Appendix I.

7.9 Analysis of Sitting posture

After categorizing all the test person's sitting posture in 'a', 'b', 'c' or 'd' by studying the side picture, taken from the user test, a graph was plotted where the mean value of the VAS rating (nominal state) was plotted against the test person's X-coordinate for the eye position. The following RQ are answered in this section.

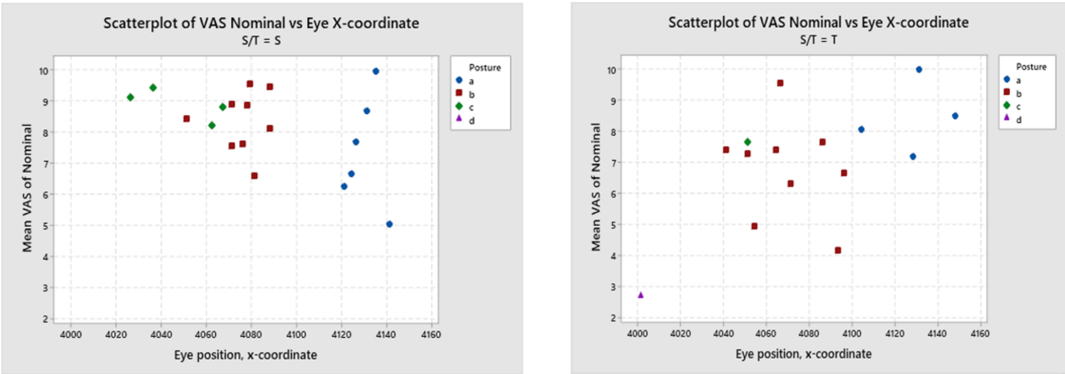
> *RQ 12. Is there a trend between the sitting posture (X-coordinate) and the VAS rating?*

The Short and Tall group were plotted on separate graphs where the test person's sitting posture is visualized in different types of marker depending on the posture. Because the sitting posture is predominantly affecting the eye position in X-coordinate hence choosing eye's X-coordinate as a parameter.

The sitting posture 'a' Head on head rest, is symbolized with a blue circle, 'b' Head off and body in a upright/natural sitting posture, is symbolized with a dark red square, 'c' Head positioned far forward from head rest, with a green rhombus and 'd' sitting in an extreme/awkward posture symbolized with a purple triangle. The symbol and the sketched sitting posture are presented in figure 7.55.

Figure 7.55: The four sitting posture categorize and their marker

In the plots it is shown that majority of the people were sitting in posture 'b'. The Short group has three distinguished sitting areas; one area where 6 test persons were sitting with their head against the headrest and where the eye's X-coordinate was positioned between 4121-4141 mm. The next area was dominated by the sitting posture of character 'b'. These 9 test persons were clustered within 4051-4088 mm in eye position. 2 people with posture 'c' were also identified, in this are. If determine an area for posture 'c' calculated from the outer most dots the area was within 4026-4067 mm. None of the test person in the Short group was identified sitting in the posture 'd'. Furthermore, studying the sitting posture against the mean value of the VAS rating, it was self-evident that the sitting posture do not affect the perception of the interior space. Otherwise different sitting postures would not be lined up in a horizontal way, but rather in an inclining/declining feature, see figure 7.56.



(a) Short group **(b)** Tall group

Figure 7.56: Scatterplot of VAS rating vs X-coordinate of eye position

Studying the Tall group's plot, the sitting posture areas which were distinguished by the different symbols were not as distinctly separated and clustered together as they were for the Short group. However, 4 test persons had the sitting posture 'a' within 4104-4148 mm for the eye's X-coordinate. 8 people identified with posture 'b' were within 4141-4096 mm, 1 person had posture 'c' at 4051 mm and another participant at 4001 with an extreme sitting posture, 'd'. This person was the tallest participant among the Tall group with a 99th %-ile of sitting height. With not having the possibility to sit in a upright, the person were cramped into an awkward sitting posture where the eye position was much further forward in x coordinate than the other participants. Once again when studying the mean value of VAS rating and the posture, no strong trend were found to say that the sitting posture affects the perception of the interior space.

7.9.1 Discussion and Conclusion

Comparing the Short and Tall's plot against each other there were some differences between them. The Short group was more clustered in different areas considering the X-coordinate of the eye position where the sitting posture following the eye position. Contrasting to this finding, the Tall group was having more spread in the eye position, and not as grouped together. However, there were still distinctive areas characterized by different sitting postures.

When calculating the ratio for the different sitting postures within the groups it became clear that Short test persons tend to have their head more often against the head rest compared to the Tall people, see figrue 7.38. It was also evident that most of the Tall test persons choose to have a posture 'b', head off and body in an upright/natural sitting posture.

Referring back to one of the research questions, *RQ 12. "Is there a trend between the sitting posture (X-coordinate) and the VAS rating?"* the answer is "No". By the look of the plots and previous discussed topics there is no trend between the two elements, meaning that the sitting posture did not affect how the interior space was rated.

Table 7.38: Calculated ratio for a chosen sitting posture within the group S/T

Sitting posture	**A**	**B**	**C**	**D**
Short(19)	32% (6)	47% (9)	21% (4)	0
Tall(15)	27% (4)	60% (9)	7% (1)	7% (1)

8
Compared Analysis

The results and discussion in the Investigation phase about the analysis of various parameters are presented in *chapter 7* within the parameters, separately. This chapter is intended to present and discuss comparisons among the results of the analysed parameters to understand the interrelationship and connection between the parameters. This is also done to arrive at answering all the ERQ's for phase 3, stated in chapter 6.

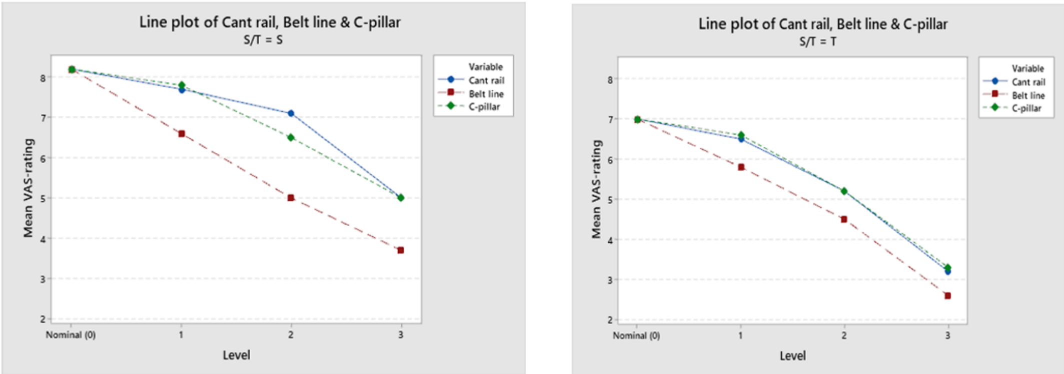
Results presented in section 7.6 provided that all Vision parameters (Cant rail, Belt line and C-pillar) did affect the visibility in the rear seat thus creating a negative impact on the perception of the upper interior space in terms of narrowing head roominess. This answered the hypothesis H2 to be true.

H2: Parameters related to visibility in the rear seat of a car can also affect the perception of the upper interior space. - True

When studying the Vision parameters together comparisons can be made and conclude which one of the parameters had the largest impact on the perceived upper interior space, referring to ERQ 3.1.

ERQ 3.1. Which parameters have the largest impact on the perceived upper interior space?

The line plots in figure 8.1 are the similar ones that have been presented earlier in the chapter "VAS rating and position" however here they are summarized together and separated in Short/Tall. The line plots were interpreted, and the Vision parameters were ranked based on the mean value of VAS rating. For both groups, Belt line had received the lowest VAS rating compared to the other parameters, therefore the most influential parameter of the three. The second most influential parameter for the Short group would be the C-pillar due to a lower VAS mean value than Cant rail for the second level, and lastly would be Cant rail. For the Tall group both Cant rail and C-pillar were perceived to affect the roominess the same. The lines are intersecting each other and will then be ranked as the second most influencing parameters. The parameters are ranked in table 8.1 accordingly to the line plot.



(a) Short group **(b)** Tall group

Figure 8.1: Comparison lineplot for mean VAS rating vs positions of Vision parameters

Table 8.1: Rank of the most influential parameters by the VAS rating

Rank - VAS rating			
	1	**2**	**3**
Short	Belt line	C-pillar	Cant rail
Tall	Belt line	C-pillar Cant rail	-

When comparing the VAS ranking presented in table 8.1 with the initial ranking attained in the *Ranking trend*, some differences were identified. The initial ranking are summarized in table 8.2.

Table 8.2: Rank of most influential parameters - rank analysis

Rank - Rank Analysis			
	1	**2**	**3**
Short	Belt line	Cant rail	C-pillar
Tall	Cant rail	Belt line	C-pillar

For the Short group, it is seen that Belt Line was the most influential parameter which was in line with the result from the VAS ranking. However, Cant Rail and C-pillar have swapped rank positions with each other. For the Tall group, it was concluded that the Belt line was the most influential parameter when compared to the Cant Rail or C-pillar. This was contradicting with the initial ranking trend where the Cant rail was thought to be most influential. Even if Belt line was ranked as the most influential parameter for the Short and Tall, the parameter was concluded to be complex including contradicting aspects, for example safety. This was also reflected upon the correlation coefficient where no to low correlation was found within the different groups between the β-angle and the VAS rating. All the r-values for the Vision parameters are compiled in table 8.3.

Table 8.3: Summarized table for Pearson's correlation coefficient for all Vision parameters

Pearson's Correlation Co-efficient			
	Whole group	**Short group**	**Tall group**
Cant rail	0.67	0.55	0.70
Belt line	0.22	0.44	0.42
C-pillar	0.51	0.64	0.40

Only Cant rail with α-angle, did achieve moderate to high correlation between the pertained angle and VAS rating for the different groups. Ultimately, with this knowledge an assumption can be taken for the Swedish population that 95% (due to the 95% CI for all of the calculated Pearson correlation coefficient) will follow the determined regression line presented within the Cant rail results. C-pillar did achieve moderate correlation for the whole group and in the Short group. However, no correlation was found for the Tall group between their VAS rating and Θ-angle. To sum up, ERQ 3.2. can be answered.

ERQ 3.2. Is there a trend between the body dimension (Short/Tall group) and the most influential parameters?

Yes, there exist a different trend of which parameter were perceived as the most influential parameter within the Short and Tall group from both the initial ranking and VAS rating rank, even if it's not substantial.

When studying the *ERQ 3.3: Is there a correlation between the Spacial parameters and the subjective perception of roominess?*, further analysis can be performed on the initial ranking for the Spatial distances. In the table below, table 8.4, the initial ranking for both Vision parameters and Spatial distances is presented. An interesting aspect which was mentioned during the *Discussion and Conclusion* in *Ranking trend* was that for both Short and Tall group, the Spatial distances were ranked higher than the Vision parameters. If then studying the calculated correlation coefficient for the measured Spatial distances and the VAS rating, respectively, the Short group did not establish any correlation. In other words, no proof supports their assumption (from their initial ranking) that Spatial distances will influence on how they perceive the upper interior space. A summarized table for all the calculated r-values can be found in table 8.5.

Table 8.4: The initial ranking for both Vision parameters and Spatial distances

Falling Order	**1**	**2**	**3**	**4**	**5**	**6**
Short	Diagonal	Belt line	Vertical	Lateral	Cant rail	C-pillar
Tall	Vertical	Cant rail	Diagonal	Lateral	Belt line	C-pillar

Table 8.5: Summarized all the calculated correlation coefficient for the Spatial distances in Short, Tall and the whole group

Pearson's Correlation Co-efficient			
	Whole group	**Short group**	**Tall group**
Vertical Distance	0.48	0.20	0.55
Diagonal Distance	0.48	0.15	0.66
Lateral Distance	0.40	-0.05	0.46

Studying the Tall group, they got the highest r-values for all the analysed Spatial distances. Due to the Tall group's exposure to much smaller distances and substantial experience of enclosure compared to the Short group, a moderate to nearly high correlation was found. This can support the Tall group's initial rank of ranking the Spatial distances high.

However, these correlation coefficients were obtained from the nominal state of the car. Because no manipulation where done towards the Spatial distances, there might as well not be enough evidence to state that there exists relationship between the perception of upper interior space and the Spatial distances.

With respect to the analysis of eye position, the correlation coefficient(r) for the X-coordinate was 0.148 for the whole group, which was very low when compared to other studied parameters. This result also falls in line with the cluster analysis (section 7.4.3) that X-coordinate of the eye position was dissimilar by larger margin than other predictor variables in the cluster analysis. Other interesting observation that falls in line with previous findings from cluster analysis was that the correlation of the eye Z coordinate with VAS rating (r=0.48) was similar to Vertical distance (r=0.48) in influencing the VAS rating. So, it is suggested that any one of the predictor variables can be used for future study of perception of head roominess. Since it is evident that the visibility outside is affecting the perception of the interior space, it is more relevant to study head roominess with respect to the position of eye in the upper interior space.

The results from the analysis of the eye positions draw answer for the ERQ 3.4.

ERQ 3.4: Is there a correlation between the body dimension and the subjective perception of roominess?

The body dimensions of sitting height (results of cluster analysis) were translated to the position of the eye. For the whole group, the eye positions did not establish direct relationship with the perception of upper interior space as the Pearson correlation coefficient was found to be r=0.14 for X-coordinate and r=0.48 for Z-coordinate. This evidence is true only to the nominal state of the car and the results may vary if the eye positions were manipulated by some means. There exists a difference in sitting posture between the Short and Tall group. Short group tend to have their head against the head rest more than the Tall people. Tall people tend to sit in a natural position with head upright and off the headrest. However, there was no strong trend between the sitting posture and VAS rating to say that it influences the subjective perception of roominess.

The last exploratory research question which still has not been brought up is ERQ 3.5.

ERQ 3.5: Are there any critical measures for the most influential parameters?

From the analysis done from the acceptance angle, critical measures have been revealed for the Vision parameters. The acceptance angles are compiled in table 8.6, where the interquartile are presented together with the mean in brackets. Only C-pillar had the similar values for the Short and Tall group.

Table 8.6: Acceptance angles for the short and tall group

Group	Acceptance Angles (interquartile)		
	Cant rail	**Belt line**	**C-pillar**
Short	30-37(34)	12-19(15)	92-102(97)
Tall	18-31(24)	20-27(24)	89-105(98)

Further analysis of the critical measurements are presented in the next chapter, where these were evolved to what will be known as acceptance ranges. These ranges will act as recommendations and guidance for how different levels will be perceived in a roominess aspect.

