MSc. Integrated Product Design
Faculty of Indsutrial Design Engineering
Delft Univerisity of Technology

Comfort in a Vehicle Seat:
Research and Redesign of a Head Support for Sleeping Purposes

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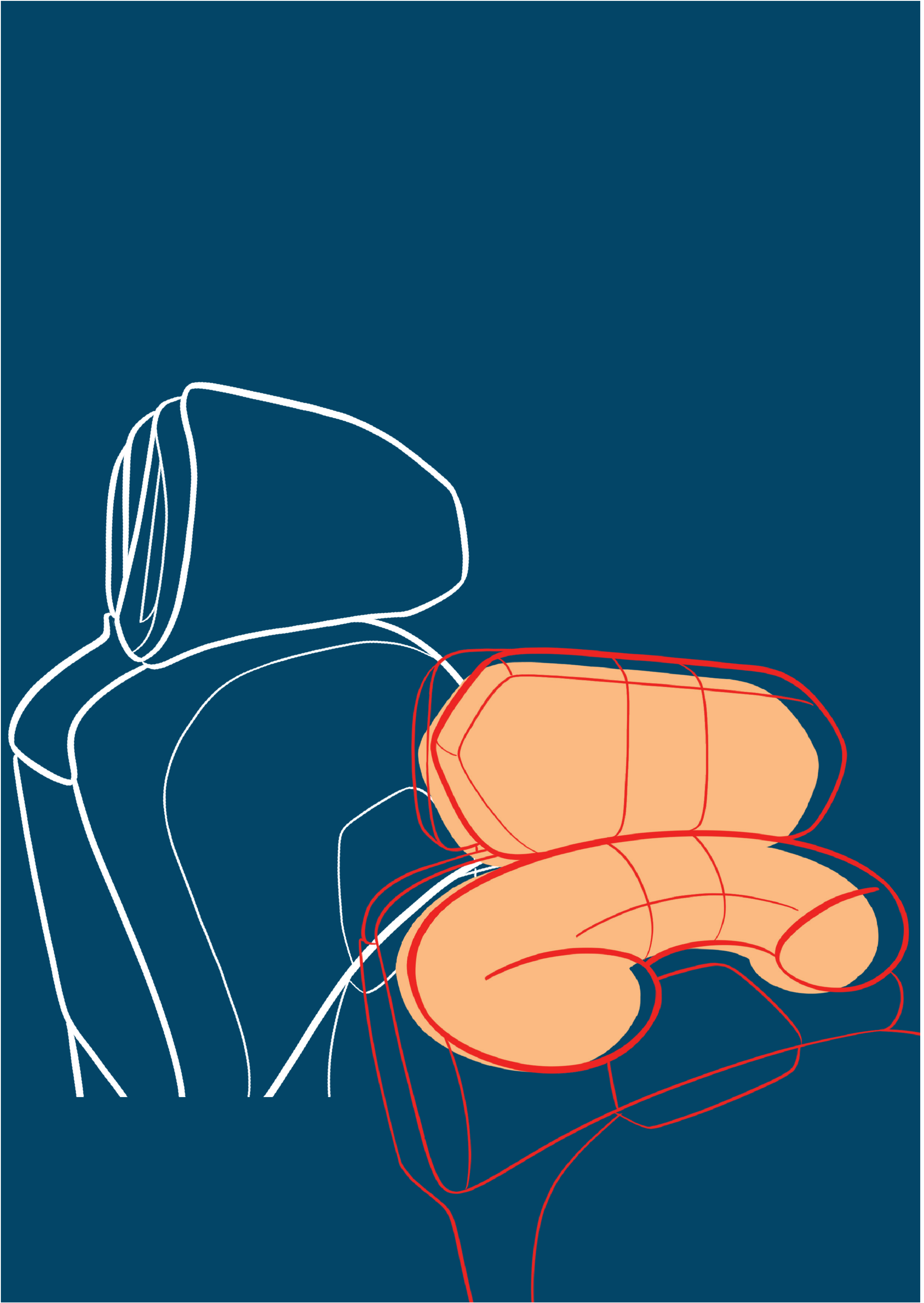

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Master Thesis
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Last but not least, to my friends in my home country and in the Netherlands, who provided me with all the emotional support and laughs during the most stressful moments.

I hope you all enjoy this report as much as I have developing it!

Abstract

With the evolution of Autonomous Vehicles for the near future, BMW has designed a new seat for their vehicles, whose aim is to offer the greatest amount of comfort possible. Their main challenge now is to transform this level of comfort even when passengers want to sleep on the road, or while charging their vehicles. When it comes to confined spaces such as seats, obtaining a comfortable sleep has always been a challenge.

Taking into account the difficulty in achieving comfortable sleep in a seat, one of the main goals of BMW is to further enhance this seat within the context of sleeping. Sleeping is becoming one of the most popular activities among those passengers during a journey, and it is expected to grow with the integration of fully autonomous vehicles. Therefore, the first goal of the project is to analyze the seat to ensure maximum comfort when sleeping, and the second goal is to tackle the main area of discomfort with a design proposal.

For this, a thirty-minute sleeping research is conducted with sixteen participants, evaluating two different backrest angles (120º and 140º). The results show a preference of reclined backrest of 140 degrees, and an increase in comfort compared to sleeping in conventional seats. All participants had a good nap with this reclination, with an average amount of sleep of fourteen minutes. Regarding the seat analysis, the most uncomfortable part of the seat is the headrest, due to the lack of support for neck and head, and the lack of height adaptability to different demographics. The second area of discomfort is the leg support and the lack of footrest.

With these results in mind, the second goal is to develop an attachable head support that can be integrated in the BMW seat, for offering more comfort while sleeping in a reclined position. The main requirement considered is to make it adjustable in the area of head, neck, and height of the user.

The proposed design consists of two main components: a head support and a neck support. An integrated mechanism in the foam allows the adjustment of both to the width of the head and neck. In addition, a mechanism allows adjusting the height of the support to the desired position. Different prototypes are developed to assess the viability of the design features and feasibility for its integration in the seat.

A subsequent user test involving ten participants is conducted to validate the comfort and functionality of the design. The participants were asked to sleep in the seat making use of the new support. In order to obtain more objective results, four pressure sensors are integrated in the product to calculate the ideal pressure distribution exerted by the users. The data obtained from the sensors corroborated findings from literature research. Additionally, the support significantly increases the comfort after a thirty-minute nap in comparison to sleeping without support.

Content

1 Project Introduction

This chapter provides the readers with an overview of the motivation and how the project became. Additionally, it introduces the initial assignment of why it is necessary to focus on comfort in the design of a vehicle seat and why sleeping is chosen as a main activity. A short overview of the main topics that will be deeper researched throughout the report is provided.

1.1. Motivation

As an industrial designer, I have always been taught the need of prioritizing user-centered design during the development of a product, because it places the end user at the forefront of the design process. In order to create successful and impactful designs, it is fundamental to consider how users interact with a product and to ensure its comfort.

In the field of mobility, researching and understanding how users interact with vehicles and learning how to incorporate ergonomic considerations into automotive design is essential for enhancing usability and safety. By prioritizing comfort in the mobility sector, the functionality of the vehicles can be elevated while meeting the diverse needs of users.

The combination of these two fields of design have always sparked my attention during my period as a Master student, collaborating with Ford for enhancing user interaction with Electric Vehicles or during my internship at an electric bikes company in Amsterdam.

When Peter offered me the opportunity to participate in the BMW research for identifying the optimal backrest angle while sleeping and preferences in constrained spaces, I was intrigued and eager to delve deeper into the project details.

Analyzing together with Gerbera the feedback provided by the participants made me realize about the needs and consequently design opportunities that are still not addressed for obtaining better sleeping comfort when sleeping in journeys.

After showing the results to the BMW seat department, they gave us the opportunity to research and analyze the seat that had been developing during the last years, whose main goal was to offer the ultimate comfort to passengers. Considering that the seat had not undergone user testing yet, and that they were trying to ensure better comfort for sleeping on it, these challenges sparked my interest in delving further into it as a graduation project.

Figure 1.1. Set up for identifying optimal backrest angle (Vledder et al., 2024)

Figure 1.2. Visit to BMW Group Research and Innovation Center FIZ May 26, 2023

1.2. Introduction & Background

The following thesis is divided into two main assignments. The first goal, and the one proposed by BMW is the research on the seat designed and provided by them. From this research, the second goal is to improve the seat consideing its main weak points that users experience during the research phase. The seat can be seen in Figure 1.3.

The first objective aims to discover which are the most critical points of their seat. Currently, the seat is designed for integrating it in the passenger side, and designed for offering its occupants the best possible sleeping comfort on the road. BMW is interested in developing this seat further. Their main goal is to make use of this seat for resting or taking a short nap when the vehicle is being charged, or in the future, for sleeping in Autonomous Vehicles (AV).

Considering the initial assignment and goal regarding the seat analysis, the following challenges are addressed:

- What are the parameters that affect to (dis)comfort of a passenger in a seat?
- How (dis)comfort can be measured?
- Are there any areas of the seat that provide discomfort? If so, what are the main redesign opportunities of the BMW seat for improving its sleeping comfort?

Considering BMW goal, the research and further redesign proposals on the seat, will be mainly focused on improving sleeping comfort.

From the research phase, the main discomfort area of the seat is identified. As expected by BMW researchers, the neck and head of the participants was evaluated with higher discomfort ratings, due to the head support provided by the seat. Previous research already demonstrated that this area of the body tends to suffer bigger discomfort when sleeping in different transports due to its constrained space. From the research, the project will focus on the redesign opportunities for the upper part of the seat due to the insights obtained by the participants.

For the second goal of the project (redesign proposal on the head support for comfort improvement), the following challenges were addressed:

- In what ways can the comfort of sleeping be enhanced, particularly with a focus on the head and neck region?
- How can the new proposal be integrated into the seat?
- To achieve a seamless integration, what dimensions, materials, and mechanisms would be most conducive for ensuring comfort to a broader end user?

Figure 1.3. Seat provided by BMW for further analysis. Source: BMW Blog (2020)

Further knowledge about general comfort and sleeping is explained in the following paragraphs.

1.2.1. Comfort

Comfort and discomfort are aspects of human experience that influences our well-being, productivity and quality of life. Whether in the use of daily products, transportation, routines or choices, comfort and discomfort terms are often present. The study of comfort together with its counterpart, discomfort, is essential for improving the way we live, work and interact with the world.

Comfort is defined as "pleasant state or relaxed feeling of a human being in reaction to its environment". Discomfort is defined as "unpleasant state of the human body in reaction to its physical environment" (Vink and Hallbeck, 2012). Both concepts are independent entities associated with different elements. Comfort is related to a sense of well-being and aesthetics, and discomfort to biomechanics and fatigue (Helander and Zhang, 1997). Therefore, comfort and discomfort can't be comparable or measured as opposites on one scale, but are preferably evaluated in an individual way. Reducing discomfort will not necessarily increase comfort, but in order to accomplish a higher level of comfort, the level of discomfort should be low (Helander and Zhang, 1997).

Vink and Hallbeck (2012) proposed a comfort model (Figure 1.4) with the interaction of products and what factors influence this.

In the model, the contact between the human and the product and its usage creates the interaction (I). This leads to human body effects (H), such as tissue changes, blood flow, or muscle activation). The perceived effects (P) are influenced by these human body effects as well as expectations (E). The expectations and effects can be intercepted as comfortable (C) , nothing to feel (N) or discomfort (D). The discomfort can result in musculoskeletal complaints (M). Last, the environment in which the interaction between the user and the products takes place is integrated by the person, the characteristics of the product, and the task that the person will perform with that product.

1.2.2. Sleeping

With the development of AV, the concept of in-vehicle sleep is gaining attention and consideration among researchers (Tang et al., 2020). With the next stage of Level 4 automation, as vehicles become increasingly capable of automated driving, passengers evaluate the opportunity to use the travel time for other activities such as resting.

Understanding the basics of sleeping stages and phases is core in order to analyse and research further sleeping results. During an average of eight-hours sleep, we go through a cycle of five stages of sleep (Figure 1.5) multiple times a night.

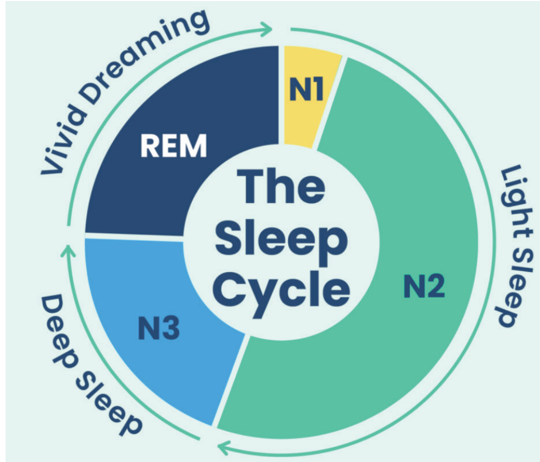


Figure 1.5. Different stages of a full sleep cycle (SleepFoundation, 2023)

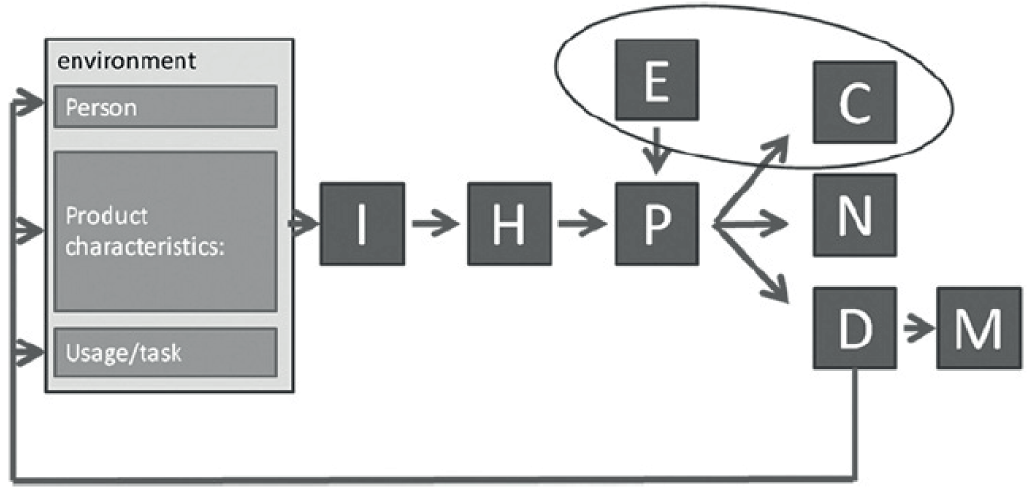


Figure 1.4. Vink & Hallbeck comfort model (2012)

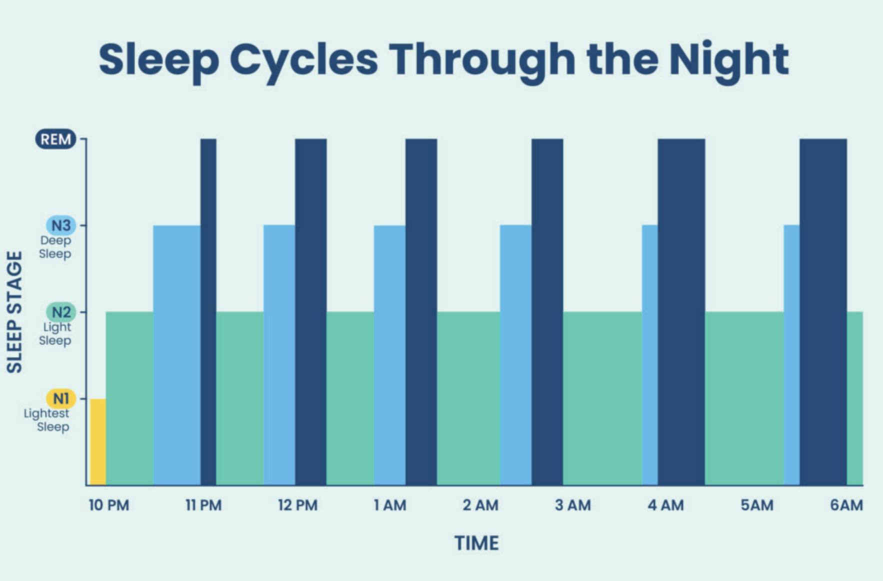


Figure 1.6. Sleep cycles through the night (SleepFoundation, 2023)

During stage 1 (or N1), a person first falls asleep. This stage lasts from one to seven minutes. During this stage, the body has not fully relaxed, though the body and brain activities start to slow with periods of brief movements. Although it is easy to wake the person up during this sleep stage, they can move quickly to stage 2.

During stage 2 (N2) the body enters in a more relaxed state of muscles and slows breathing and heart rate. Brain waves create a new pattern and eye movement stops. Brain activity stops but there are short bursts of activity (Schönauer & Pöhlchen, 2018).

During stage 3 and 4 (N3), also known as deep sleep, it is harder to wake someone up. Muscle tone, pulse and breathing rate decrease and the body relaxes even further. During the early sleep cycles, N3 lasts for 20 to 40 minutes. During more sleeping, this stage gets shorter and more of the time goes to REM sleep, as it can be seen in Figure 1.6

1.3. Project scope & Structure

PROJECT SCOPE

This project contributes to the fields of ergonomics and comfort design with the focus of seat design in seat vehicles. It begins by examining the requirements for a comfortable sleep in current constrained spaces such as seat vehicles. From these insights, it investigates the main areas of comfort and discomfort of the latest BMW seat concept, aimed at offering an ultimate relaxing time.

Finally, the the project proposes an easy implementation in the seat that improves sleeping comfort by adding a customized head and neck support with different configurations. A user test involving ten end users confirms that the proposed implementation highly improves the overall comfort and time to fall asleep.

PROJECT STUCTRURE

The project initiates with an extensive exploration of comfort, addressing various areas of the body while focusing specifically on vehicle seats. Since it is discovered the main area of redesign of the seat, a wider research is done to understand what factors influence comfort in the context of automotive seating.

The sleeping research is performed with 16 participants, and after evaluating the questionnaire provided and the recordings, the redesign is narrowed to the area of the head and neck support.

From there, literature research on ergonomics in the neck and head support is performed in order to discover how the discomfort can be avoided in this area.

Prototypes and iterations are developed in order to obtain a design that improves the sleeping comfort. Details on the final design and how it improves the comfort while relaxing in the seat are explained thoughout the report.

1.4. Approach

For the research and definition of the future improvement area of the seat, the structure follows the workflow outlined in the Vision in Product Design (ViP) method proposed by Hekker and Van Dijk (2016). An overview of the method can be seen in Figure 1.7

The problem Definition and Deconstruction section explores the current interaction that users have with the seat, and how these interactions are affected (in this case, sleeping)

Once the deconstruction phase is concluded with the further area of redesign, in Chapter 5 a vision is developed in order to design with more clarity a product that meets the desired qualities.

Additionally, the approach adopted during the whole project follows the "double diamond" structure (Figure 1.8). The process started with literature research that was helpful to better analyse the data from the sleeping research and to stablish design requirements that will be taken into account in the ideation phase.

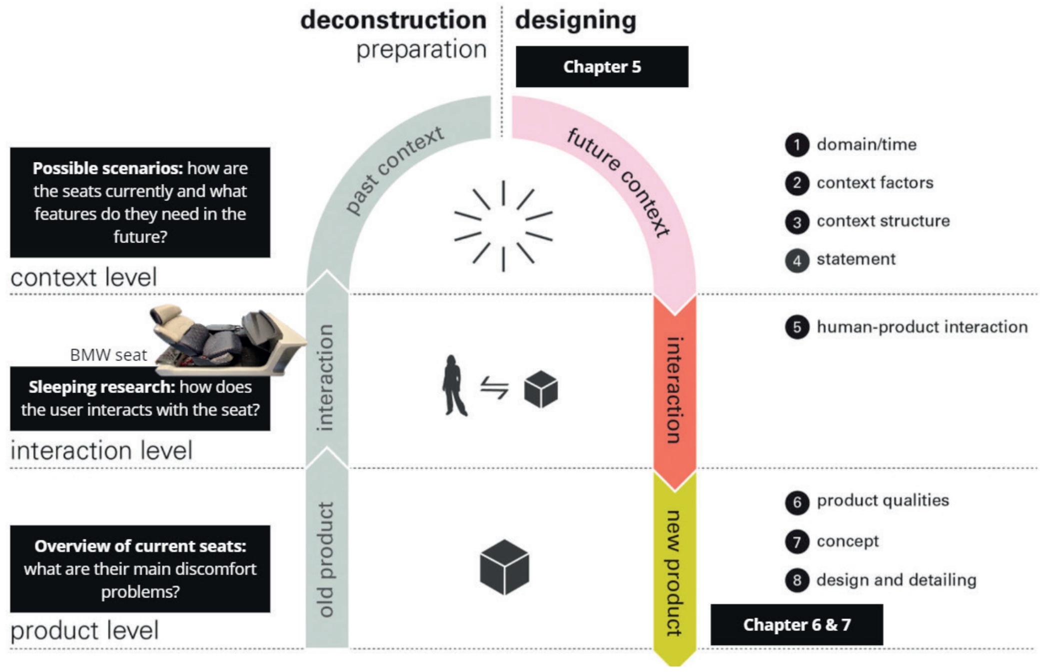


Figure 1.7. VIP method followed for the development of a new proposal

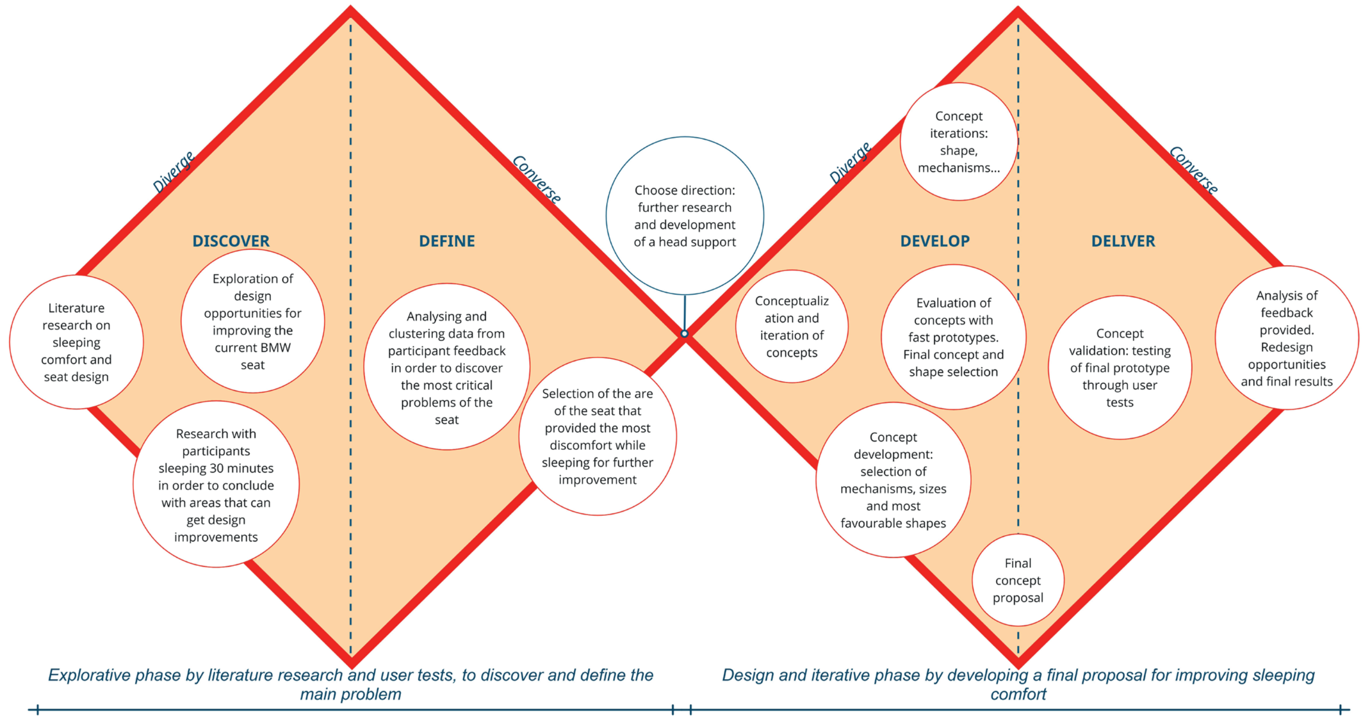


Figure 1.8. "Double diamond" structure followed during the project

2 Context Exploration

The aim of this chapter is to provide an overview and study of the current research and knowledge in seat design and seat comfort, focusing as well on sleeping and sleeping in constrained spaces. The research aims to assess the parameters that contribute to both comfort and discomfort in order to establish a comprehensive understanding of the factors influencing comfort in the context of automotive seating. It will also analyse future scenarios for the interaction with the BMW seat.