9
Recommendation

As recommendations the acceptable angles for all the Vision parameters have been translated into a concretized design colour range guidance of what would be acceptable, critical or poor for the Vision parameters (α, β and θ) when perceiving the interior space. With this the RQ13 are answered.

ERQ 3.5: Does the borderline for every parameter reflect upon a range of an angle for a specific parameter?

This is visualized in CAD. While defining the different range of acceptable/critical/poor, a VAS rating is identified when assessing the different ranges. C-pillar is presented first followed by Cant rail and followed by Belt line.

9.1 C-pillar's Acceptance Range

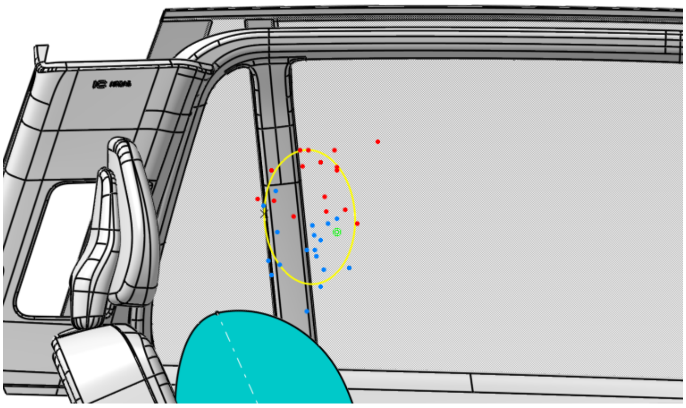


Figure 9.1: The whole group's eyellipse with all the eye points. The green symbol is representing the mid-eye centorid point for the car and the back cross on the eyellipse's line contour is representing the 95th %-ile (furthest back)

Referring back to the findings of last acceptable angle for θ (section 7.6.3.4) a normal distributed histogram graph was presented to describe the borderline to what would be the last acceptable angle before exceeding the limit to unacceptable. For θ, the mean value for Short and Tall group was calculated approximately at the same angle, at 97-98 degrees. For this reason the whole group became the study object, hence using the eyellipse representing all test persons. To be able to represent majority of the people when creating the designed colour range, the range is designed from an eye point located on the ellipse's line contour, furthest back, representing the 95th %-ile. This means that every eye point located in front of this coordinate are covered by the designed colour range of acceptance. Figure 9.1 is presenting the whole group's eyellipse with the mid-eye centorid point and the 95th %-ile.

The angles that were defined to represent different acceptance ranges were determined by the median (Q2) and the lower quartile (Q1) from the data of last acceptable angles for the whole test group. As for θ, Q1 was determined at 89.7 degrees and Q2 at 98 degrees. With these identified bounding angles three ranges can be identified as "Acceptable" that is defined from the Q2 to the maximum angle and the range is marked with a colour green. In other words, for C-pillar to be on an acceptable level regarding the perceived interior the theta angle must be above the 50th %-ile of the identified last acceptable angles. The next range is identified as "Critical" that is defined from Q1 to Q2 and is coloured orange. Last range is identified as "Poor" which will cover the minimum angle until Q1. The figure 9.2 presents a histogram of the acceptable angles for the whole test group. The three ranges are coloured as described above where the bounding angles Q1 and Q2 are displayed as well.

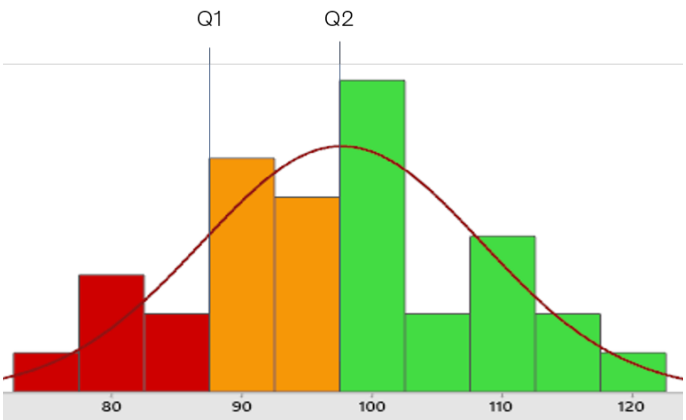


Figure 9.2: Histogram presenting C-pillar last acceptable angle for the whole group with the coloured acceptance range displayed

These acceptance ranges were translated into a CAD file together with the eyellipse and eye points. At the same plane as the existing C-pillar the acceptance range will elevate out until the last C-pillar level of manipulation. From the chosen eye point (95th %-ile) the acceptance ranges "Acceptable" (green), "Critical" (orange) and "Poor" (red) were determined, see figure 9.3.

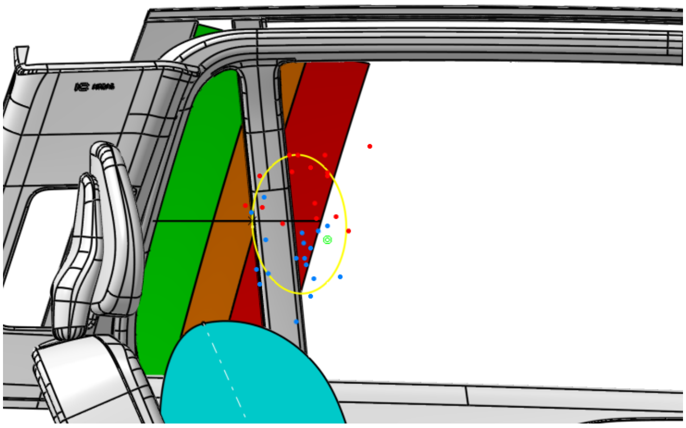


Figure 9.3: The coloured acceptance range created from the 95th %-ile of eye point intersecting the yellow eyellipse (whole group) at a furthest back position for C-pillar

For determining the expected VAS rating within the different acceptance ranges the previous correlation analysis of VAS rating and theta angle was used. By using the trendline for the whole group a VAS rating can be determined by a specific angle. So at the bounding angles (Q1 and Q2) two VAS rating can be taken out from the graph. In figure 9.4, at Q1 (89.7 degrees) the VAS rating would lay at 5, and for Q2 5.8. With this knowledge the VAS rating can be predicted once entering the different acceptance ranges, hence understand whether the rating indicate an acceptable/critical/poor roominess feeling. For the "Acceptable" range the predicted VAS rating would lay above 5.8, for the "Critical" range it will lay between 5-5.8 and for the "Poor" range the VAS rating will lay below 5.

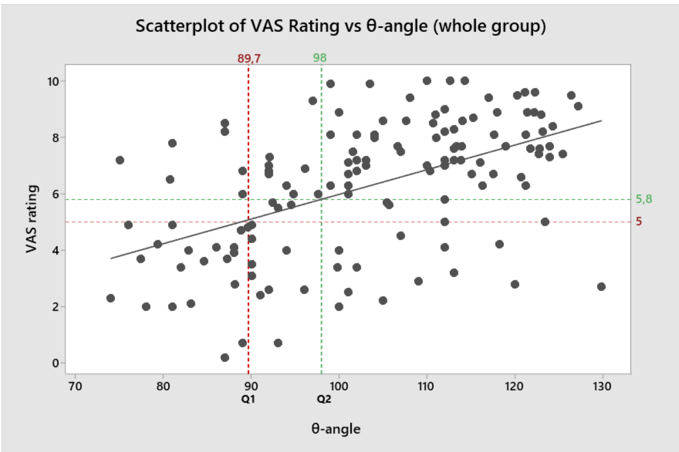


Figure 9.4: The bounding angles Q1 and Q2 for C-pillar (whole group) are marked out with a vertical line, where the line is intersecting the trendline is where the VAS rating is obtained, marked with a horizontal line

The predicted VAS rating for the different acceptance ranges are summarized in the table 9.1.

Table 9.1: Predicted VAS rating at the bounding angles Q1 and Q2

ACCEPTANCE RANGE	PREDICTED VAS RATING
Acceptable	>5.8
Critical	5.0-5.8
Poor	<5.0

However, the correlation coefficient should be taken into account to understand how accurate the prediction is. The correlation co-efficient for the this graph was 0.51 which is described as a moderate correlation according to Heumann and Schomaker (2016). Thus not having a high correlation the expected VAS rating for the different ranges might vary.

9.2 Cant rail's Acceptance Range

While studying the last acceptable angle graphs for the Cant rail it varied a lot between the Short and Tall group. For this case two designed acceptance ranges will be created for the two groups, and not a common one as for the C-pillar. This is because the Cant rail is a parameter which is more disturbing and affecting the taller people, the ranges will be designed for the 95th %-ile of eye points, positioned furthers up intersecting the eyellipse. The acceptance ranges will then include the other participant (95% of them) which is positioned underneath. In figure 9.5 the eyellipses are visualized with the design point (symbolized as a back cross) for the acceptance range in respective group.

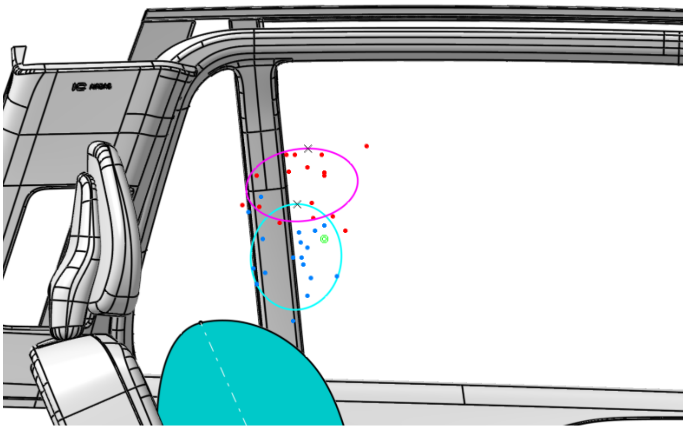
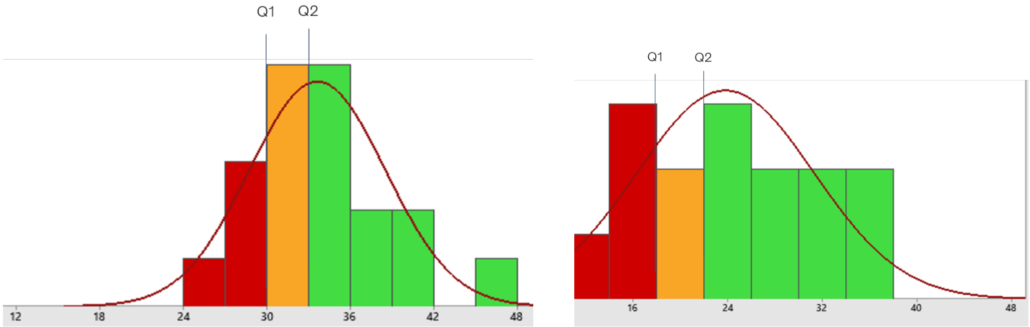


Figure 9.5: The Short (blue) and Tall (purple) group's eyellipse. The green symbol is representing the mid-eye centorid point for the car and the back cross on the eyellipse's line contour is representing the 95th %-ile (furthers up)

Table 9.2: Bounding angles for the Short and Tall group for Cant rail

GROUP/BOUNDING ANGLES	Q1	Q2
Short	30.0	33.0
Tall	17.9	22.0

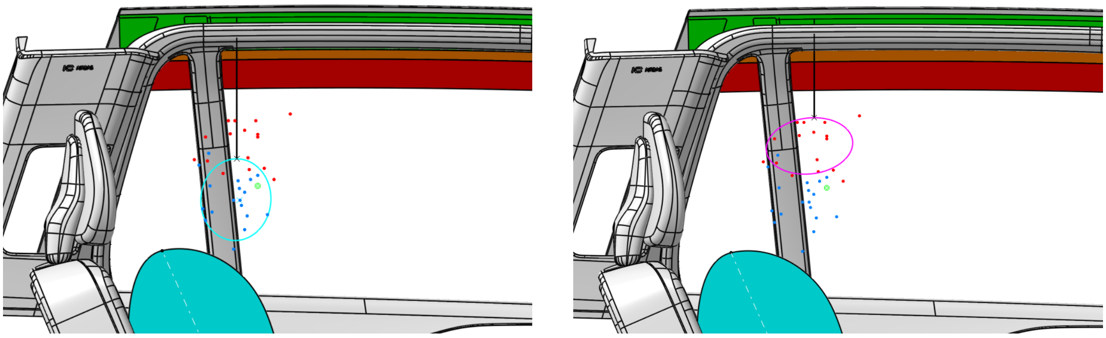
As seen in table 9.2 the acceptance ranges are differentiating between the Short and Tall group. For the Short the “Acceptable” range is from 33 degrees to the maximum angle at 46 degree, the “Critical” range is between the bounding angles, 30 to 33 degrees, and the “Poor” range is defined between the minimum angle at 26.8 and 30 degrees. The Tall group has the “Acceptable” range from 22 degrees to 37.4 degree, “Critical” between 17.9 and 22 degree s and the final “Poor” range defined at 13.1 to 17.9 degrees. These acceptance ranges are visualized in a histogram where the distribution as well is presented, see figure 9.6.



(a) Short group **(b)** Tall group

Figure 9.6: With the colour scheme for the acceptance ranges the “Acceptable” /”Critical”/”Poor” are presented in the histogram for the a) Short group b) Tall group

From the 95th %-ile of eye point these acceptance ranges for the perceived interior space was translated into the CAD file. The figure below (figure 9.7) presents the acceptance ranges from a side view in CATIA.



(a) Short group **(b)** Tall group

Figure 9.7: Images taken in CAD showing Cant rail’s acceptance ranges for the a) Short group and b) Tall group, from the 95th %-ile eye point

Determining the expected VAS rating for the three acceptance ranges were done the same way as previously for C-pillar, by studying the trendline in a correlation plot where VAS rating are plotted against the alpha angle. The VAS rating at the bounding angles linked to the acceptance ranges are summarized in the table 9.3 for the Short and Tall group. The plots will be placed in Appendix J.

Table 9.3: The predicted VAS rating for the three acceptable ranges, for Cant rail

	PREDICTED VAS RATING	
ACCEPTABLE RANGES	**SHORT**	**TALL**
Acceptable	>6.0	>4.5
Critical	5.5-6.0	3.9-4.5
Poor	<5.5	<3.9

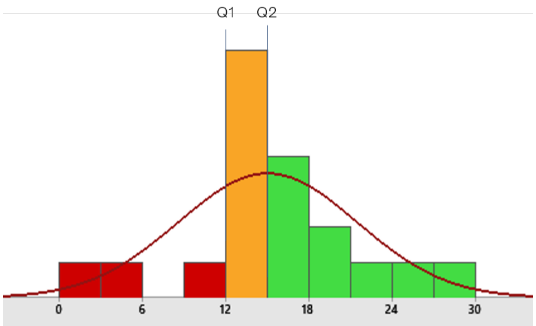
The correlation co-efficient value for Short and Tall group varies from 0.56 to 0.7 for the Tall group. The accuracy for the Tall group's predicted VAS rating should be relatively high hence high correlation. However for the Short group at 0.56 might not be as accurate with the predicted VAS rating thus need to carry out more investigation to be able to give a good prediction of what acceptable range would be considerable for a given VAS rating.

9.3 Belt line's Acceptance Range

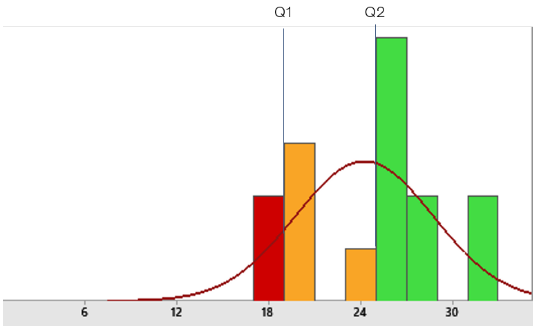
From the analysis of the Belt line, it was concluded that the parameter is complex hence including contrasting opinions that involves not only the roominess aspect but as well safety as in being protected and visibility in a sense where it is designed for not causing motion sickness. Due to these various opinions regarding the Belt line which is also reflected on the low correlation co-efficient values (r) for the whole group (r=0.22) and separately in the Short (r=0.44) and Tall (r=0.42) group, a designed acceptance range might be hard to create for being representable for all test persons.

Despite having the issue of not being representable for all, the acceptance range was created from the collected data just to give a visualized presentation and understanding of the Belt line and the ranges for the two groups. To start with the ranges were designed from the 5th %-ile, with the same argument as previously that majority of the people will then accept the settings of the Belt line (hence having the eye point above the reference and having a larger α-angle). Thus being interested of also visualize the 50th %-ile and compare the differences in how the Belt line affect the perceived roominess.

Studying the distribution of the acceptable angle for the Short and Tall group the bounding angle can be determined at Q1 and Q2. In the following figure 9.8 the acceptance ranges in the histogram are coloured with the representative colour for "Acceptable", "Critical" and "Poor".



(a) Short group



(b) Tall group

Figure 9.8: Histogram presenting the last acceptable angles for β (Belt line) together with the representative colours for "Acceptable" (green), "Critical" (orange) and "Poor" (red)

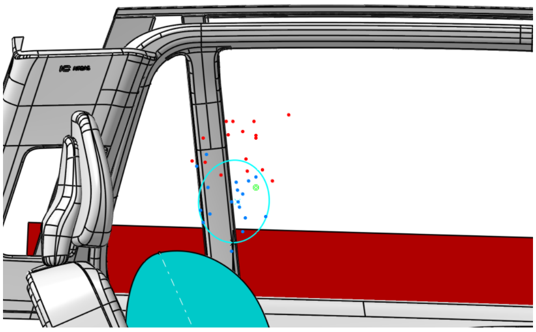
The predicted VAS rating for the bounding angles in the acceptance ranges are presented in the table 9.4. Due to low/no correlation (r<0.5) for the VAS rating and the beta angle the prediction will not be accurate and should be further investigated to be able to link the VAS rating to the acceptance ranges. The figures where these values are extracted from can be found in Appendix J.

Table 9.4: The predicted VAS rating for the three acceptable ranges, for Belt line

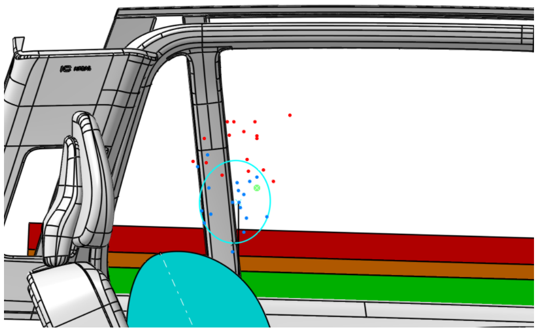
	PREDICTED VAS RATING	
ACCEPTABLE RANGES	**SHORT**	**TALL**
Acceptable	>6.0	>5.0
Critical	5.5-6.0	4.0-5.0
Poor	<5.5	<4.0

From the 95th %-ile and 50th %-ile of eye point the acceptance ranges for the perceived interior space was translated into the CAD file, see figure 9.9. In Appendix K, font views, plane view and extended side views of the acceptance ranges for all Vision parameters are presented for the regarding groups for the 95th %-ile.

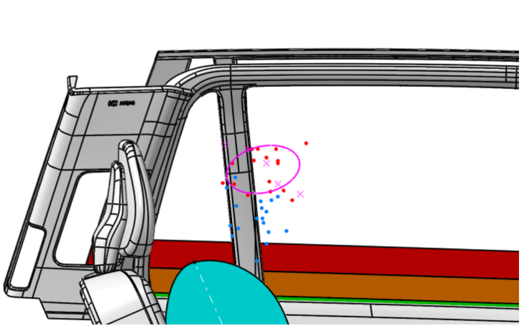
For the Short group, the difference between the two reference points was considerably noticeable. From having the whole range being marked red and identified as "Poor" when having the design point at the counter line (95th %-ile) (9.9 (a), to being more diversely when designing it for the 50th %-ile (9.9 (b). For the Tall group the "Acceptable" range was determined to be quite small from the 95th %-ile ((9.9 (c). While studying the ranges from the 50th%-ile the "Poor" range is not identified in the manipulation span (9.9 (d).



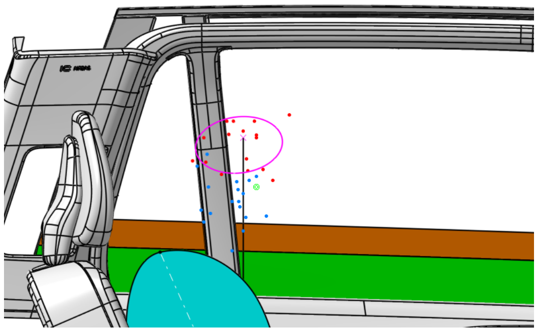
(a) Short group - 95th %-ile



(b) Short group - 50th %-ile



(c) Tall group - 95th %-ile



(d) Tall group - 50th %-ile

Figure 9.9: Images taken in CAD showing Belt line's acceptance ranges for the a) Short group and b) Tall group, from the 50th and 95th %-ile eye point

10
Discussion

This chapter is focused to bring forth the reflective thoughts about the various theories used and the results from the thesis study. The research approach and methods that helped in arriving the results are discussed first. This is followed by the discussion about the presented results. This chapter also includes a discussion on ethical implications when conducting study that involves data from test persons. Lastly, a discussion about the sustainability aspects regarding research and development to this project in particular is presented.

10.1 Research Appraoch

The research was designed in such a way that when moving forward in phases, the knowledge obtained become narrower and deeper. In this thesis the initial phase focused in identifying the influencing parameters and later phase focused in obtaining detailed knowledge about specific parameters. The knowledge obtained from results of a phase served as the base for input for designing the research of the forthcoming phase. Another challenge faced was to define the research questions within a field that required entirely new competence. This research approach helped to overcome this challenge to explore initially and gain knowledge beforehand to define the research questions. This research approach has also paved a way to understand the future work needed where the vision will be to study a confined space made up of the parameters rather as parameters alone.

10.2 Research Method

One interesting outcome of the study is the suitability of VAS in studying the upper interior space. In addition to the result that it is a reliable scale in use for perception of head roominess, the structure of the VAS can be leveraged to use in study of other factors in the upper interior space. The anchoring words can be used appropriately to study other aspects of the upper interior space. For example, in order to study illuminance in the upper interior space, anchoring words such as dark and bright can be used. The anchoring words used in this study were ‘narrow’ and ‘spacious’ referred to the measure of roominess and the test persons were seen to be clear that they are assessing the roominess of the upper interior space.

As mentioned in section 3.4.1, the difficulty in translating a multidimensional experi--ence to a linear scale as in VAS was counteracted by using only one aspect of the interior space, i.e roominess. The anchor words of narrow and spacious restrict the multidimensional experience in the space to the measure of roominess. On the contrary, if the VAS was used to measure comfort in rear seat with anchor words comfort and discomfort, this would involve converting a multidimensional experience of comfort which is influenced by many factors such as air quality, roominess, seat comfort, lighting etc. In this case, the mentioned drawback of VAS would have highly influenced the results.

Another drawback of the VAS is the initial understanding of the scale for the test persons. This was overcomed by the design of the semi-structured interview. There was a part where the test persons were introduced to the VAS scale and explained. Also, it was made sure that the test person can ask doubts about VAS at any point of time. Mentioned as an advantage is the scale's sensitivity to changes, this can also be a disadvantage when the respondent like to place it on the same spot as previously but does not remember where. This can result in misleading interpretation of data if the marker is misplaced unintentionally.

10.3 Research Results

It was decided that the outliers were not eliminated during the analysis of parameters when the person provided an abnormal rating during the user test. It was decided to do that way because the goal of the thesis was to gain a holistic knowledge about the upper interior space in terms of roominess rather than statistically significant results. Not eliminating these outliers have improved the validity of the results and provided satisfactory statistical results. Another strong point supporting this decision was the internal consistency result in section 7.4.4. The test persons were consistent in rating the upper interior space which means their rating can be trusted even it appears to be a outlier. Other reasons were that the outliers did not affect any of the assumptions of the hypotheses testing and use of a VAS had made the outliers in the valid range of 0-10 (VAS rating).

One main discussion about the results from phase 3 is that they are only valid for the setup of XC90 rear seat. The experimentation methodology involved a decoupled parameter study which means that the other parameters were placed in their nominal state. For example, when Cant rail was manipulated Belt line, C-pillar and Vertical distance were in their nominal (original state). So, at this stage, the results pertaining to Cant rail is valid only when the Belt line, C-pillar and vertical height are in the nominal state of the XC90 car. Manipulating two or more parameters at a single time (coupled study) may provide in a different result. So, this study can be considered as first-degree study and upcoming study can be extended to second degree (2 manipulations in single time). The future work will be to design and study the parameters in a coupled setup where each parameter level would be studied against all levels of every other parameter.

This creates a result for a manipulated space rather than a manipulated parameter. On the other hand, results from an experimental set-up involving a car is always influenced by the expectation and preconception of the user. So, the results of VAS rating from phase 3 are also influenced by the expectation and the preconception of the test person's involved. If results are required to be excluding the influence of the expectation of the user, the methodology followed in this thesis study cannot be suggested.

From chapter 9, it could be seen that the Short and Tall group have similar acceptable angle range for C-pillar but different for Short and Tall. This could be due to a reason that they have been exposed different ranges of α and β angles during the manipulations. Table 10.1 contains the range of angles that the two groups have been exposed during the manipulation of parameters. It would have been an ideal experimental set-up where the Tall and Short group can be exposed to the same range of angles to the parameters to obtain a more valid statistical result. However, this set-up does not resemble the reality. For every car designed there will be a difference in the position of the studied parameters for the Short and Tall group. So, these critical angles are valid in real terms, i.e with respect to the test car.

Table 10.1: Parameters with respective exposed angles

	Range of Exposed Angles	
Parameter	**Short**	**Tall**
Cant rail	19.3 - 56.6	8 - 45.7
Belt line	-5 - 28.4	12.5 - 34.6
C-pillar	76 - 127.2	74 - 129.8

10.4 Ethical and Social Aspects

To arrive at the results of this this thesis work both qualitative and quantitative tests were conducted involving test persons and experts within Volvo Cars. Due to the involvement of people, ethical and social aspects were considered before conducting any of these tests to protect a person's integrity and identity. For this purpose, the Volvo Cars GDPR policy was used. All test persons where informed of the GDPR policy, they agreed and consented that the data collected from them could be used. Accordingly, only relevant measurement was gathered in the study. Furthermore, during the study photos and subjective data were collected which were blurred out and made non traceable to the person. These data were stored against specifically created TP number starting with TPx01 and this method helped in deleting any traceable links to the person's identity.

The tests were designed to be semi-structured and planned not to intrude on the participants personal space nor make the person feel uncomfortable. It was also informed that the participants had right to withdraw/end the test in any case if needed. This covers their consent as well of the GDPR, the data will be saved as long the participant like or as long as the participant is hired at Volvo Cars.

To cover different aspects/perspectives and comments, the demographic was considered when choosing the test people. The goal was to have an even distribution between men and women of the participants with different backgrounds preferably. Due to less research in the rear seat compared to the front seat/driver seat this study will contribute to more knowledge about the actual head roominess in the rear seat, and how to account for it when designing a car. Likely, the result will favour the design of the car and as well having beneficial impact on the society in the sense of comfort when designing for various anthropometry of the passenger.

10.5 Sustainability

Among the 17 sustainability development goals put forth by the United Nations in 2015, three goals were focused upon in this thesis study and are presented in Figure 10.1; Good health and well-being, Reduced inequalities and Responsible consumption and production.

Figure 10.1: Icons of the focused sustainability goals
Reprinted from (*Sustainable Development Goals POSTER AND INDIVIDUAL GOALS FOR WEB AND PRINT*, n.d.)

According to Öst, Claustrophobia is the fear of confined spaces and it is found to be prevalent in 4 percent of the general population for their lifetime (Öst, 2007). It was also mentioned that the degree of claustrophobia varies from person to person. Cars have a closed environment and have a high probability for a person to experience claustrophobia. The study focuses in assessing the parameters that affect the perceived roominess and enabling the designers to design car interior spaces in order to provide required head roominess. Thus, providing the required roominess could reduce the probability of experiencing claustrophobia or reduce the degree of claustrophobia thus promoting good health for the users.

Though the result of the study will be delimited to the Swedish market, the guideline would form the basis for further research into several other markets making the future cars more suitable for the global population and reducing the bias towards developed nations. As mentioned earlier, subjective study's test persons was selected so that there is maximum possible balance in gender (gender equality) and anthropo--metry. However, Covid-19 has partly an impact of on this through making it harder to involve test persons as planned. It was a societal aspect to have an even distribution in gender and was not achieved. Though it was a downfall on the societal aspects side, the trade-off decision was taken on ethical basis to complete the thesis in the provided time frame. Counter measures were taken to nullify this effect during the analysis by eliminating the parameter of gender.