To familiarize with this topic, and with the previous knowledge acquired about seating comfort, research questions are established for further development.

COMFORT

- What are the key ergonomic factors that influence performing different activities (in seat vehicles)?
- What are the key ergonomic recommendations for designing comfortable seats for sleeping in constrained spaces?
- What are the most common discomfort issues and weak points in seats?
- What materials and technologies have been used to enhance comfort in vehicle seats?

SLEEPING

- What are the benefits of taking a short/long nap in a car?
- How is sleeping quality measured and how does comfort affect it?
- How is the (sleeping) comfort addressed in vehicles and in other seat industries (trains, aircrafts)?
- How can the (sleeping) comfort be measured in constrained spaces?

2.1. Stakeholder Analysis

It is important to differentiate the different stakeholders that are involved in this project "development of a seat for optimal napping", and the ones that need to be taken into account for the success of the project, as each of them have different interests. The main goal of the project is the research and redesign of the seat designed and manufactured by BMW. The main stakeholders are the future user (BMW drivers and passengers), the designer, the manufacturer, the dealer/maintenance and the client, in this case BMW. Figute 2.1. shows all the scakeholders. The focus of this project is on the end-user.

END USER

The occupants are the end user of the product,and will depend on the time scope in which the product will be launched in the market. There will be mainly the drivers, BMW owners and their passengers. The main goal of BMW is to focus on Autonomous Vehicles (AV) drivers, with the purpose of them sleeping during the journey. However, other users for a shorter time scope can be explored, such as Electric Vehicles (EVs) drivers that want to sleep while their car is being charged, or passengers that just want to sleep while someone else is driving. The different scenarios and end users will be deeper analyzed and selected in Chapter 2.6.

TU DELFT

BMW and TU Delft have been collaborating together since a long time, offering the research knowledge on the projects that BMW has interest in. This collaboration led me to participate as assistant in a previous sleeping research performed by TU Delft and BMW. This gave me the opportunity to visit the facilities of BMW to present the results and to continue the research as a graduation project. Although TU Delft is not a direct stakeholder for the product design, plays an important role for the research phase.

BMW SEAT DEPARTMENT

Their ultimate goal of the department is to obtain knowledge for designing the best and most comfortable seat for sleeping. They are interested in knowing factors that affect a good quality and comfortable sleep, such as postures, stages of sleep, pressure, ideal backrest angle and similar features. Since they are currently developing a seat for ultimate comfort in sleeping , there

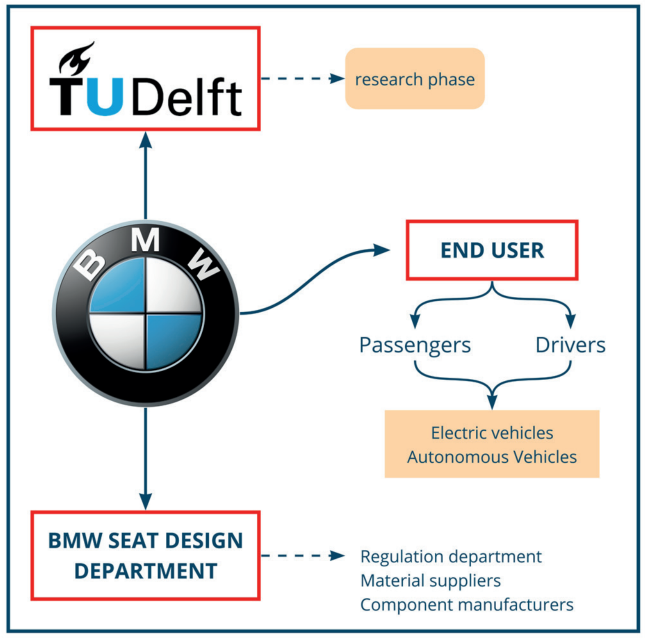


Figure 2.1. Stakeholder analysis

is an ideal opportunity to obtain this data by analyzing the seat. Additionally, they are aiming to improve the seat and all new insights regarding its comfort and future redesign opportunities are welcome.

Unlike other automotive companies, BMW is distinctive by internaly designing and manufacturing its own seats tailored to specific vehicle models. This enables BMW to oversee the entire design process and test the final product with further research. This ongoing evaluation helps them to identify both advantages and drawbacks, enabling a continuous improvement cycle for their seats.

2.2. Comfort in (vehicle) seats

The objective of this section is to conduct an in-depth review of the current state of research regarding seat design and comfort, while focusing on vehicle seating. The main goal of the analysis is to provide a better understanding of the key factors influencing comfort and discomfort in seating, and how these occur.

It is well known that people like comfortable seats. (Vink et al. 2012). However, according to Romelfanger et al. (2019), only 67% of customers report being extremely satisfied with their automotive seat, and this complaint is consistent across the industry. Car seat comfort is one of the main factors for customer's purchasing a car (Quattlebaum et al., 2021).

2.2.1. Conditions for a comfortable seat

Hiemstra-van Mastrigt et al. (2017) described the factors and relationships between the variables related to passenger seat comfort (Figure 2.2). The comfort of the seat can't be determined by only analyzing the seat itself. Context factors, such as activities performed by the passenger will determine the level of comfort. The comfort on a seat will not be the same if the passenger is trying to sleep, or just talk with someone else. Different activities activate more muscles than others, and longer durations on the same activity can lead to musculoskeletal complaints and pain. Environment includes all sensory inputs which the user receives (visual, audio, olfactory stimuli...). The anthropometrics of the passenger, the seat and the context will result in a set of body postures and interface pressures (interaction between the seat and the user). These interactions will result in feelings of comfort and discomfort.

This insight is important in order to understand that comfort and discomfort do not only come from the product itself (the seat) but there are multiple factors that contribute to the perception of comfort/discomfort. Certain studies highlight that physical environment factors affect more to the (dis)comfort than the features of the product (Liu et al., 2017). Variables like vibration, noise, light, or temperature can significantly impact the comfort of a cabin aircraft. For instance, unpleasant odors cause the most discomfort, affecting the overall comfort experience for the majority of passengers.

The correlation between overall perceived seat comfort and specific comfort features was found to be moderate to strong, indicating that specific design features can significantly impact the overall comfort. However, Naddeo (2017) demonstrated an indirect correlation between the expected comfort and the perceived comfort: when the expectation is higher, the final perception is lower and vice versa.

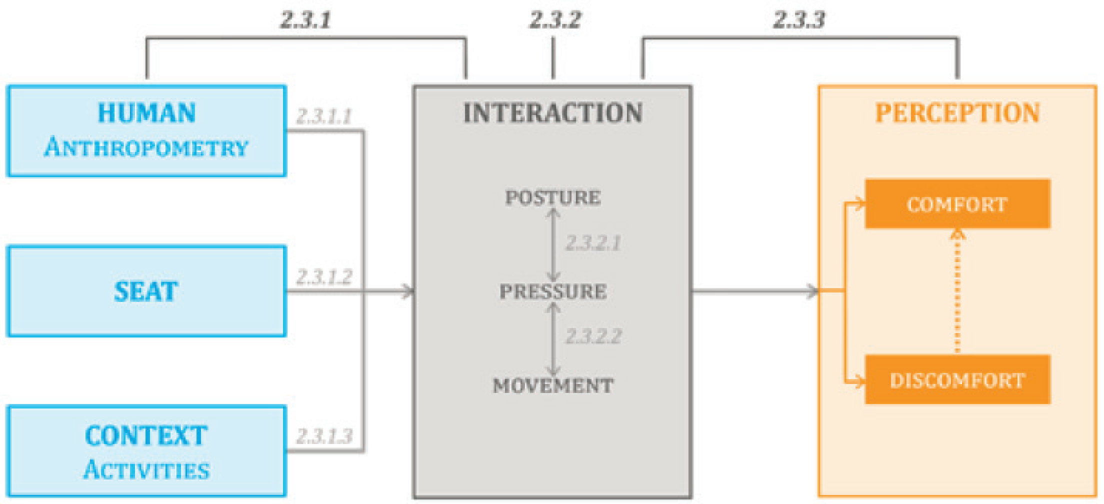


Figure 2.2. Framework model to describe the variables regarding the seat comfort by Hiemstra-van Mastrigt et al. (2017)

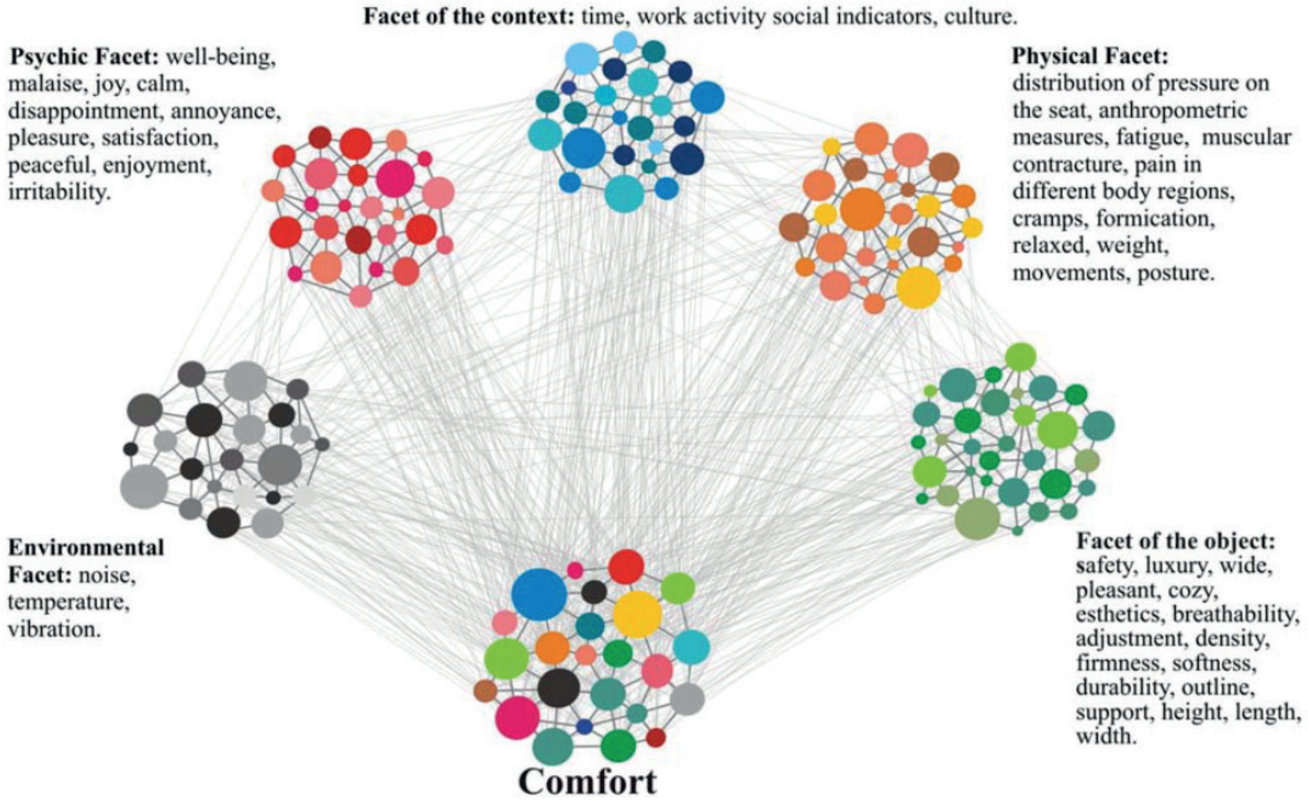


Figure 2.3. Elements that influence the driver and passenger perception of comfort (Da Silva et al., 2012)

Da Silva et al. (2012) developed a theoretical model of comfort on automobile seats, evaluating the main elements that influence the driver's and passenger's perception of comfort (Figure 2.3).

The study mentions that although the target of the automotive industry is to sell the comfort on the seat, different research highlights that the focus should be reducing the current discomfort experienced in car seats. The model developed identifies the facets and indicators that interfere with the comfort.

Car seats are the key to improving driving and passenger experience while reducing fatigue. Although each user has their own subjective evaluation and preferences for comfort, with various influence factors, research has found the common factors that influence the (dis) comfort of passengers and drivers.

2.2.2. Pressure distribution and comfort

One of the most common approaches for studying the (dis)comfort in seats is based on the measurement of pressure between seat/user and the improvement of this.

Improvement of the comfort can be achieved by getting a uniform pressure distribution through the seat, while reducing pressure peaks. Additionally, a broader contact with the seat surface will contribute to improved comfort. Discomfort in seating is often associated with shear stress by passengers that spend a long time in the same seat position (Grujičić et al., 2009).

Li et al. (2020) also studied the effects of pressure during long term driving. The study demonstrated that bigger pressure distribution in one area can lead to less comfort. They have found that there is a strong correlation between maximum pressure of cushion and perceived comfort.

Kyung and Nussbaum (2008) identified recommendations for designing comfortable seats considering the applied pressure: the seat should provide lower rates of pressure on the buttocks and higher on the back. Also, there should be a balanced pressure among the buttocks, upper part, and lower part of the body. Ebe & Griffin (2001) proved as well that sample seats that created less pressure were related to a higher comfort rather than those with higher total pressure.

The level of comfort is closely related to the pressure experienced in buttock, thigh and back areas. A bigger pressure distribution in these areas can lead to less comfort (Li et al., 2020). Studies found that short-term seating leads to increased discomfort in the thigh and buttock regions, while long-term seating can lead to increased discomfort in the back region, as can be seen in Figure 2.4. Research additionally remarks the importance of designing car seats that can provide adequate support and pressure relief in the regions to maximize (driving) comfort.

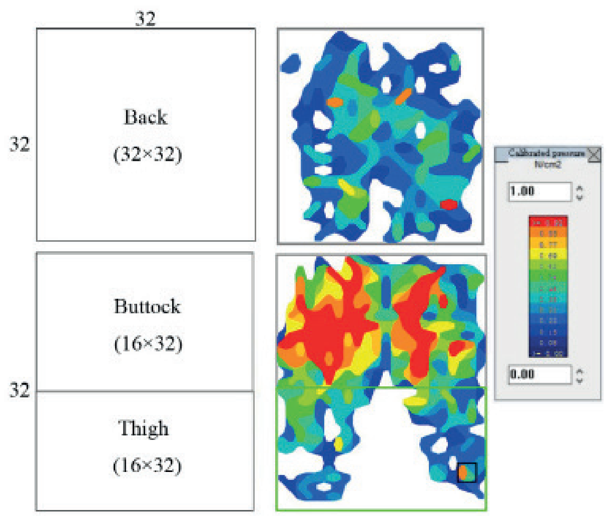


Figure 2.4. Results of two pressure mats in three body parts (Li et al., 202). It shows the increase on pressure on the buttock after long-term driving, while pressure on thigh and back regions decrease.

Vink and Lips (2017) also found that the sensitivity of areas in the back and buttocks touching the seat are significantly different. Those parts in contact with the front of the seat pan are more sensitive. Therefore, these areas will have a bigger impact when analyzing (dis) comfort. Additionally, the area of the seat touching the shoulders was significantly more sensitive than the area in between the shoulders and lower back.

Research has also found strong correlation between seat shape, pressure and comfort. A cushion that is too long can put pressure on the back area of the legs, near to the knees and calf muscle. Therefore, the shape of the seat pan can contribute to an ideal pressure distribution.

Zenk et al. (2012) defined the ideal pressure distribution based on body maps (Figure 2.5) and that the bigger pressure was concentrated in the buttock area. However, this will vary depending on the backrest angle reclination. Research shows that in an angle reclination closer to the horizontal, there will be more pressure applied in the back area than in the buttock area.

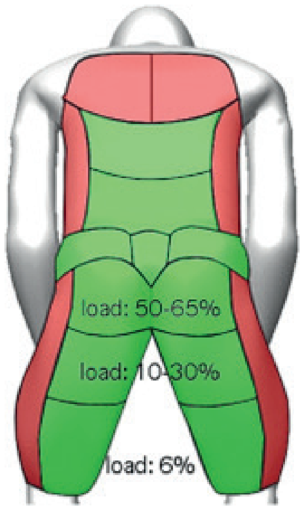


Figure 2.5. Ideal load distribution showed in the body map (Hartung, 2006)

CONSIDERATIONS FOR FUTURE REDESIGN OPPORTUNITIES

From this subsection, some conclusions can be extracted in future design considerations. Depending on the selected redesign area of the seat, they will be considered as needs or wishes.

- Reduce pressure distribution over time for avoiding discomfort
- Ensure a broad contact from the body to the design surface
- The design provides the possibility to change posture and avoid long time in the same posture
- Consider different pressures depending on the final backrest angle

2.2.3. Human Anthropometry

Studies have shown the impact of anthropometric variability regarding the experience of (dis)comfort.

Vanacore et al. (2019) demonstrated that different body parts are more exposed to seating discomfort in males and females, and in short and tall people, mentioning mainly the upper body areas (head, neck and arms). The research recommends designing seats that can provide better support and comfort for these areas. Vanacore also suggests that current aircrafts seats do not take into account the impact of anthropometric variability on seat comfort, and mentions the importance of designing seats that can accommodate a wider range of body sizes and shapes. The study mentions the need of improving comfort features such as lumbar support, headrests and legroom regarding aircraft seats.

A study performed by Hiemstra-van Mastrigt (2015) concluded that seat pan length is correlated to stature: tall people prefer a larger seat pan length than short people. Jonsson et al. (2007) found similar results, and reported a high correlation between passenger stature and lateral adjustment of the car seat. Both recommend an adjustable seat pan length.

Branton and Grayson (1967) found that tall people sat in postures with knees crossed for longer periods than short people. Teraoka et al. (1994) additionally found common differences between tall and short people. Short people had less foot contact with the floor and less contact with the backrest, in combination with a slumped posture. Taller participants tend to experience more discomfort in certain body parts (Vanacore et al. 2019)

- The design should accommodate a wide range of body sizes and shapes
- Consider an adjustable design to different anthropometrics no matter what area of the seat will be integrated

2.2.4. Sitting and durability

Different studies (Porter et al., 2003, Jackson, 2009, Sammonds et al., 2017) report an increase in discomfort over time. Additionally, it takes between 30 to 45 minutes before discomfort occurs. Also, there is a direct relationship between discomfort over time: the longer the duration, the greater the discomfort and the bigger the pressure applied (Noro et al., 2005). Seating positions can bring some disadvantages if seated in awkward postures for long periods of time, such as increased pressure on the buttocks and sciatic tuberosity. The possibility of several seat adjustments (back inclination, neck support, horizontal seat positioning...) can offer support and comfortable accommodation for the lumbar area, allowing variations of posture and alleviating the pressure (Lis et al., 2006).

Vanacore et al. (2019) also found that discomfort significantly increased over time for all seats under study, with different body parts affected depending on the seat configuration (upright or reclined). Although lots of design considerations can be taken into account for improving the comfort of car seats, all seats will cause discomfort over time. Therefore, it is important that the seat should provide the possibility to adopt different body postures in order to reduce discomfort (Van Rosmalen et al., 2009). Considering that movements are used as an indication of discomfort, an active seating that allows different body positions can reduce discomfort and improve comfort. Van Rosmalen et al. also found that a seat supporting a variety of postures when watching television is experienced as comfortable.

- For testing the comfort of the seat in the future sleeping research, more than 30 minutes seated are necessary in order to estimate if the seat causes discomfort over time and where
- Different adjustments on the design and alternating postures can improve comfort over time

2.2.5. Ergonomic considerations

To conduct a comprehensive analysis of the BMW seat, some features of the seat contribute to the overall (dis) comfort more than others. Researching these key aspects will provide an initial understanding of the desired results.

BACKREST ANGLE AND POSTURE

Different research (Vanacore, 2019; Caballero-Bruno, 2022) has already proved the relation between comfort with the seat configuration. In a studio, it was shown that the most reclined angle was significantly more comfortable than the other two with less reclination. This is also proven by Hostens et al. (2001), mentioning that a smaller backrest inclination angle leads to higher sub-maximum pressures on the seat pan and smaller sub-maximum pressures on the backrest.

Van Veen et al. (2012) also found that there is a need for varying the back rest angle in relation to the level of activity (low level: relaxed activities vs. high level: intense activities).

Additionally, different activities have related sitting postures that are significantly different from each other. Depending on the activity, the seat configuration and the sitting posture, the level of (dis)comfort will vary (Ellegast et al. 2012; Kamp, Kilincsoy, and Vink 2011...).

Hiemstra-van Mastrigt (2015) found that people look for possibilities to turn/lean to one side while seeking support, enabling variation in posture and creating more leg room. This way it is possible to reduce discomfort over time, perform other activities and relax better.

Park et al. (2013) observed that the height of the seat in the car also influences the posture that the passengers will take. A posture with knees bent predominantly occurred in a seat height of 305 mm, but not on a seat height of 176 mm. Additionally, the neck flexion angle of passengers could be significantly reduced when using specially designed armrests, and therefore increasing the ratings for overall comfort.

HEAD / NECK SUPPORT

Neck support is crucial for maintaining a proper alignment and reducing strain on the neck muscles. Adequate neck support, such as headrests or adjustable pillows, can help prevent discomfort and potential injuries.

Overall, there is a preference of using neck support in the development of different activities while seated in constrained spaces. Smulders et al. (2019) tested that subjects expect to experience more comfort with a headrest when watching in-flight entertainment. In a long-term flight, the comfort was rated highest in the condition with a headrest, indicating that a headrest might have a positive effect on the user's expectations. The expected long term comfort can be seen in Figure 2.6.

Among some design recommendations, it is suggested to implement neck support for slouched postures when watching screens to improve user comfort, in car and in aircraft seats. The study also mentions that such insight should be applied as a new design requirement for headrests in future car seats (autonomous driving).