Every research and development activity would involve use and consumption of products and resources. Consideration was taken to reduce the use of resources and using better alternative technology throughout the project. The user test was planned to make use of reusable rating scale, documentation of test responses was made digital and questionnaire used was in the form of mobile application.

11

Conclusion

The perception of head roominess in the outer rear seat was studied considering physically measured Spatial distances and subjective parameters. Cognitive factors such as compensatory behavior and expectations have been included in the research to understand subjective part of roominess.

Cognitive factors were considered during the early phases of the study and later focused research was done with Spatial distances and Vision parameters. A wholesome knowledge about the perception of the upper interior space was obtained and the influencing parameters were identified.

Moving from Phase 1 & 2 to Phase 3, these parameters were studied quantitatively to arrive at statistical results (in Appendix L are all the RQ's compiled and answered). Based on these results recommendations were created that acts as a guideline to understand the critical parameters and its influence on the perception of head roominess. The important findings from the thesis are:

- The subjective parameter of Vision had affected the perception of upper interior space. This proves that head roominess currently studied as a physically measured entity had to be extended to subjective parameters.
- For Tall group, the position of Cant rail had established a high correlation with the perception of head roominess. Hence Tall group can be involved in the study of Cant rail position in terms of height and its influence with the head roominess.
- The vision parameters exhibit acceptable positions in terms of head roominess and the positions were converted to acceptance angles from the eye position of the users.
- The Short and Tall group exhibit different acceptable positions for Cant rail and Belt line, but similar position for C-pillar.

The results from this thesis study can be used when the following terms that limit the validity of the results are satisfied.

- The results are specific to XC90 range of cars with light interior trims and panorama roof covered.
- The results are limited to the Swedish adult population.
- The results for every parameter are valid only if the other parameters are placed in the original configuration (nominal state) of the XC90 car.
- The results can be used if the influence of expectation will not affect the intend of the study.

11.1 Future Work

This chapter is intended to discuss the progressive work that can be done to arrive at an inclusive conclusion about the perception of roominess. The speculated work is explained in a progressive way to achieve the goal.

The initial work will be to make up the discrepancies in the distribution of the test persons based on sitting height. As mentioned in section 7.4.1, the missing data points of sitting height can be filled by making use of the same experimental set-up of phase 3 and conducting the user study. Now the distribution aimed in the sitting height will be achieved. Secondly with the data from this user study can be updated to the data set and the before done analysis can be done again to improve the validity of the results. The scatterplots can be checked to identify gaps and focused to fill those data points to check if that results provide in better correlation results. By doing this procedure, the aimed distribution in sitting height is achieved and at the same time the validity of the results is improved.

With the discussions about the limitations of decoupled experimental design, the research can be focused to study parameters together. The number of parameters can be considered as the degree and the degree of study can be increased when moving from one phase to another. Two parameters coupled study can be second degree and 3 parameter study to be third degree and so on. By doing this the interdependencies between the parameters are studied. When all the parameters are included in the coupled design, it makes a study about the head roominess in the confined space made up of parameters rather than the study about parameters. When progressing with the coupled experimental design, the subjective parameters that were considered to be a limitation in this thesis study can be included at a appropriate junction. These parameters include color of the interior trims, lighting (illumination), expectation and preconception about the car. On the other hand, it should be noted that the study in coupled design will be complicated and time consuming in manipulations and building the test setup. So the parameters should be chosen accordingly. From this study we could say that the combined study of

Cant rail and C-pillar will enclose the visibility in the up- outward and rearward influencing the headroominess more than the combination of C-pillar and Belt line. However, enough evidence is not interpreted for this discussion from the results obtained from this study.

When results have been obtained about the head roominess in the space that includes all the objective and subjective parameters, it is ideal to extend the study to different segments of the car. This enables to compare the results between the different cars. To start with, the presence of panorama roof can be studied. Then a approach that is suitable to study different cars can be adopted. When different cars are studied, the results obtained will be including all the parameters and the effect of these parameters in different types of car.

The approach is the vice versa of the research approach of this thesis study, focusing to start with deeper knowledge and broadening the focus area as we progressed.

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A

Ranking List from nine Experts (Identification phase)

Table A.1: Ranking list from the participants ordered in increasing sitting height. The number in brackets are the calculated percentage given from the "Pairwise comparison".

	Parameters								
Rank	TP-Q1	TP-Q2	TP-Q3	TP-Q4	TP-Q5	TP-Q6	TP-Q7	TP-Q8	TP-Q9
1	Pano line (21)	Belt line (22)	Vertical heigth (19)	Rear Header (29)	Vertical heigth (24)	Vertical heigth (23)	Length of window (23)	Vertical heigth (22)	Rear header (21)
2	Vertical heigth (21)	Vertical heigth (22)	Rear header (19)	Vertical heigth (24)	Rear Header (24)	Distance to cant rail (17)	Pano size (17)	Cant rail shape (19)	Vertical Height (21)
3	Distance to cant rail (18)	Length of window (19)	Distance to cant rail (17)	Distance to cant rail (20)	Distance to cant rail (24)	Rear Header (17)	Distance to cant rail (14)	Rear Header (17)	Distance to cant rail (18)
4	C-pillar angle (14)	Window divider (15)	Pano size (17)	C-Pillar Placement (12)	Belt line (10)	Pano size (14)	Vertical heigth (11)	Distance to cant rail (14)	Pano size (18)
5	Pano size (14)	Cant rail shape (11)	C-pillar placement (11)	Belt line (10)	Cant rail shape (10)	Window Divider (11)	Cant rail size (9)	Pano Line (11)	C-Pillar Placement (7)
6	C-pillar width (7)	B-pillar placement (7)	Cant rail shape (8)	Window Divider (5)	Window Divider (10)	C-Pillar Placement (9)	Belt line (9)	C-Pillar Placement (8)	Window Divider (7)
7	Rear header (4)	Distance to cant rail (4)	Window Divider (6)	B-Pillar Placement (0)	B-Pillar Thickness (0)	Belt line (6)	C-Pillar Placement (9)	Window Divider (6)	Belt line (7)
8	B-pillar thickness (0)	C-pillar placement (0)	Belt line (3)			B-Pillar Thickness (3)	Window Divider (9)	Belt line (3)	B-Pillar placement (0)
9			B-Pillar Placement (0)			Cant rail shape (0)	B-Pillar Placement (0)	B-Pillar Placement (0)	
TP Sitting heigth	905	911	912	952	974	978	991	994	1002

B

Documentation Sheet - Questionnaire- Phase 2

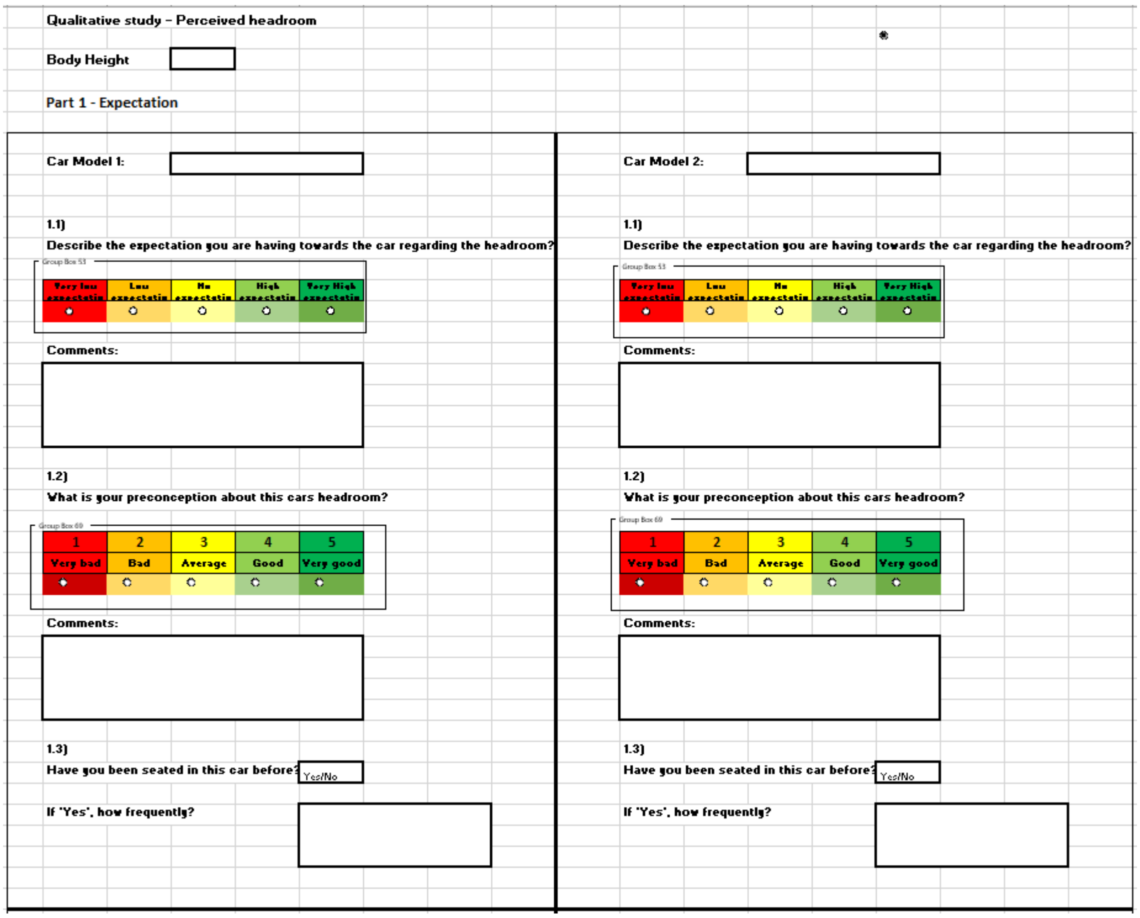
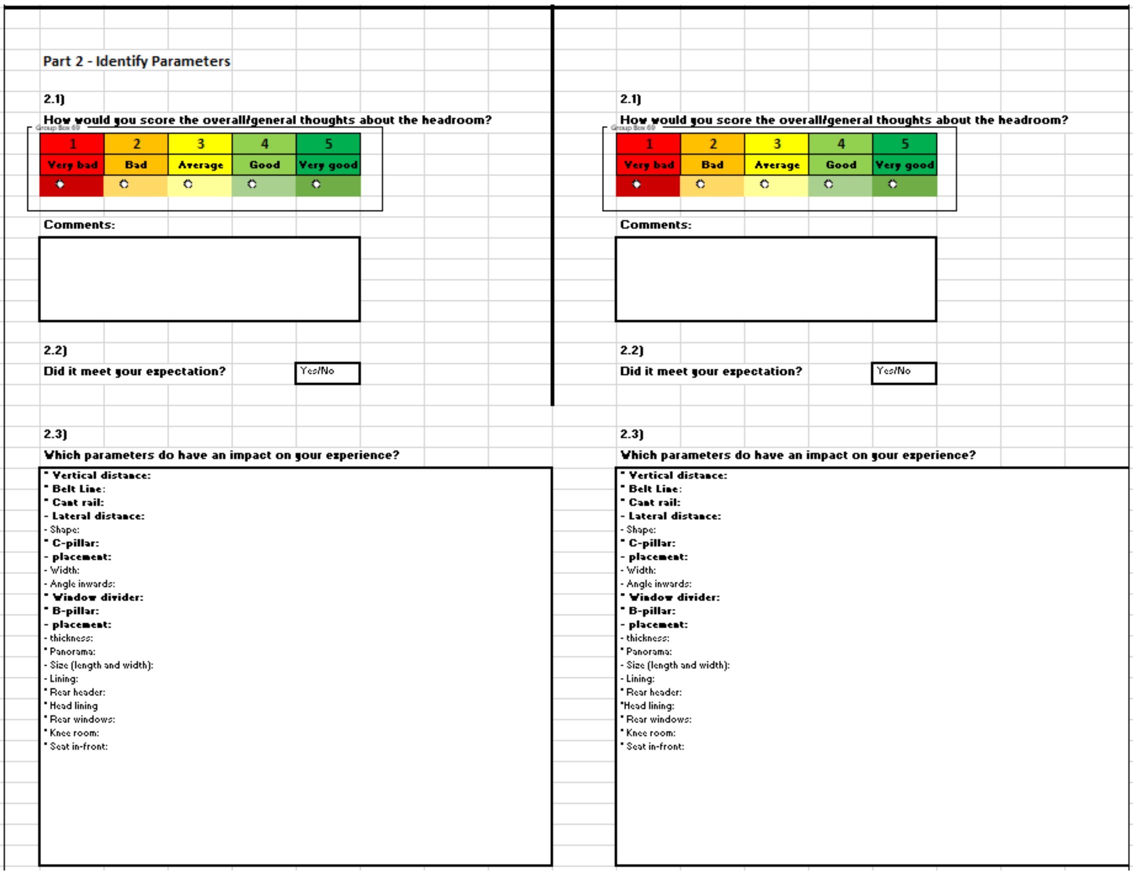


Figure B.1: Documentation sheet in excel for the questionnaire of phase 2 - part 1



Part 2 - Identify Parameters

2.1)

How would you score the overall/general thoughts about the headroom?

1	2	3	4	5
Very bad	Bad	Average	Good	Very good

Comments:

2.2)

Did it meet your expectation? Yes/No

2.3)

Which parameters do have an impact on your experience?

* Vertical distance:
* Belt Line:
* Cant rail:
- Lateral distance:
- Shape:
* C-pillar:
- placement:
- Width:
- Angle inwards:
* Window divider:
* B-pillar:
- placement:
- thickness:
* Panorama:
- Size (length and width):
- Lining:
* Rear header:
* Head lining
* Rear windows:
* Knee room:
* Seat in-front:

2.1)

How would you score the overall/general thoughts about the headroom?

1	2	3	4	5
Very bad	Bad	Average	Good	Very good

Comments:

2.2)

Did it meet your expectation? Yes/No

2.3)

Which parameters do have an impact on your experience?