LEG SUPPORT

Proper leg support or footrest ina seat can avoid leg fatigue, create a better body posture and promote better circulation (Ademiluyi & Aruin, 2022). A seat design that includes adjustable leg support can help passengers to find a comfortable position depending on the activity.

Caballero-Bruno (2022) found that legs and feet are commonly rated more negative in upright and reclined seat configurations, than in flat surfaces. The previous sleeping research at TU Delft (Vledder, 2023) showed that legs suffered pain and numbness in all different backrest reclinations.

ARM REST

Hiemstra-van Mastrigt (2015) mentions design opportunities for car interior design based on their research, in which having an arm support facilitates some tasks. She proposes a need for an integrated arm support for improving comfort in different tasks. Overall comfort increases while discomfort decreases when using the armrest compared to not being supported by any armrests. Last, the subjects consider a more natural and relaxed posture, the seat configuration with armrests. However, there is no research up to this moment that proves that arm support improves comfort while sleeping.

LUMBAR SUPPORT

Research indicates that lumbar support is a crucial factor in improving comfort and influencing seat design. Vergara and Page (2000) found no discomfort on the lumbar area in postures with back support on the lumbar area. A proper support reduces pressure on the spite and acts as a tilting mechanism for the vertebrae, causing a beneficial effect for the body (Lueder, 2004). Hiemstra-van Mastrigt (2015), mentions that a lumbar support is preferred for different activities, but it should

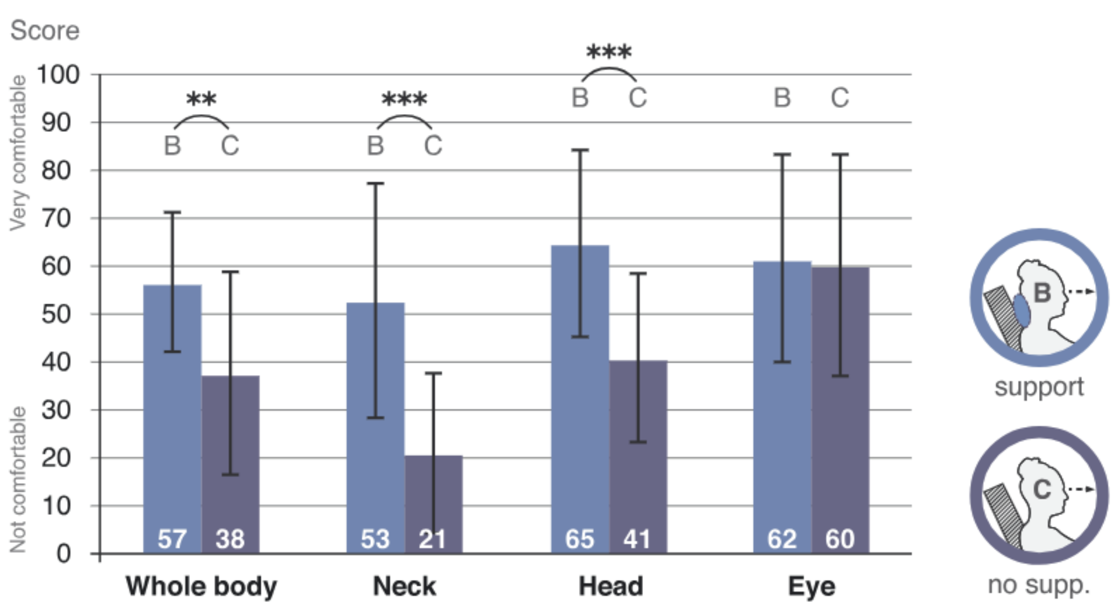


Figure 2.6. Mean "expected long-term comfort" with and without neck support (Smulders et al., 2019)

be adjustable according to the backrest angle and performed activity. Franz (2010) mentioned that the "roll function" in the lumbar support is the most appropriate as it does not alter the position of the body nor the H-point (Figure 2.7).

Figure 2.7. "roll function" in the lumbar support by Franz et al. (2010).

From the insights gathered in the literature review, Figure 2.8 highlights the primary design elements and features of car seats that contribute to overall comfort, serving as a focal point for the project development.

The main body areas affected from discomfort identified in literature research are summarized in Figure 2.9. Taking these findings into consideration, the forthcoming sleeping research will have deeper analysis on these seat and body regions.

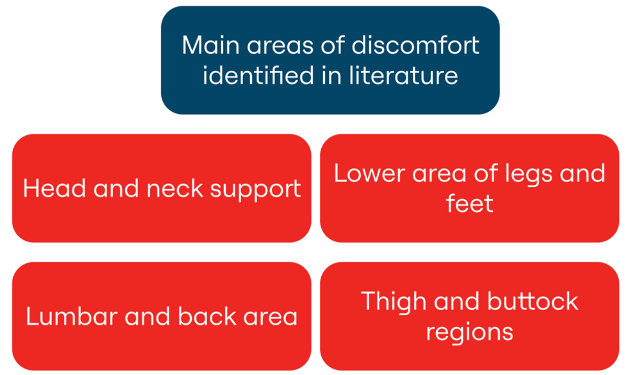


Figure 2.9. Main body areas that suffer discomfort.

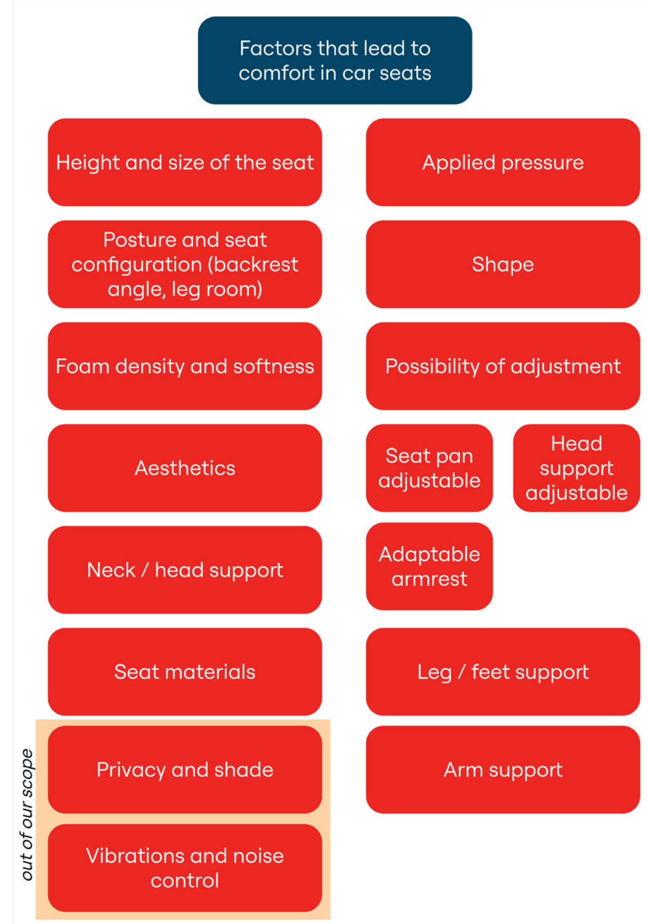


Figure 2.8. Design features that contribute to (dis) comfort.

The findings are as well supported by a prior sleep study carried out at TU Delft. The aim of the research wat to evaluate the most comfortable backrest angle for a nap in standard seats. Data was obtained regarding seat and physical discomfort factors, as seen in Figure 2.10.

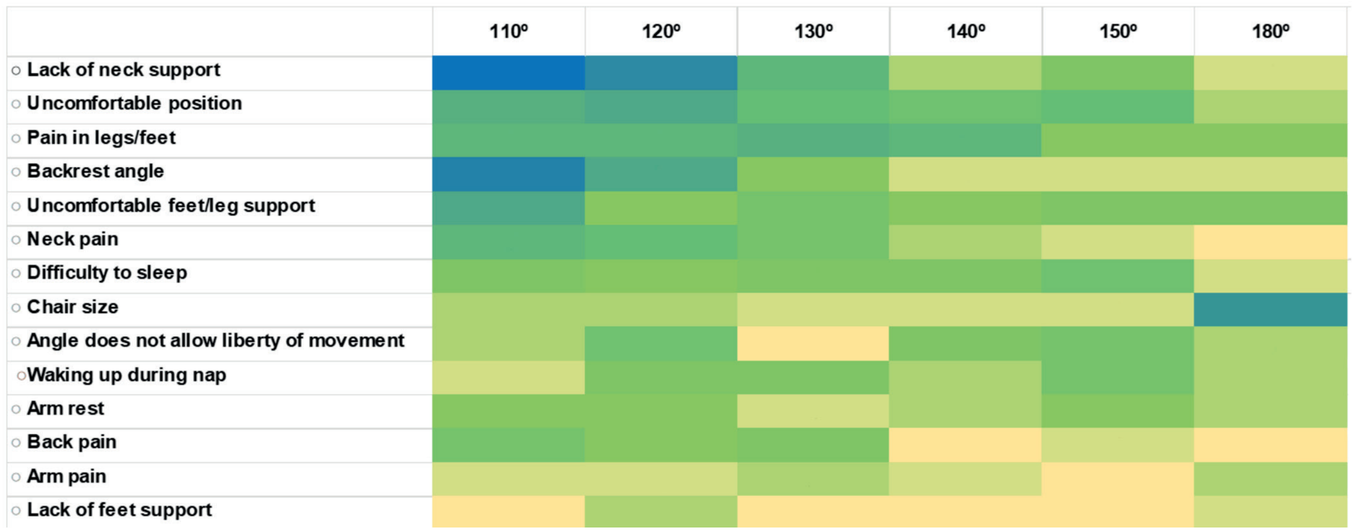


Figure 2.10. Main seat and physical discomfort factors from previous research (Vledder 2023, presented at BMW)

2.3. Seat design for different activities

The activity that passengers perform in a seat car is a crucial factor that influences both postures and posture shifts. The activity performed will determine both postures and posture shifts. The main activities that are currently performed by passengers can be found in Figure 2.12, together with the posture variables, in a literature review conducted by Hiemstra-van Mastrigt et al. (2016). Due to our interest in sleeping in current and future seats, it is remarked the sleeping activity being one of the main activities performed.

Kamp, Kilincsoy and Vink (2011) found a significant relationship between most activities and the head, trunk and arms positions during transport. In low-level activities (sleeping, relaxing and watching), the head was supported in 49% of the observed situations, whereas in medium-level activities (reading, talking and eating), and high activity levels (using electronic devices), only in 39% and 36% of the situations, respectively. The trunk position varied mainly in the low-level activities, being straight against the backrest. Differences in using armrests were unclear.

van Rosmalen et al. (2009) analyzed the postures of people at home while watching television (Figure 2.12). For the design of an appropriate seat, the results showed that the seat should enable a large variety of sitting positions, and that a moving arm support and adjustable feet support were good solutions.

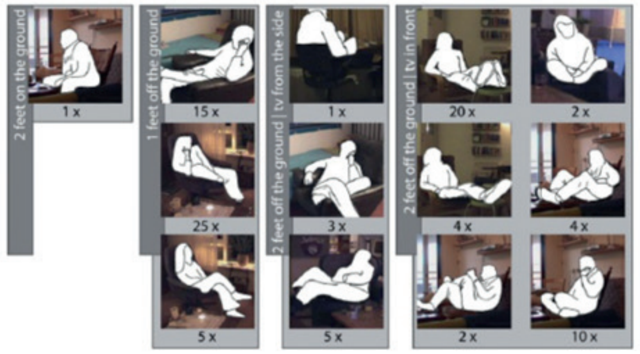


Figure 2.12. . Positions and their frequency of people at home watching a screen (Rosmalen et al., 2009)

Reference	Activity variables	Posture variables	Study design	Conclusions
Kamp, Kilincsoy, and Vink (2011)	Sleeping	Head, trunk, arms and legs	Momentary observations $N=743$ on trains and in semi-public situations	Significantly different posture of head against headrest, trunk slumped and arms upon armrest and uncrossed feet
	Relaxing			Significantly different posture of head against headrest or supported by hands, trunk slumped and arms upon armrest
	Watching			Significantly different posture of head unsupported, trunk free or against backrest and arms free from armrest
	Reading			Significantly different posture of trunk against backrest and arms free from armrest
	Talking			Significantly different posture of head free of support and arms free from armrest
	Using small electronic devices			Significantly different posture of head free or against backrest and arms free from armrest
	Eating/ drinking			Significantly different posture of head unsupported, trunk free from backrest or slumped
	Working – using larger electronic devices			Significantly different posture of head unsupported and trunk free or against backrest
Graf, Guggenbühl, and Krueger (1995)	Computer programming compared to general office work	Variation in postures	Postures at 5 workplaces	Computer programming workers have less variability in postures in comparison to general office workers
Lueder (2004)	Use of screen and input devices	Sitting postures	Office chairs ergonomic review study	Visual demands of the task and the reach distances can play a role in leaning forward
Ellegast et al. (2012)	7 standardised office tasks	Postures/joint angles	Office chairs, $N=10$	Many significant effects of performed tasks on postures and joint angles
Groenesteijn et al. (2014)	Staring/sleeping	Body part positions of head, trunk and seat contact and comfort score in relation to activity on 10-point scale	Top 4 of most observed activities during momentary observations $N=786$ and journey observations $N=30$ on trains	Tendency highest comfort score with posture: head straight up, trunk straight and up and full seat contact
	Reading			Tendency highest comfort score with posture: head straight up, trunk backwards and full seat contact
	Talking			Tendency highest comfort score with posture: head sideward, trunk backwards and full seat contact
	Working			Tendency highest comfort score with posture: head forward, trunk straight and up and full seat contact
Babski-Reeves, Stanfield, and Hughes (2005)	Standard data entry (typing task)	Posture shifts	Office work station, $N=8$	Significant larger number of neck posture shifts with data entry task compared to math task
	Simple math calculations	Posture shifts		Significant larger number of feet posture shifts with math task compared to data entry task
	Task repetition *(set of times each task was completed within each session)*	Posture shifts		Significant increase in posture shifts across task repetitions
Groenesteijn et al. (2012)	Computer work	Postures/joint angles, physical activity of body parts	Office chairs field study, $N=12$	Lowest physical activity in all body parts, together with upright trunk, upright head position and low backrest inclination
	Telephoning			Medium physical activity and the highest kyphosis
	Conversation			Highest activity of head and legs, and the highest cervical spine extension
	Desk work			The second lowest activity, most cervical spine flexion

Figure 2.11. Overview of studies regarding activities performed in which some measures for anthropometry and some pressure variables were obtained (Hiemstra-van Mastrigt et al., 2016).

With the rapid development of technologies, AVs are becoming a reality in a few years. With the increasing level of automation, new activities in the vehicle will be integrated not only for the passenger, but mainly for the driver.

Sleeping is one of the main activities performed by passengers when travelling in constrained spaces. Liu et al., (2019) recorded and analyzed the activities carried on by passengers in a two-hour simulated flight. The passengers remained the greater time sleeping and resting.

Because of this, ome research has already analysed which will be the main activities performed by passengers. In a study performed by Tang et al. (2020), six main categories were extracted, as it can be seen in Figure 2.13. It is notorious how Resting/Sleeping it's placed in 2nd place.

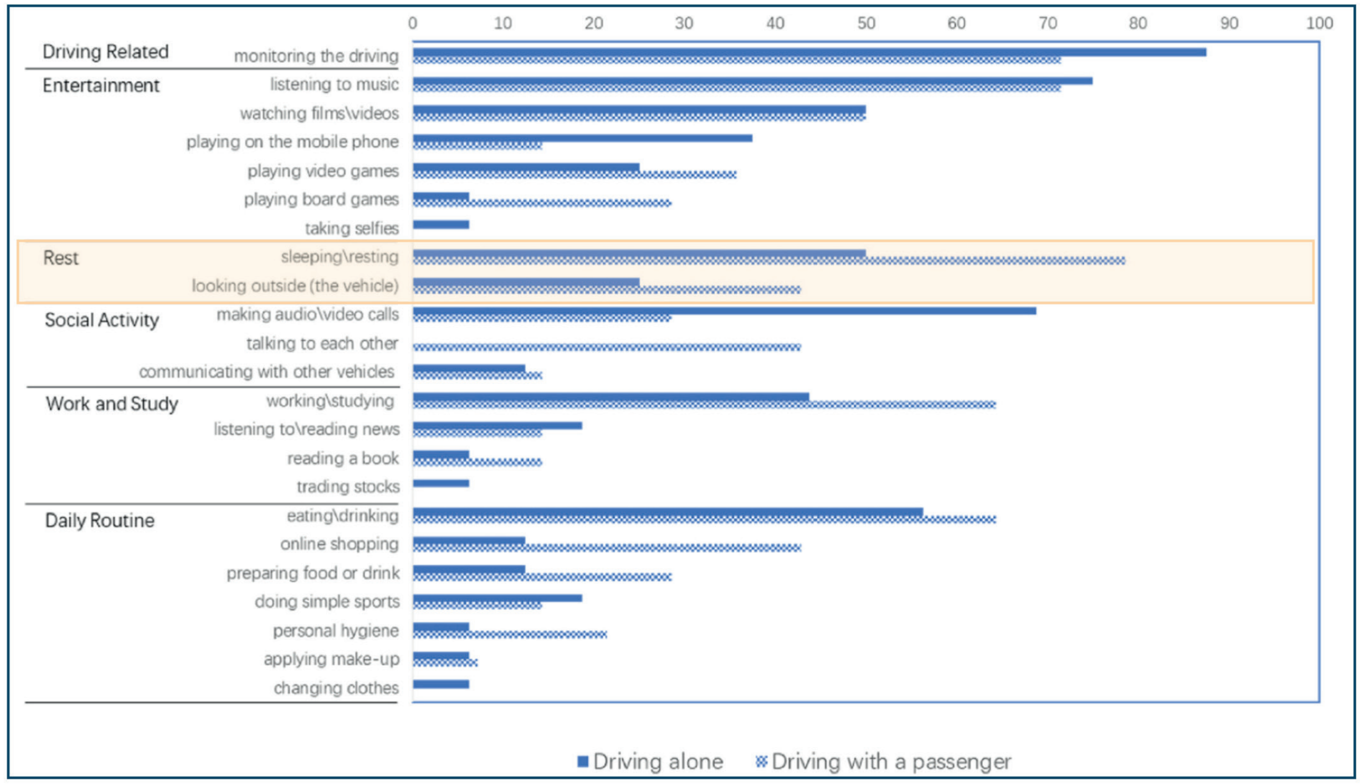


Figure 2.13. Main activities performed in AVs, by Tang et al. (2020)

Some considerations from this subchapter for taking into account in the further redesign are:

- The head support plays an important role when sleeping/relaxing in vehicle seats
- Analysing different postures while sleeping will help to evaluate the comfort of the seat and the participant sleep.

2.4. Why sleeping?

With the development of AV, the concept of in-vehicle sleep is gaining attention and consideration among researchers (Tang et al., 2020). With the next stage of Level 4 automation, as vehicles become increasingly capable of automated driving, passengers evaluate the opportunity to use the travel time for other activities such as resting.

2.4.1. Importance of sleeping

Naps can be classified in several ways, depending on how long they last and what function they serve. For instance, Faraut et al. (2017) defined nap as sleep the length of less than 50% of the average major sleep period of an individual. Short naps typically last from 15 to 30 minutes and longer naps are about 90 minutes. Both can be effective at wakefulness, but shorter, power naps tend to be more recommended for avoiding sleeping inertia (Hilditch et al., 2017).

POWER NAP

This brief nap generally lasts from 10 to 20 minutes. A power nap can be helpful whenever a person feels tired but needs to stay alert, such as in the middle of a work day. Power naps are meant to relieve daytime sleepiness and increase productivity. Research shows that power naps lasting only 10 minutes or less may restore wakefulness for hours afterward, since it does not involve progressing through the deeper stages of sleep (Lovato & Lack, 2010).

FULL CYCLE NAP

Stanley (2018) mentions that a 25 minute power nap can enhance performance by 34%, while a full cycle nap (90 minutes) can increase alertness for up to ten hours. However, when sleeping for more than 60 minutes, people suffer from sleep inertia. This is the feeling of grogginess and disorientation that can come from awakening from a deep sleep. It can last from 15 minutes to two hours. Additionally, napping too long increases the chances of having difficulty sleeping at night and affects nighttime sleep.

However, other studies mention that a 90-minute daytime nap is more beneficial for improving physical performance and attention, as well as the perception of recovery, reducing fatigue perception, muscle soreness and negative mood states (Boukhris et al., 2020). Additionally, since 90 minutes in the length of one full sleep cycle, the nap improves procedural and emotional memory.

Even though both types of naps can be beneficial, according to experts there's not just an ideal nap time and it mostly depends on the sleepers: their lifestyles, habits and needs. The same occurs when measuring sleep quality of the nap. There are a lot of subjective and consistent factors that users report when evaluating their sleep quality, such as noises, environment and sleeping habits. Daytime routines also influence whether or not someone will have quality sleep (add sources).

Additionally, sleep quality and sleep quantity are not directly associated. People might be able to sleep for a long period of time, but it may be disturbed sleep, uncomfortable and therefore not considered quality sleep. (Sleep Foundation, 2022)

From different research carried out by Sleep Foundation (Pacheco, 2022) and Sleep Advisor (Zwarensteyn, 2023), an overview of the main factors that affect sleeping quality are collected in Figure 2.14.

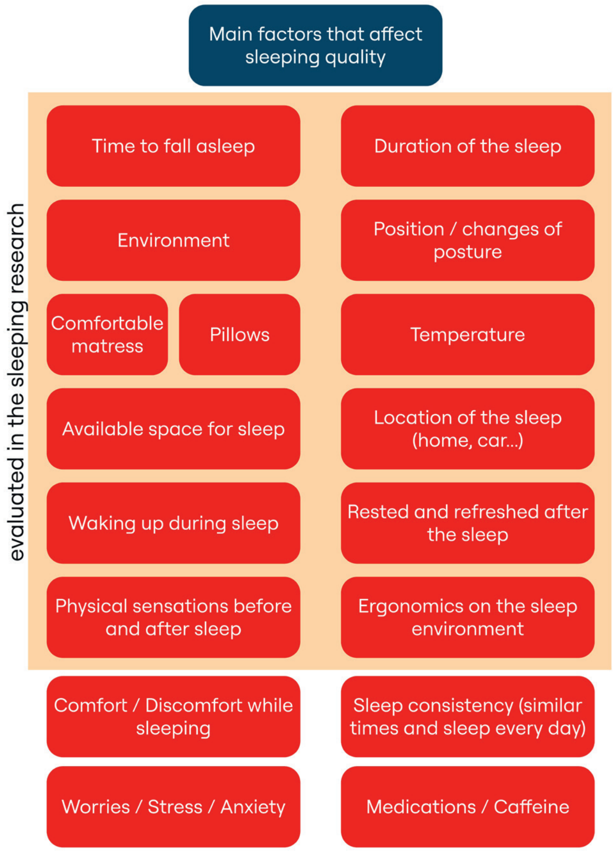


Figure 2.14. Main factors that affect the sleeping quality, obtained from Sleep Foundation (2022) and Sleep Advisor (2023)

2.4.2. Benefits of napping in the automotive industry

Short daytime naps are beneficial to relieve daytime sleepiness and increase productivity. This can also be extracted to counteract sleepiness while driving. According to Hayashi and Abe (2008), a short nap of 30 minutes is an effective countermeasure to prevent afternoon sleepiness and resulting sleep-related accidents. On average, 3-6% of drivers are involved in automobile accidents each year, being reported that sleep-related vehicle accidents account for 16-23% of road accidents (Horne & Reyner, 2001).