* Vertical distance:
* Belt Line:
* Cant rail:
- Lateral distance:
- Shape:
* C-pillar:
- placement:
- Width:
- Angle inwards:
* Window divider:
* B-pillar:
- placement:
- thickness:
* Panorama:
- Size (length and width):
- Lining:
* Rear header:
*Head lining:
* Rear windows:
* Knee room:
* Seat in-front:

Figure B.2: Documentation sheet in excel for the questionnaire of phase 2 - part 2

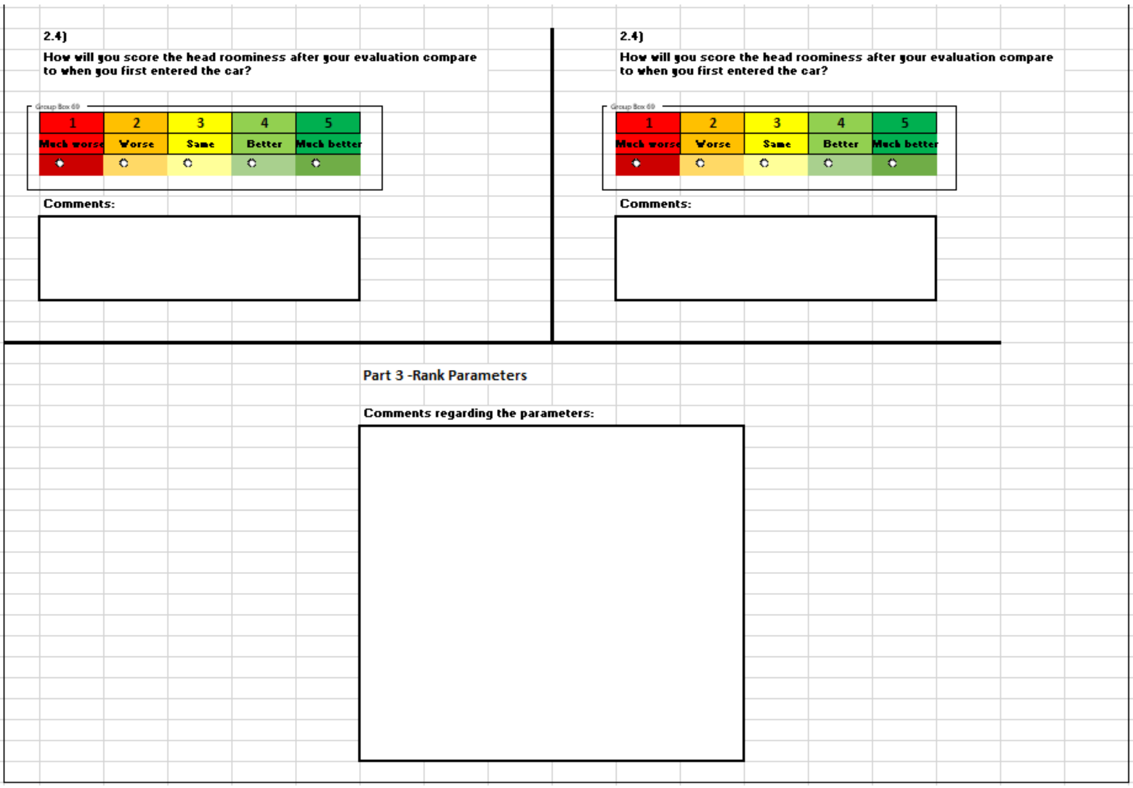
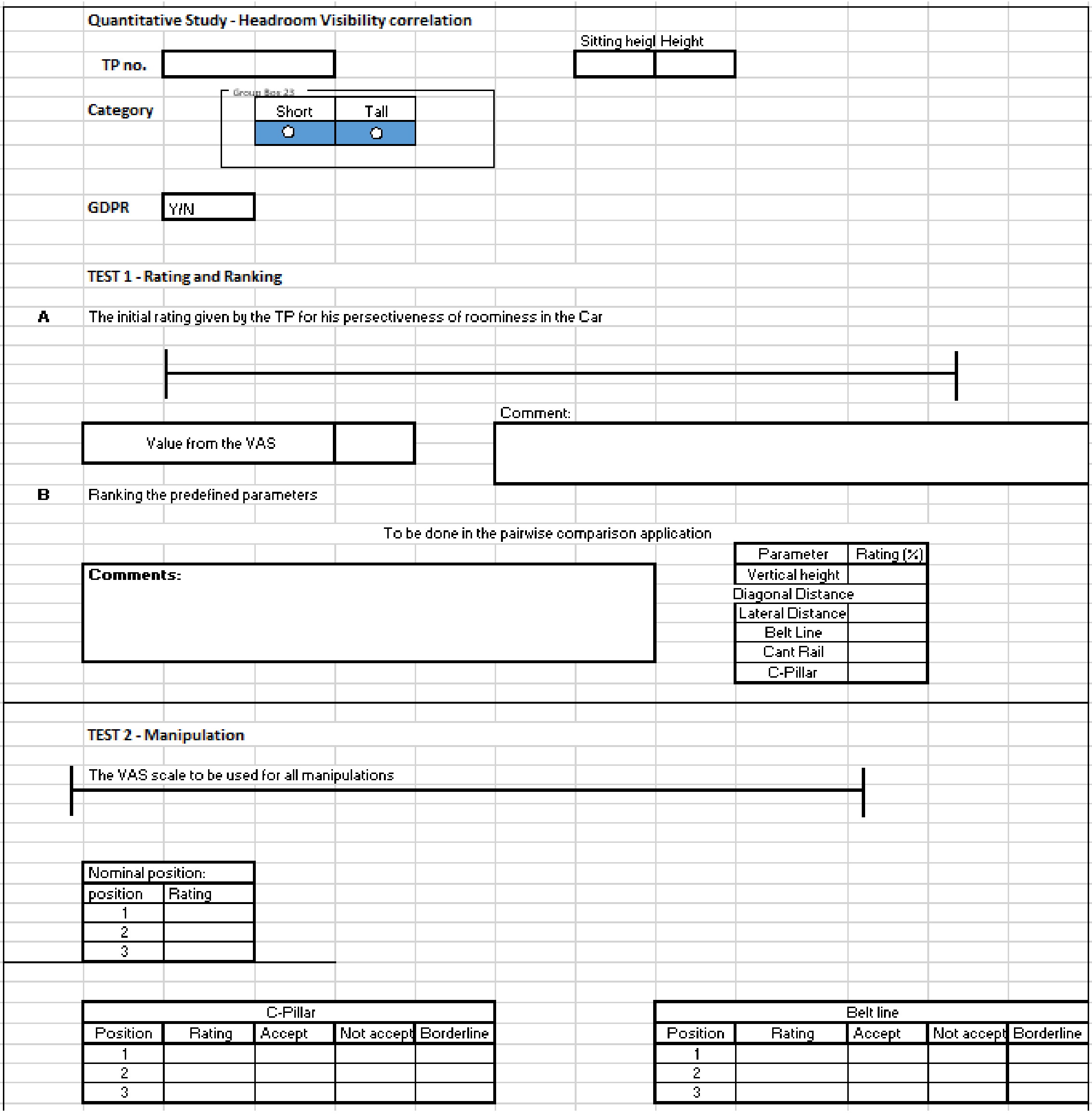


Figure B.3: Documentation sheet in excel for the questionnaire of phase 2 - part 3

C

Documentation Sheet - User test - Phase 3



Quantitative Study - Headroom Visibility correlation

TP no.

Sitting heigl Height

Category

Group Box 23

Short	Tall
○	○

GDPR Y/N

TEST 1 - Rating and Ranking

A The initial rating given by the TP for his persectiveness of roominess in the Car

Value from the VAS

Comment:

B Ranking the predefined parameters

To be done in the pairwise comparison application

Comments:

Parameter	Rating (%)
Vertical height	
Diagonal Distance	
Lateral Distance	
Belt Line	
Cant Rail	
C-Pillar	

TEST 2 - Manipulation

The VAS scale to be used for all manipulations

Nominal position:	
position	Rating
1	
2	
3	

C-Pillar				
Position	Rating	Accept	Not accept	Borderline
1				
2				
3				

Belt line				
Position	Rating	Accept	Not accept	Borderline
1				
2				
3				

Figure C.1: Documentation sheet - user test - phase3 (part 1)

Comments:

Comments:

Cant Rail				
Position	Rating	Accept	Not accept	Borderline
1				
2				
3				

Vertical Height				
Position	Rating	Accept	Not accept	Borderline
1				

Comments:

Comments:

TEST 3- Measurement and Documentation

A Physical measures with the Test Person

Verical distance from head to head lining		mm
Diagonal distance from the head to the nearest head lining		mm
Lateral distance sideward		mm

B

Group Box 17

	Yes	No
Picture from the side in natural position		

Group Box 19

	Yes	No
Picture from the front in natural position		

C

Group Box 20

	Yes	No
Interested in attending the presentation		

Figure C.2: Documentation sheet - user test - phase3 (part 2)

D

Manipulation of Vision Parameters

(a) Cant rail position- A1

(b) Cant rail position- A2

(c) Cant rail position- A3

Figure D.1: Manipulation of the Cant rail positions

(a) Belt line position- B1

(b) Belt line position- B2

(c) Belt line position- B3

Figure D.2: Manipulation of the Belt line positions

(a) C-pillar position- C1

(b) C-pillar position- C2

(c) C-pillar position- C3

Figure D.3: Manipulation of the C-pillar positions

E

Analysis of Extreme groups

To further analysis the patterns of VAS rating obtained for the Short and Tall group, similar line plots were made for the extremes group. The description about the extreme group has been discussed earlier in the section (refer). The intention of this analysis to check if the extreme group also follow the same pattern as the short and tall group or that they differ from them.

E.1 Cant Rail

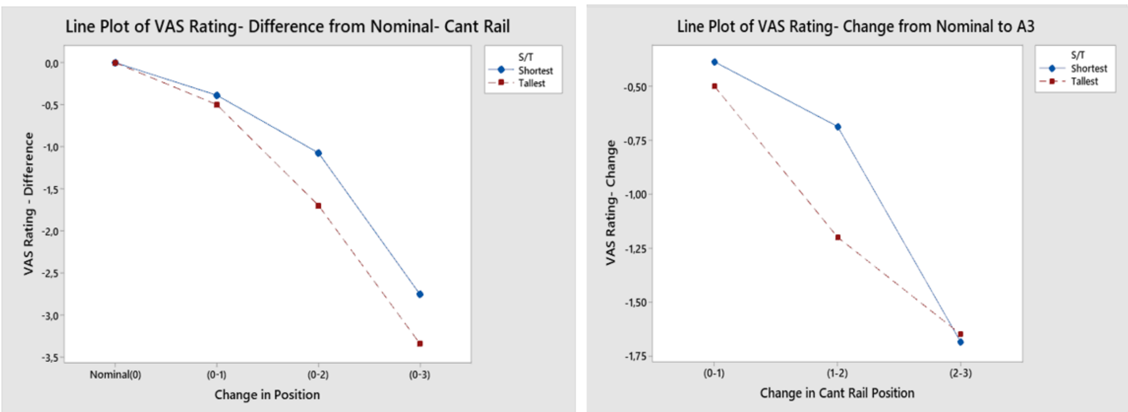


Figure E.1: Line plots visualizing the change in VAS rating from nominal state and from previous positions

Regarding the change in VAS ratings from the nominal state(0), the extreme group (shortest/tallest) also followed the same pattern as that of the short and tall group. Accordingly, the tallest group had greater impact of the Cant rail than the shortest group. Also, analyzing the change in VAS rating from the previous rating, (refer line plot), it is quite evident that all Cant rail position changes had equal impact on the tallest group and position A3 had the most impact on the shortest group. Thus, this pattern also confirms the pattern analysis results of the short and tall group. (Refer section)

E.2 Belt line

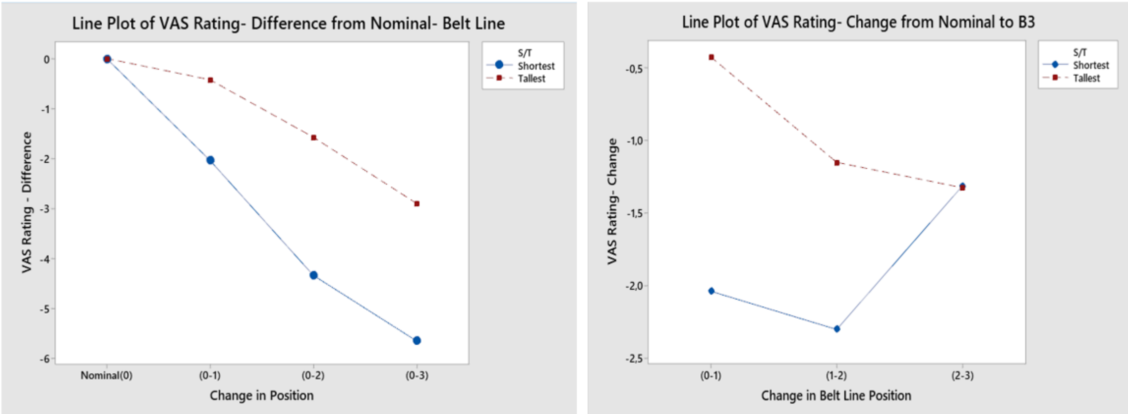


Figure E.2: Line plots visualizing the change in VAS rating from nominal state and from previous positions

This result confirms with the result drawn from the line plot xx for the short and tall group. Thus, it can be evidently confirmed that the short group are more sensitive to changes in the Belt line. Also, analyzing the change in VAS rating from the previous rating, it is quite evident that position B3 had a less impact on the shortest group and position B1 had the least impact on the tallest group. Thus, this pattern also confirms the pattern analysis results of the short and tall group.

E.3 C-pillar

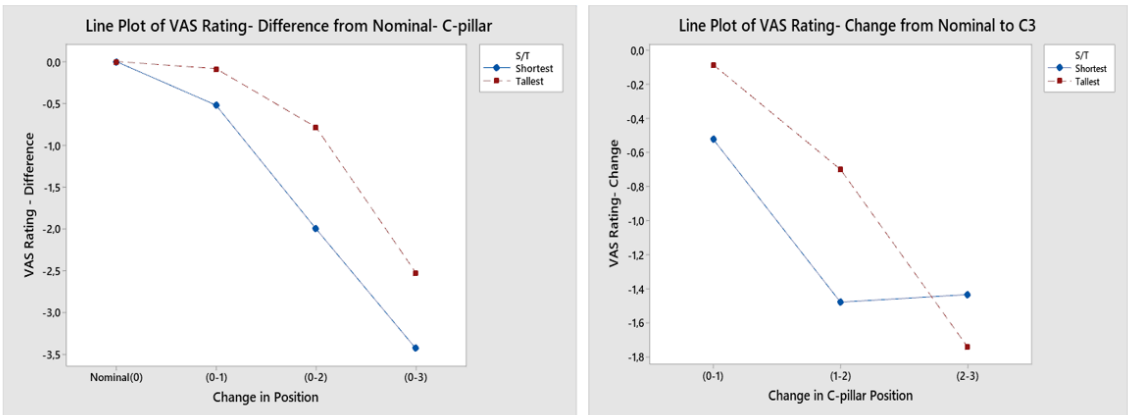
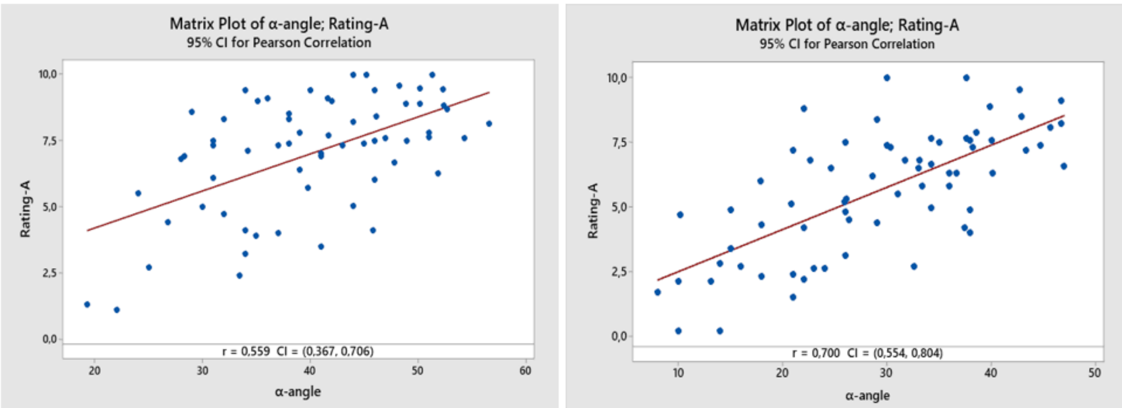


Figure E.3: Line plots visualizing the change in VAS rating from nominal state and from previous positions

F

VAS rating vs Angle to vision parameters (Short and Tall)

F.1 Cant rail

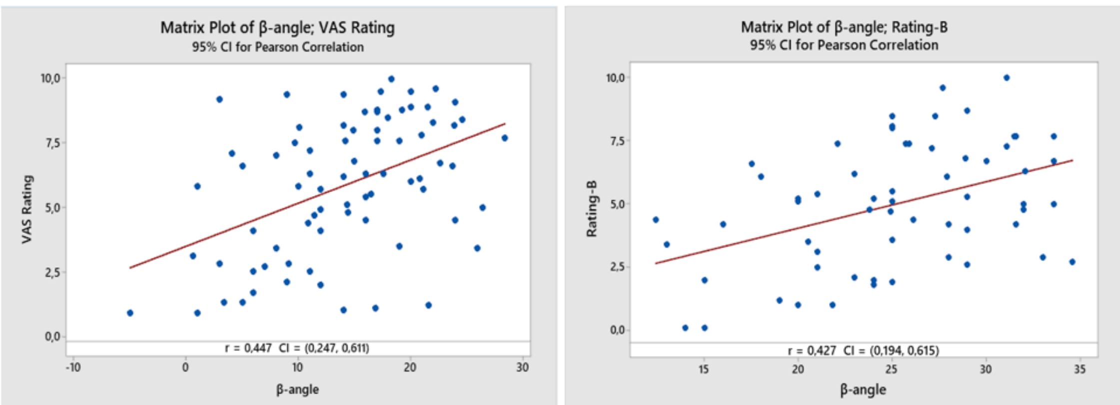


a. Short group

b. Tall group

Figure F.1: Scatterplot of VAS rating vs α-angle

F.2 Belt line

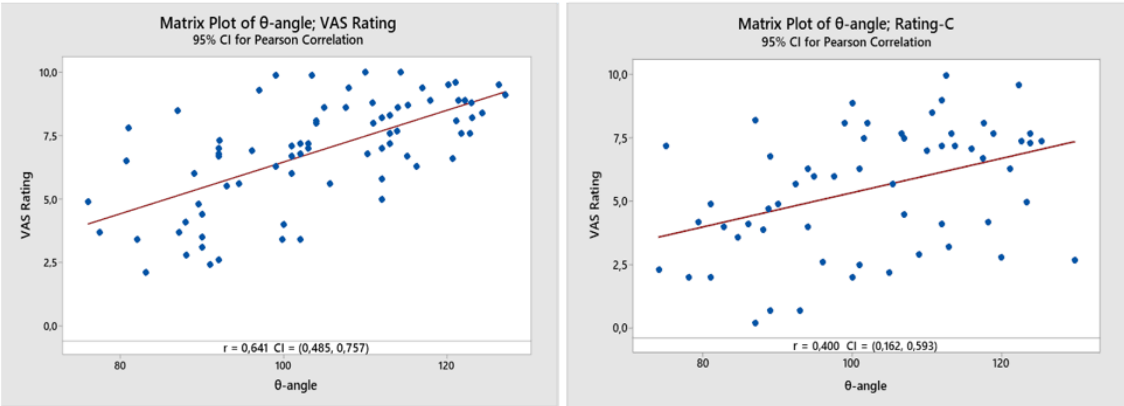


a. Short group

b. Tall group

Figure F.2: Scatterplot of VAS rating vs β-angle

F.3 C-pillar



a. Short group

b. Tall group

Figure F.3: Scatterplot of VAS rating vs θ-angle

G

2-sample t-test for acceptance angles

G.1 Cant rail

Test

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
4,40	23	0,000

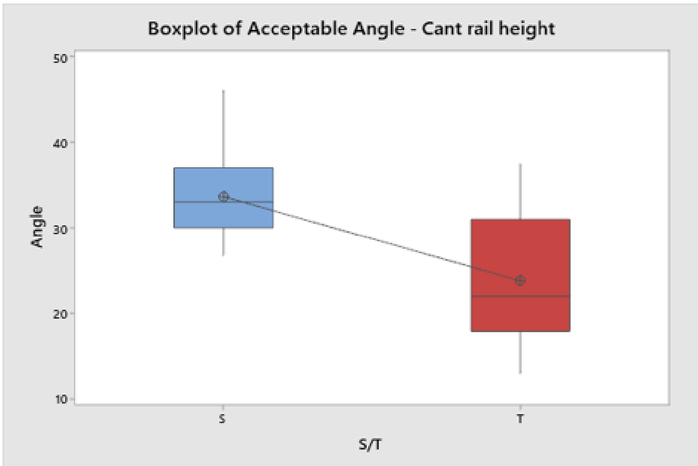


Figure G.1: Box plot of 2-sample t-test with test hypothesis

G.2 Belt line

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-4,89	31	0,000

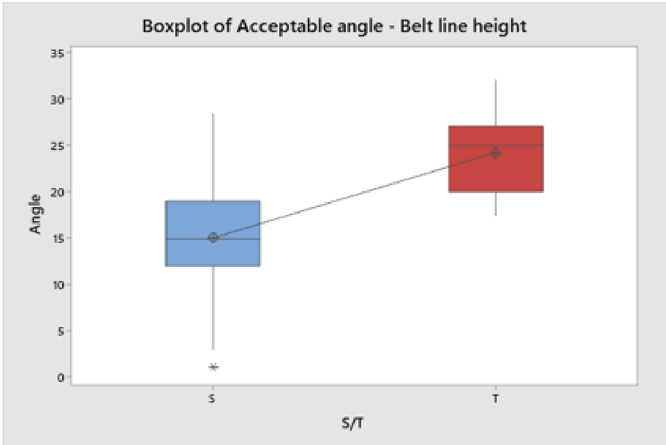


Figure G.2: Box plot of 2-sample t-test with test hypothesis

G.3 C-pillar

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-0,38	30	0,708

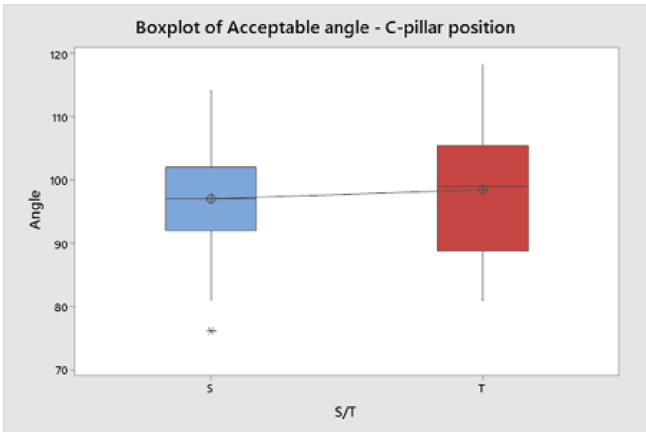
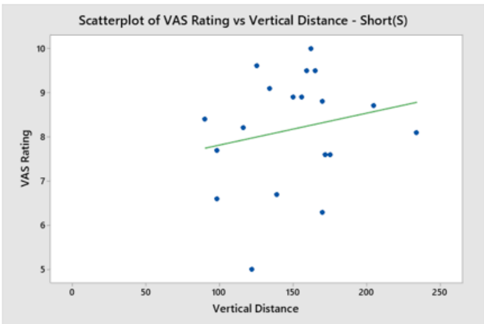


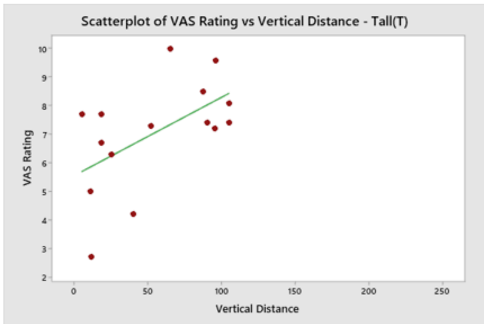
Figure G.3: Box plot of 2-sample t-test with test hypothesis

H

Scatterplots of VAS rating vs Spatial distance

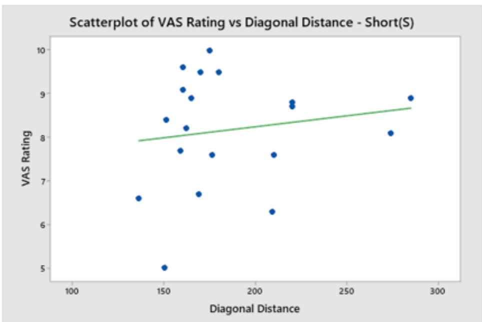


(a) Short group

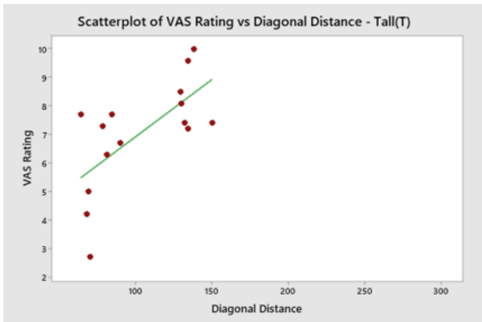


(b) Tall group

Figure H.1: Scatterplot of VAS rating vs Vertical distance

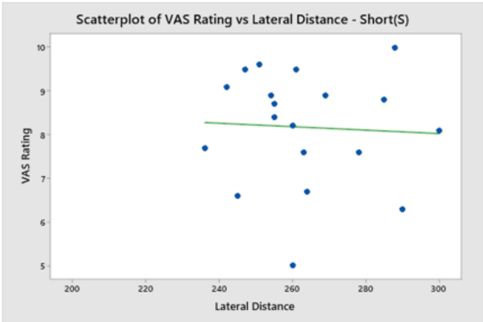


(a) Short group

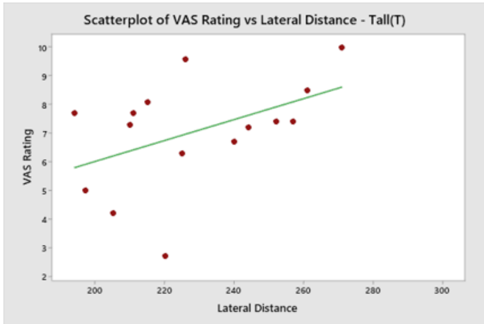


(b) Tall group

Figure H.2: Scatterplot of VAS rating vs Diagonal distance



(a) Short group



(b) Tall group

Figure H.3: Scatterplot of VAS rating vs Lateral distance

I

Analysis of Eye Position

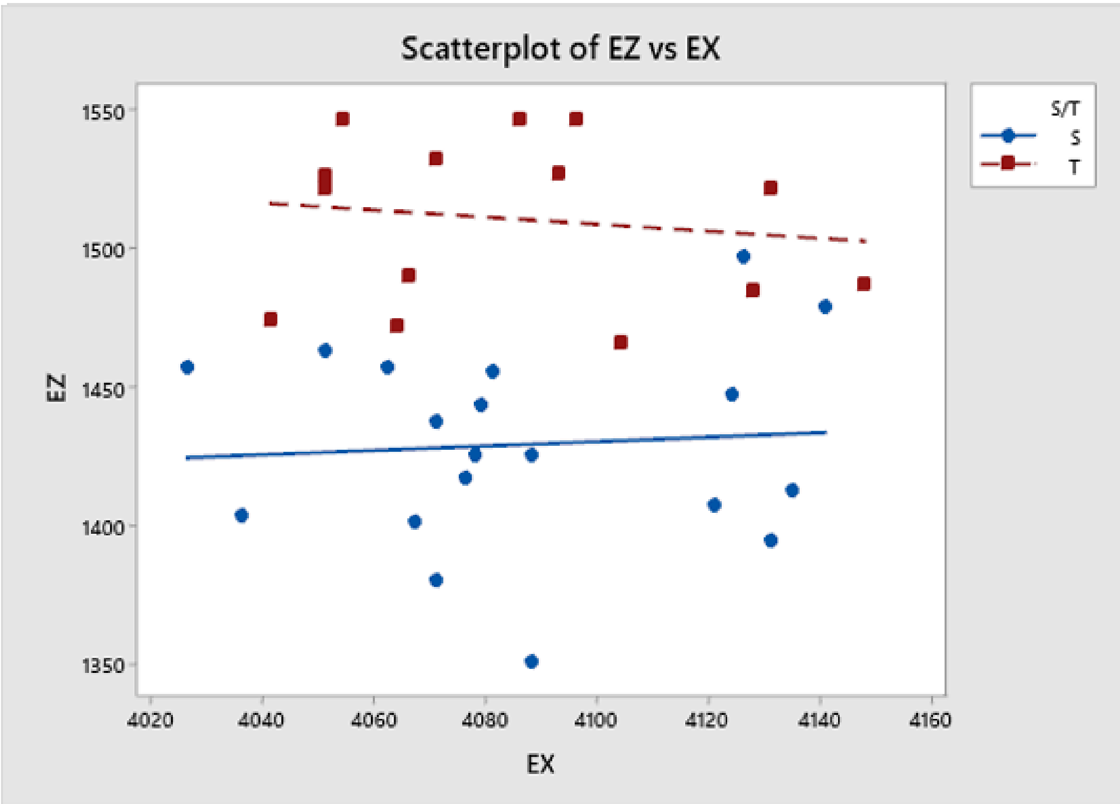


Figure I.1: Scatterplot of Eye coordinates (EX vs EZ) with regression fit line for Short and Tall group