Hayashi and Abe found that a 130º and a 150º backrest incline reduced subjective sleepiness, improved task performance, and suppressed slow eye movements (indicators of drowsiness). The 150º backrest angle reduced subjective fatigue and improved reaction time further than 130º backrest.

Brooks and Lack (2006) reported that the effects and benefits of a short nap depended on the total sleep time rather than the different stages of sleep. After examining the effects of naps of 5, 10, 20 or 30 minute length, they found that a 10-min nap was the most effective.

On the other hand, Reyner and Horne (1997) showed that when nocturnal sleep is taken in a seat, the waking period is prolonged, sleep efficiency declines and slow wave (SWS) decreases. Therefore, the effectiveness of a nap taken in a car seat is likely to vary depending on the backrest angle, with implications that longer naps than 15 minutes would be necessary to be effective.

James Wilson together with Citroen (2021) studied which are the aspects of the vehicle and the driving environment that helps the most to passengers to relax and nap in comfort, and can be found in Figure 2.15. According to a survey, Comfort (C) is a function of Seating Position (SP), Time (T), internal Ambiance (A), Legroom (L) and Suspension (S). External distractions such as road noise and bumps are characterized by (R) .

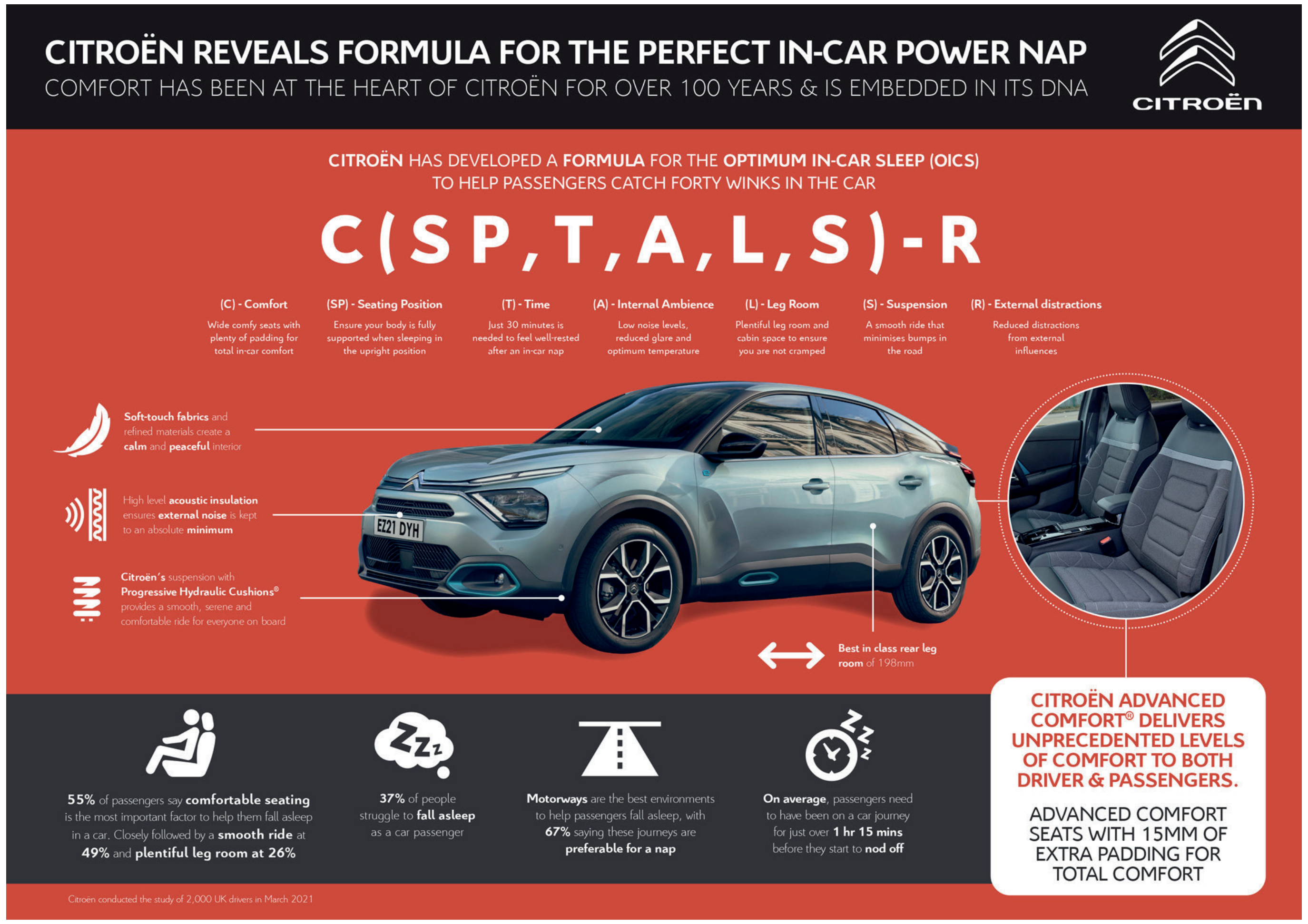


Figure 2.15. Formula for the perfect in-car power nap, by Citroen and Wilson (2021)

It is mentioned that the length of the nap depends on the journey. However, passengers should sleep for no longer than 30 minutes at a time on a car journey in order to feel the full benefit and to be well rested, without experiencing further discomfort. The research shows that, on average, passengers need 1 hour 15 minutes in the car before they can fall asleep.

2.4.3. Ergonomic and human factors that influence (dis) comfort while sleeping in constrained spaces

As analysed in Chapter2.3, it is shown how one of the main activities in a car journey is resting and sleeping. In research performed by Liu et al. (2019), in which it was studied the activities performed by passengers in a 2 hour simulated flight, the passengers remained the most part of the time performing the activity of sleeping and resting (34,4%). Regarding AVs, Wilson et al. (2022) found that resting was one of the most favored Non-Driving Tasks amongst those likely to adopt AVs (Figure 2.15)

Parameter	(Schoettle & Sivak, 2014)	(Kyriakidis et al., 2015)	(Bansal et al., 2016)	(Cunningham et al., 2019)*
Sample location	USA, UK, Australia	109 countries	Texas (USA)	Australia
Sample size	1,533	4,886	1,088	5,089
I would not ride in a self-driving vehicle	22.4%	–	–	–
Watch the road	41.0%	47.4%	77%	69.6%
Read	8.3%	39.2%	–	37.2%
Text or talk with friends/family	7.7%	47.3%	74%	
Sleep	7.0%	39.5%	52%	23.4%
Work	5.3%	–	54%	31.9%
Play games	4.9%	–	–	–
Other	2.0%	–	–	–
Listen to music	–	56.5%	–	–
Use the internet	–	44.3%	–	–
Eating/drinking	–	48.2%	–	58.2%
Interact with other passengers	–	47.4%	–	68.2%
Watch a movie	–	39.4%	46%	–
Do nothing	–	15.8%	–	42.7%
Use a personal device	–	–	–	53.3%
Resting	–	–	–	45.0%
Grooming	–	–	–	28.5%

Figure 2.16. Non-Driving tasks among drivers likely to adopt AVs (Wilson et al., 2022)

Tang et al., (2020) mentions that the majority of AV (53% when sitting with a passenger and 55% when sitting alone) would rest and sleep in the journey, as seen in Figure 2.16. However, it also mentions that drivers prefer a relaxed, comfortable environment in the seat car but that current cars do not offer that.

As a main recommendation, the research mentions a more flexible and adaptive design, requesting an adjustable and multifunctional seat design, to support mainly the activities related to rest. Participants mentioned the need for more flexible seats with memory functions to adjust automatically to different preferred positions.

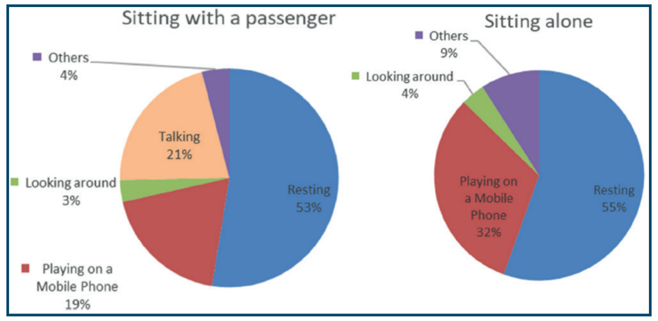


Figure 2.17. Activities in AVs when sittin with a passenger VS sitting alone

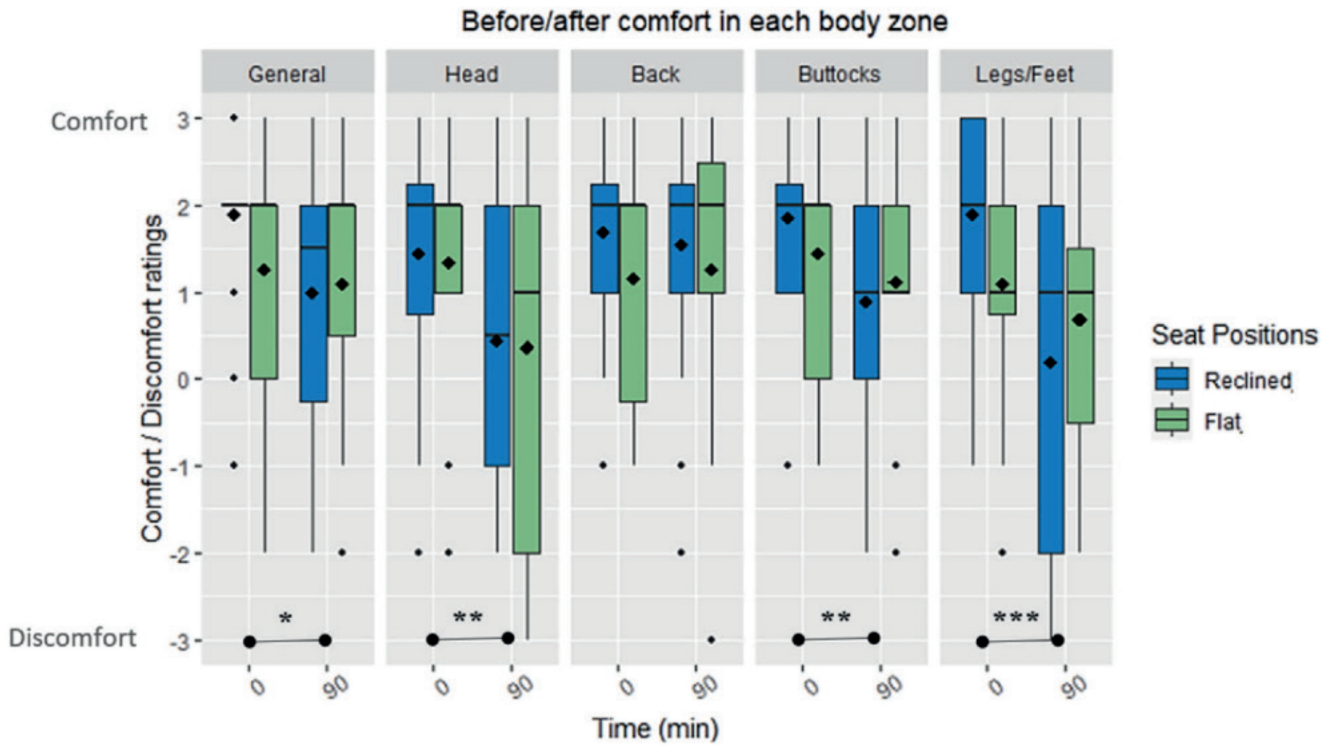


Figure 2.18. Comparison of comfort in two different seat positions after sleeping (Caballero-Bruno et al., 2022)

Users prefer to sleep in more reclined positions of the backrest angle. According to Caballero-Bruno et al. (2022), reclined positions are associated with better sleep quality and less wake after sleep onset, compared to flat seating positions (Figure 2.18). Additionally, there is a tendency by passengers to choose more reclined seat positions for sleeping while traveling.