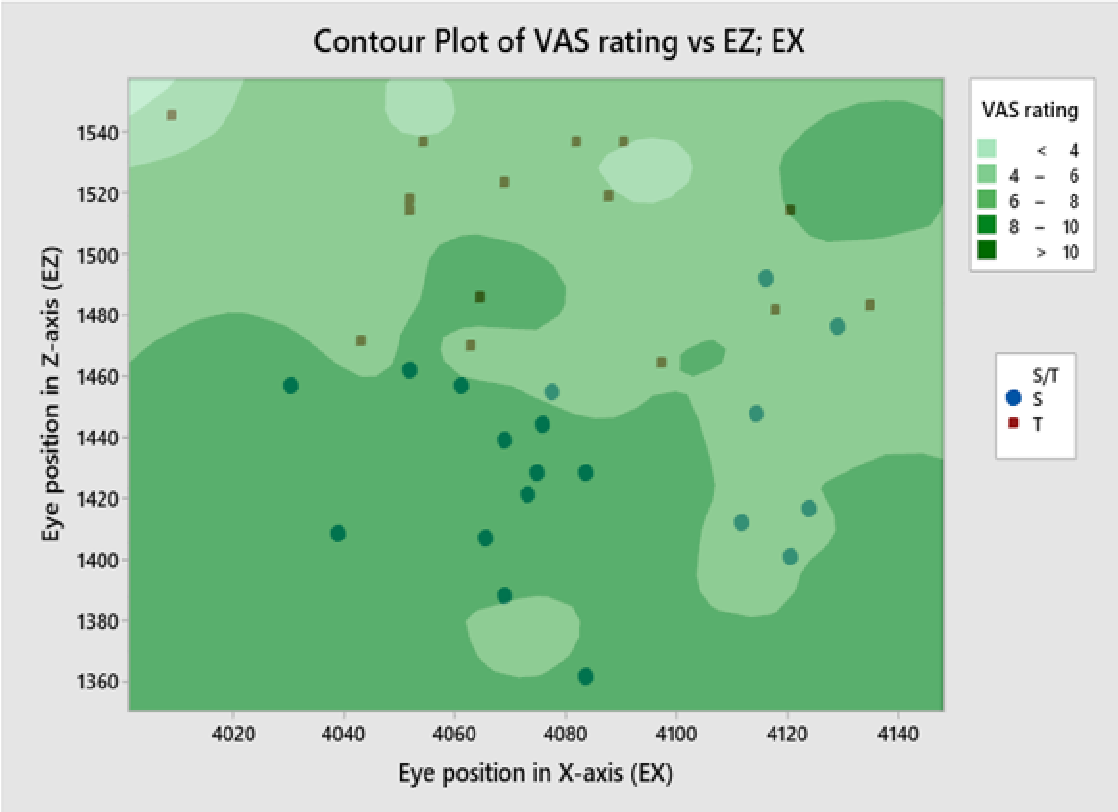
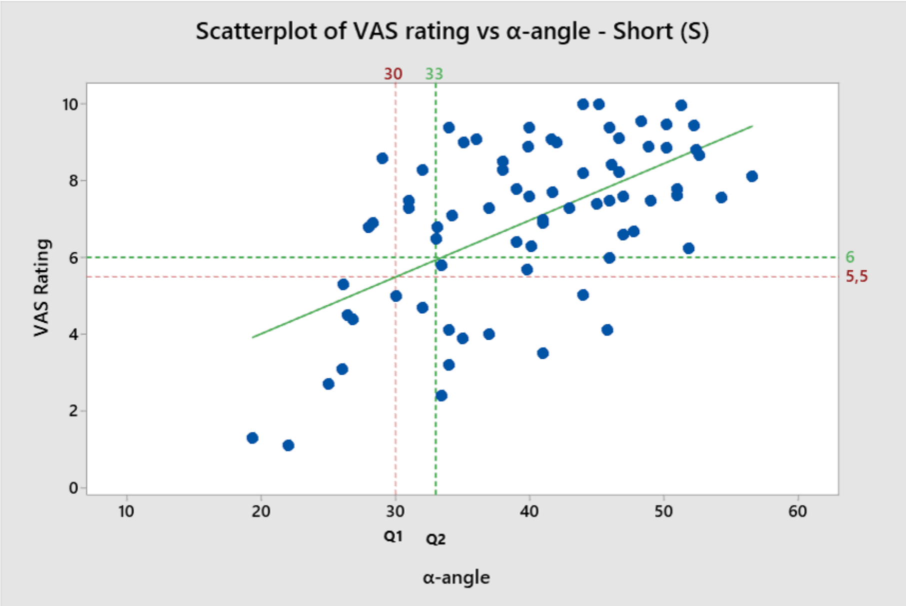


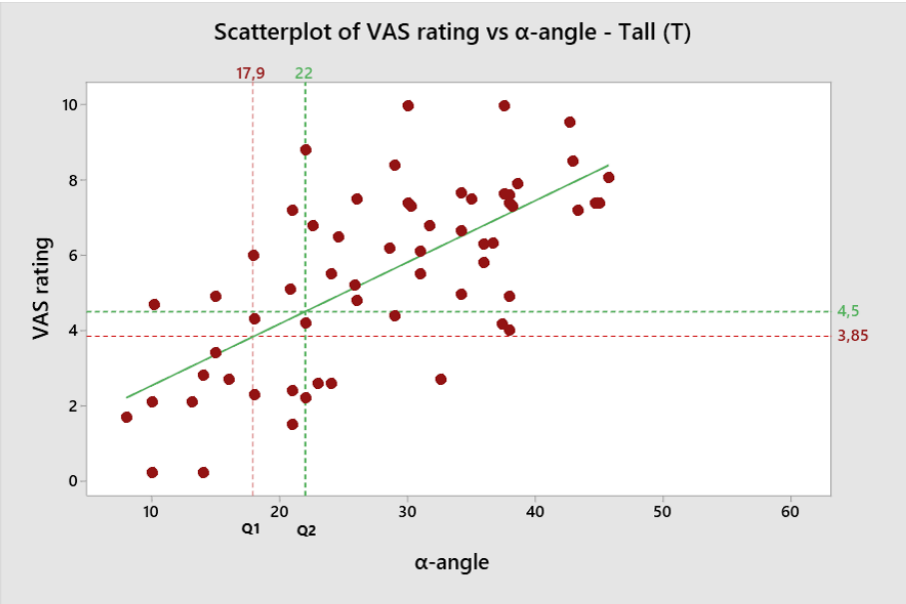
Figure I.2: Contour plot of VAS rating for EX vs EZ

J

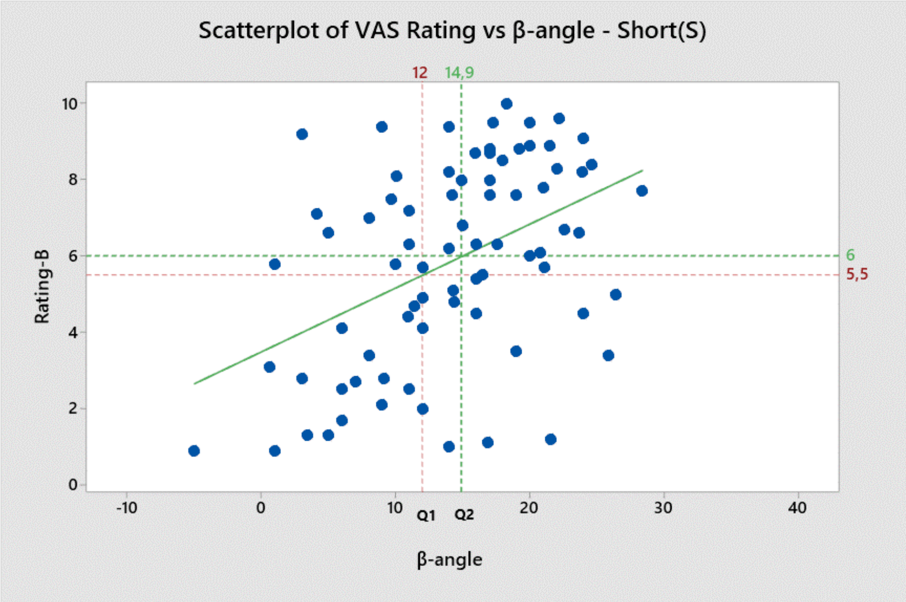
Expected VAS rating for the acceptance ranges



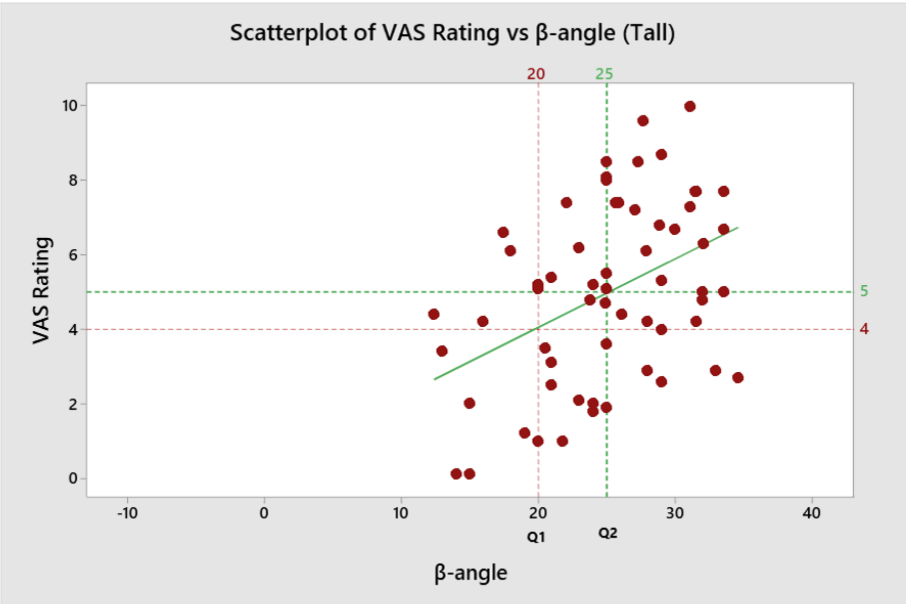
(a) Short group - Cant rail



(b) Tall group - Cant rail



(c) Short group - Belt line

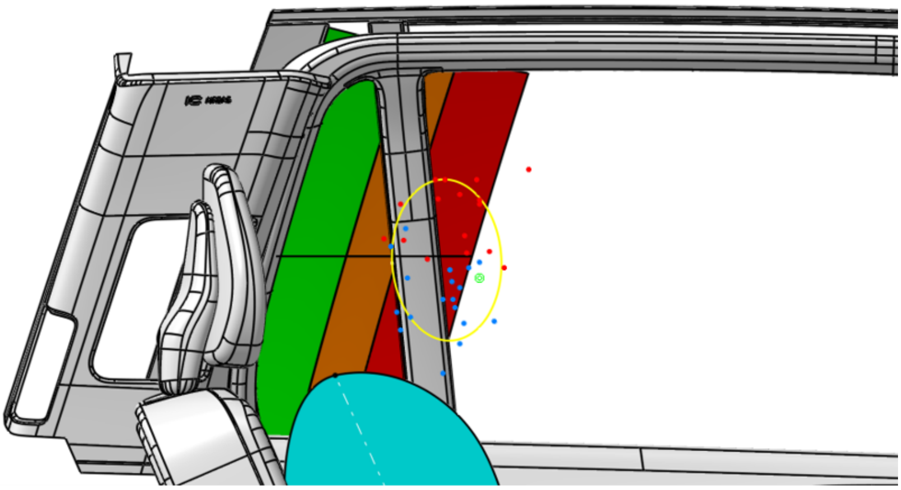


(d) Tall group - Belt line

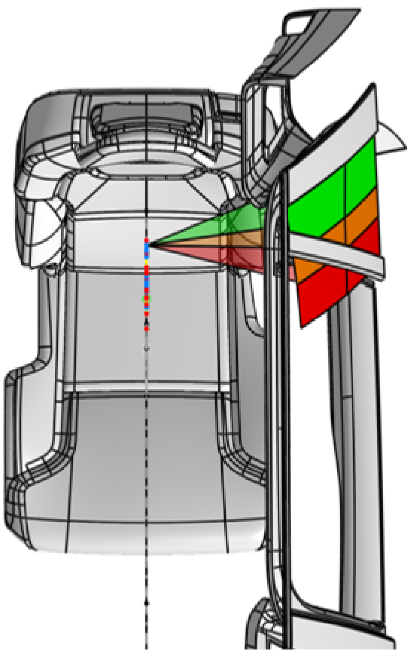
Figure J.0: The bounding angles Q1 and Q2 for Cant rail and Belt line, in respective groups; Short and Tall, are marked out with vertical lines. Where the lines are intersecting the trendline is where the VAS rating is obtained, marked with horizontal lines.

K

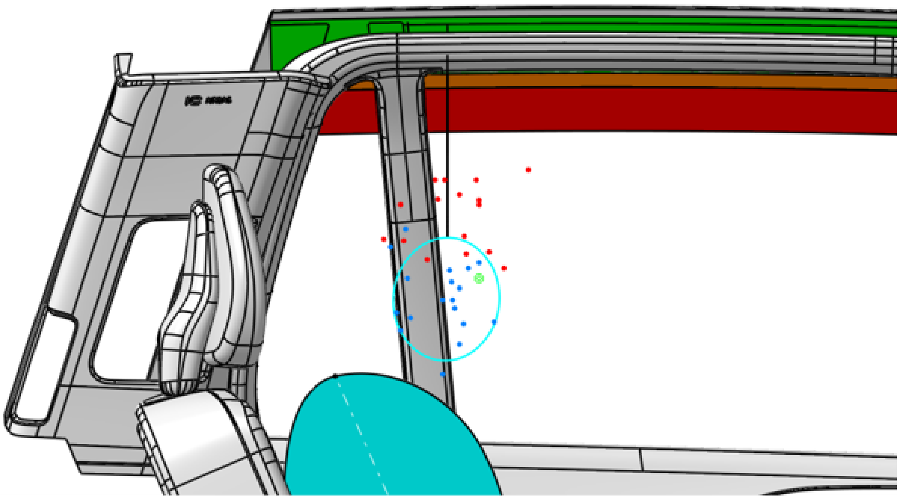
Acceptance range - extended views for the Vision parameters



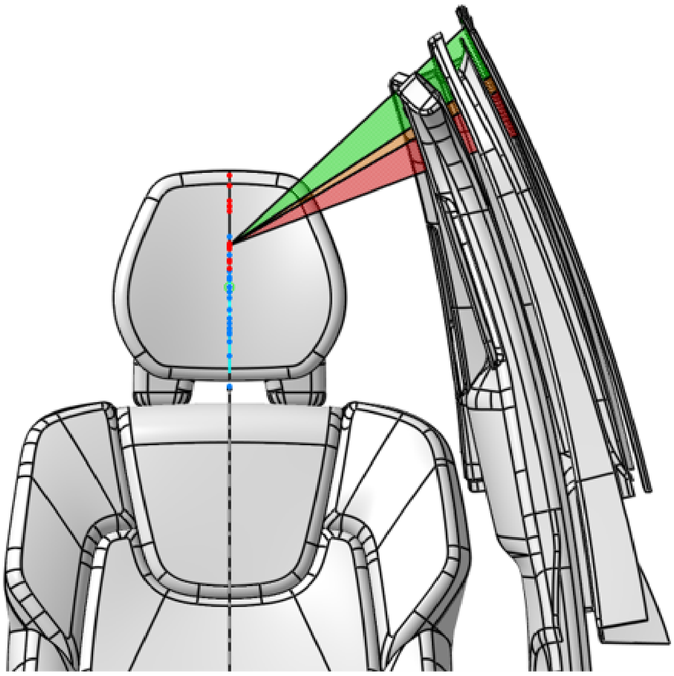
(a) C-pillar's acceptance range - side view for the whole group



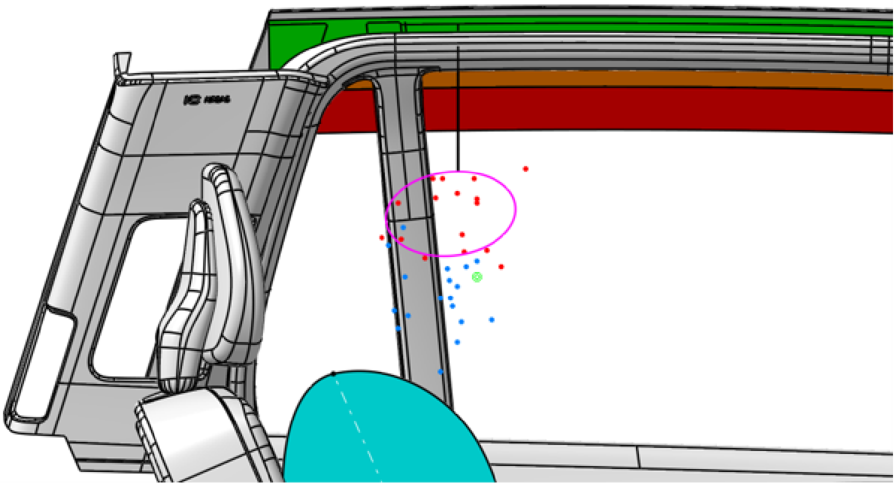
(b) C-pillar's acceptance range - plane view for the whole group



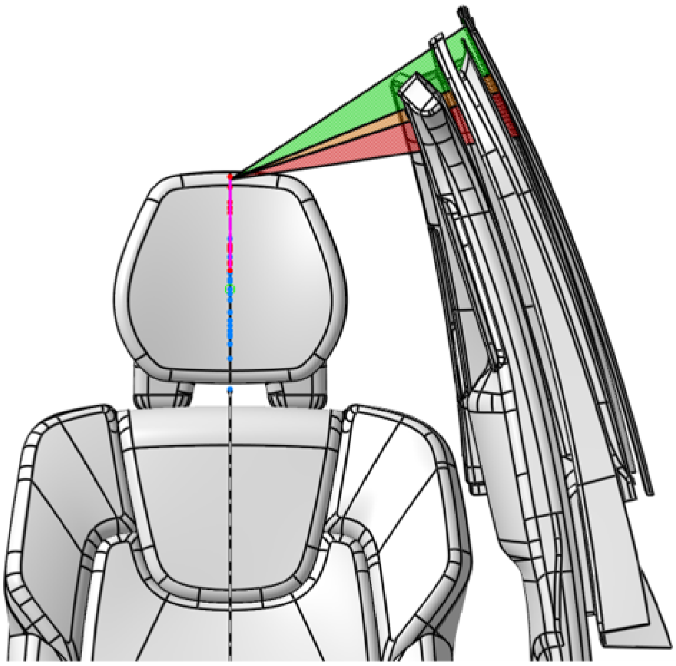
(c) Cant rail's acceptance range - side view for the Short group (95th %-ile)



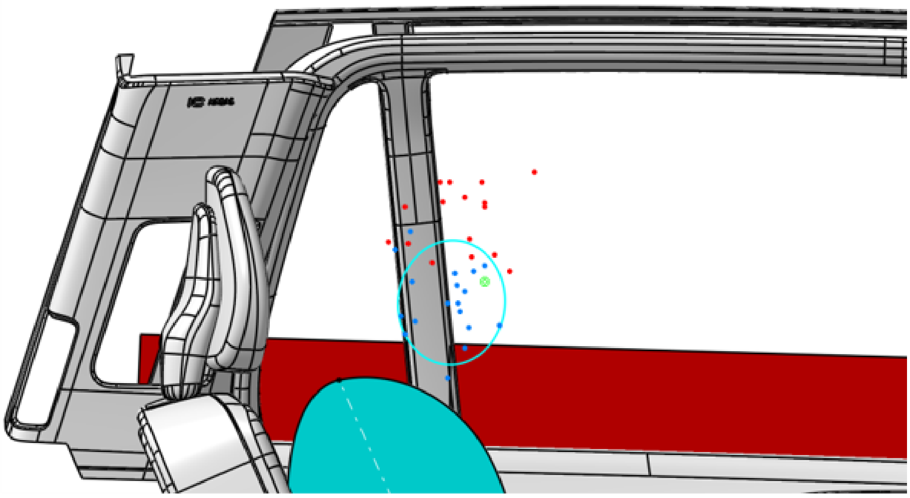
(d) Cant rail's acceptance range - front view for the Short group (95th %-ile)



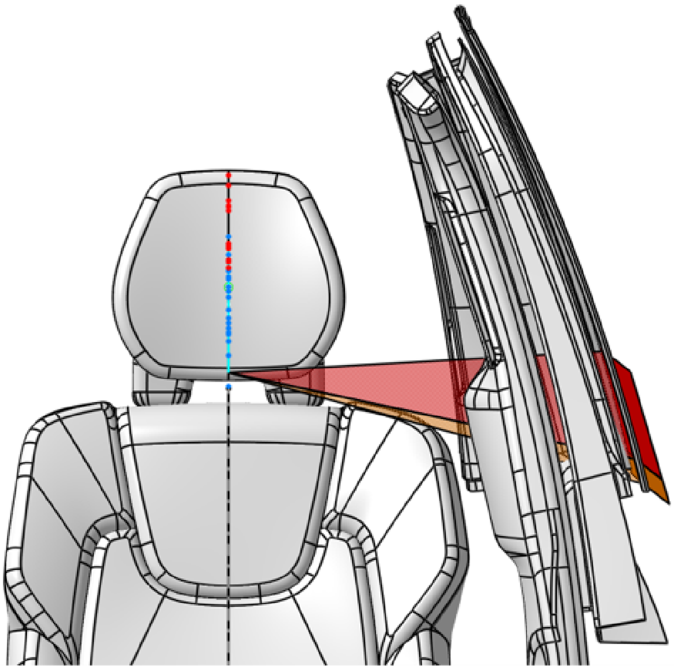
(e) Cant rail's acceptance range - side view for the Tall group (95th %-ile)



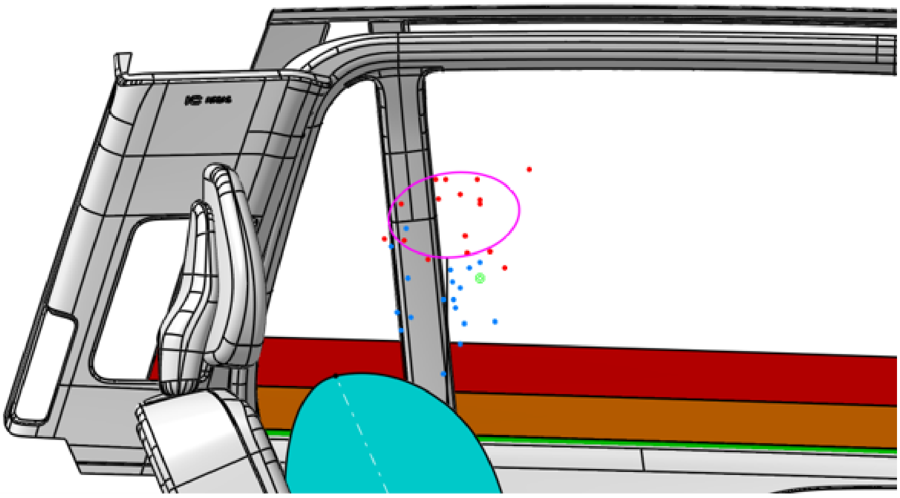
(f) Cant rail's acceptance range - front view for the Tall group (95th %-ile)



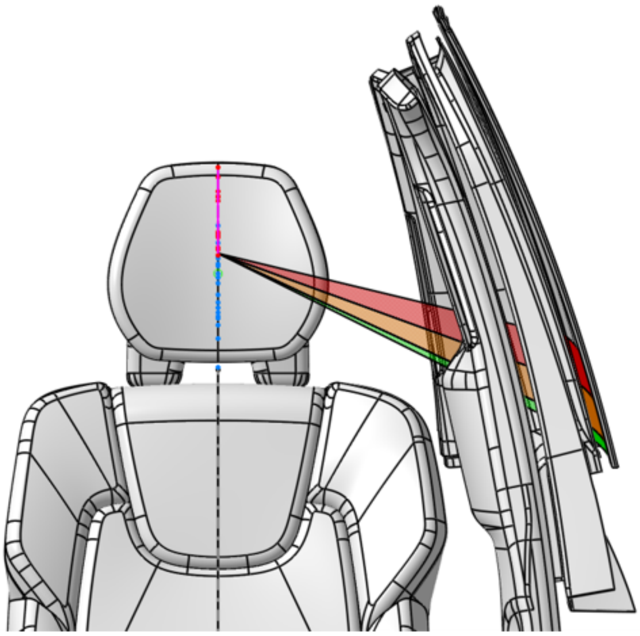
(g) Belt line's acceptance range - side view for the Short group (95th %-ile)



(h) Belt line's acceptance range - front view for the Short group (95th %-ile)



(i) Belt line's acceptance range - side view for the Tall group (95th %-ile)



(j) Belt line's acceptance range - front view for the Tall group (95th %-ile)

Figure K.-3: The Vision parameters acceptance range designed from the 95th %-ile for different groups

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Research Questions

With the results being analyzed and discussed, the research questions pertained to the overall study are answered.

RQ 1. How is the position of Cant rail influencing the Visual Analogue Scale (VAS) rating of perceived upper interior space?
The position of Cant Rail had affected the perception of upper interior space which is evident from the discussion about H2. In terms of visibility it can be said that the visibility upward-outward influences the perception of upper interior space in terms of roominess. There exists a moderate correlation with α-angle and VAS rating for the whole group and the Tall group exhibiting a high correlation.

RQ 2. How is the position of Belt line influencing the VAS rating of the perceived upper interior space?
The position of Belt line had affected the perception of upper interior space which is evident from the discussion about H3. In terms of visibility it can be said that the visibility downward-outward influences the perception of upper interior space in terms of roominess. With the manipulations done for visibility parameters it is evident that Belt line is the most influencing parameter for both the Short and Tall group. However, there is no statistical correlation established between the β-angle and the VAS rating for the whole, Short/Tall group.

RQ 3. How is the position of C-pillar influencing the VAS rating on the perceived upper interior space?
The position of C-pillar had affected the perception of upper interior space which is evident from the discussion about H4. In terms of visibility it can be said that the visibility in periphery-outward influences the perception of upper interior space in terms of roominess. There was a similar influence on the VAS rating for both the Small and Tall group. There exist a moderate correlation with θ-angle and VAS rating for the Short group and no correlation for the Tall group. The acceptance θ-angle was found to be in the same range for both the short and tall group.

RQ 4. How is the Vertical height influencing the VAS rating on the perceived upper interior space?
The tall group have ranked the Vertical height to be the most influencing parameter affecting the VAS rating of the perceived upper interior space. For the short group, the diagonal distance was the most influencing parameter. This result is based on the nominal state of the car since the measurable distances were not manipulated.

RQ 5. Is there a difference in rating the nominal Vertical distance and after the vertical change?
Yes. It is evident that the test persons have provided a lower rating on the VAS scale after the vertical change.

RQ 6. Is there a trend of how the test persons' ranking the parameters in Short and Tall group?
Yes, there exist a trend in ranking the parameters which is different for the Short and Tall group.

RQ 7. Is there a correlation between the VAS rating of nominal state and the Vertical distance?
No. There is no statistical evidence to define the correlation between the VAS rating of nominal state and the Vertical distance for whole population, Short/Tall group.

RQ 8. Is there a correlation between the VAS rating of nominal state and the Lateral distance?
No. There is no statistical evidence to define the correlation between the VAS rating of nominal state and the Lateral distance for whole population, Short/Tall group.

RQ 9. Is there a correlation between the VAS rating of nominal state and the Diagonal distance?
Yes for Tall group. There exist a moderate positive correlation between the VAS rating of nominal state and the diagonal distance, however there exist no statistical evidence for Short and Whole group.

RQ 10. Is there a correlation between a person's Z-position of eye coordinate and the VAS rating?
No. There is no statistical evidence to define the correlation between a person's X-position of eye coordinate and the VAS rating.

RQ 11. Is there a correlation between a person's X-position of eye coordinate and the VAS rating?
No. There is no statistical evidence to define the correlation between a person's X-position of eye coordinate and the VAS rating.

RQ 12. Is there a trend between the sitting posture (X-coordinate) and the VAS rating?
No. There is no trend between the two elements, meaning that the sitting posture did not affect how the upper interior space was rated on the VAS scale.

RQ 13. Does the borderline for every parameter reflect upon a range of an angle for a specific parameter?
Yes. For the vision parameters (Cant rail, Belt-line and C-pillar) there exists a range of last acceptance angle for Whole, Short/Tall group.