The research mentions the importance of prioritizing the comfort and sleep quality of passengers especially in the context of autonomous driving. It remarks the need for an overall transformation of the vehicle interior to create an optimum sleep environment. As main areas of discomfort, the legs and feet area are identified.

Similar outcomes were obtained by Roach et al. (2018). In the study, they measured total sleep time, slow-wave sleep, REM sleep and stage shifts in three different backrest angles (20º upright, 40º reclined and 90º flat).

The quantity and quality of sleep obtained in the reclined and flat seats were better than those obtained in the upright seat. These results are due to two main reasons. First, the difficult to maintain the head in a comfortable position, and second, because sitting in an upright position makes you more alert and less relaxed because the body tends to respond to its surroundings.

Stanglmeier et al. (2020) studied that the best biomechanical posture and most favorable for sleeping was the combination of 20º/150º (seat pan/backrest angles), whereas combinations with a backrest angle of 145º resulted in lower biomechanical quality. However, this results in needing more spatial requirements, as seen in figure 2.19. The study also suggests that a comfortable and large contact area, while increasing the seat pan angle will improve the quality of sleep due to an enlarged contact area.

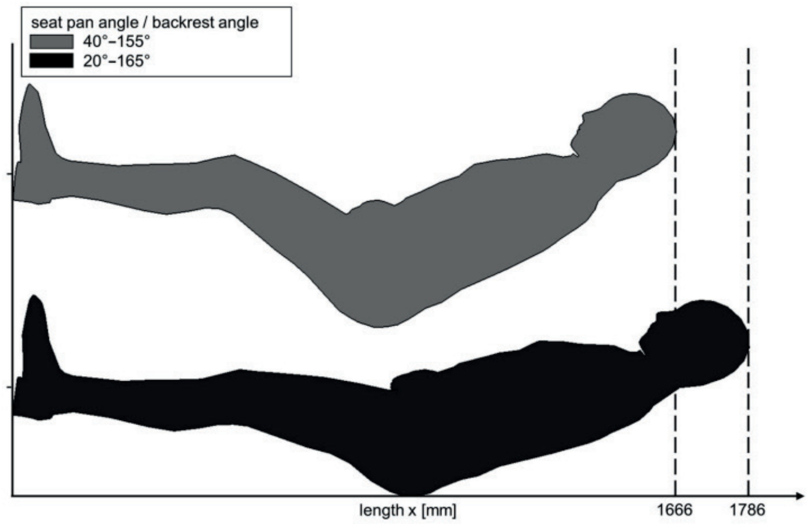


Figure 2.19. Longitudinal space requirement between two sleeping preferred configuration (Stanglmeier et al., 2020)

Tan et al. (2009) evaluated different sleeping postures in an economy aircraft seat passenger (Figure 2.20), and concluded that the turned torso posture, with head perpendicular to backrest was the more comfortable.

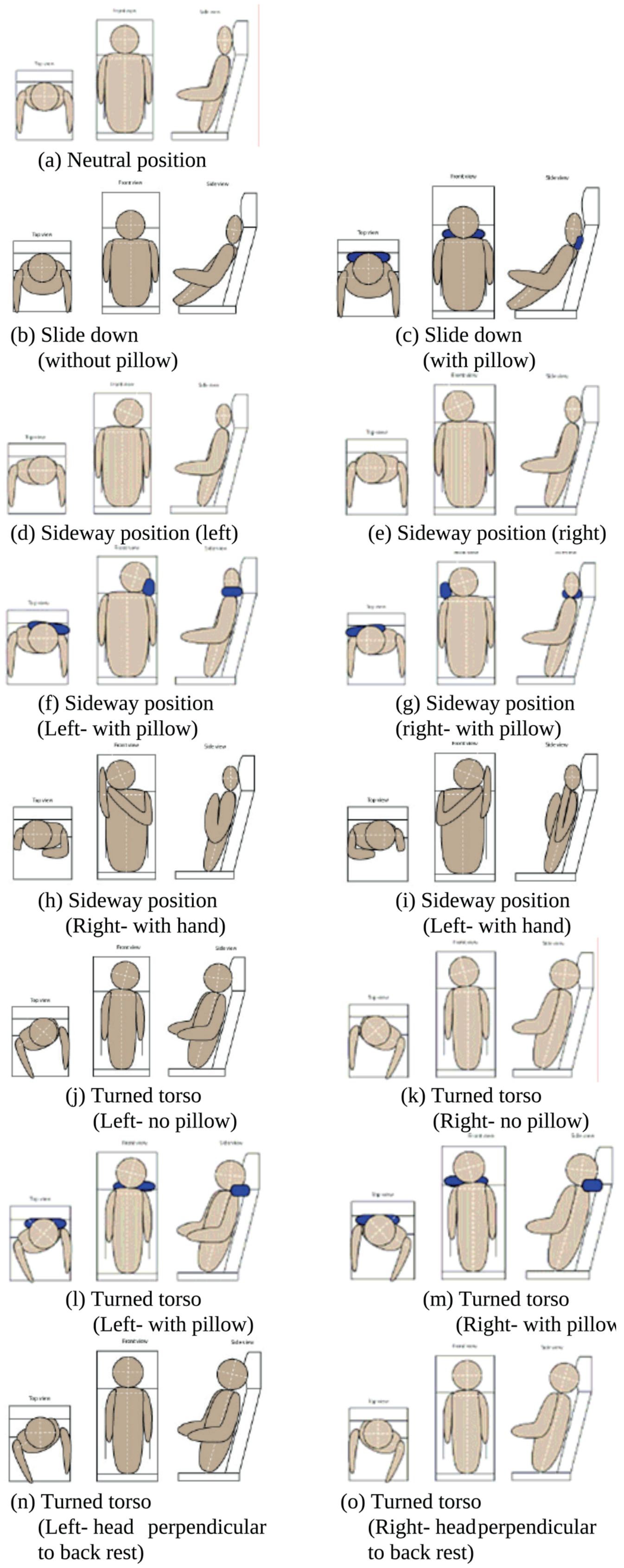


Figure 2.20. Sleeping postures in an economy aircraft seat passenger (Tan et al., 2009)

Some considerations from this subchapter relevat to the sleeping research are:

- 30 minutes nap will be enough to test if participants can sleep and how long they take to fall asleep
- The head is the body zone with bigger rates of discomfort. It will be analysed how users place the head and if they use a pillow in order to evaluate their (dis)comfort

2.5. Environments for sleeping in a seat car

2.5.1. Autonomous Vehicles

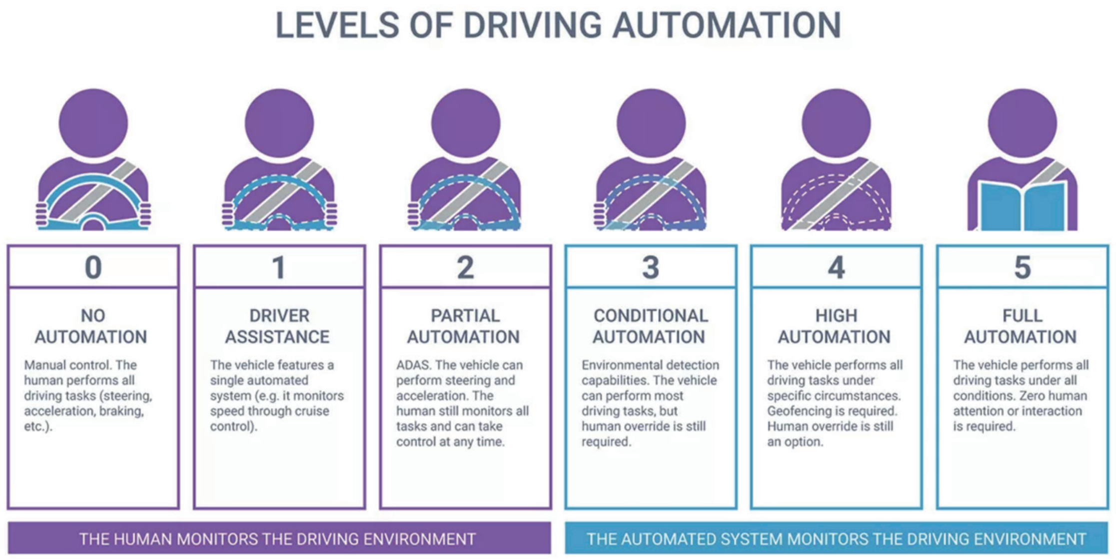


Figure 2.21. Driving Automation Levels (SAE International, 2018)

The Society of Automotive Engineers (SAE) defines six levels of driving automation ranging from 0 (fully manual) to 5 (fully autonomous), as it can be seen in Figure 2.21.

Even though the future of AVs looks promising, main car manufacturers are still in development of Level 3 AVs, where the vehicle can perform dynamic driving without human intervention. (BMW leading the main advances with the development of next-generation LiDAR sensors)

According to GlobalData and Robson (2023) fully self-driving cars are unlikely before 2035. However, they foreseen the appearance of Level 3 in 2026 with a quick development of Level 4 for 2030.

Regardless of the research done about what type of activities users would perform while driving in an AV, the perception of sleeping in an AV is still low. In research conducted by Riley (2023), 34% of users would sleep in a fully AV, as seen in Figure 2.22.

The main concerns for being willing to sleep were due to safety concerns. Of the 34% willing to sleep in a fully AV, the main reasons would be fatigue, or long-haul trip. However, they would not sleep when driving in dangerous terrain or weather conditions (Figure 2.23)

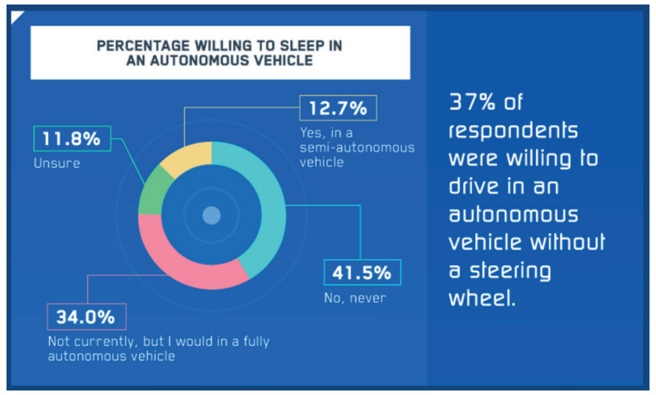


Figure 2.22. Percentage willing to sleep in an AV (Riley, 2023).

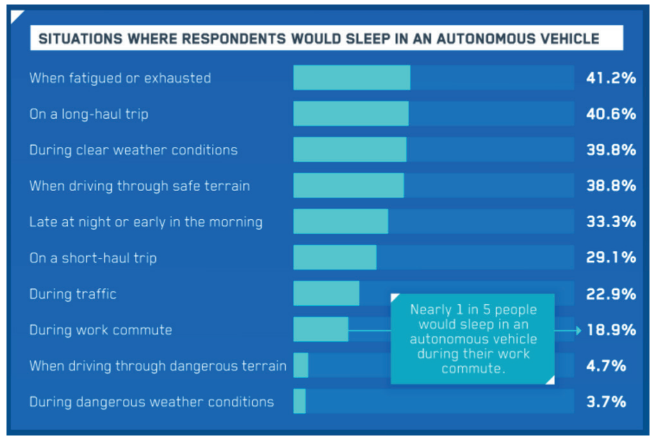
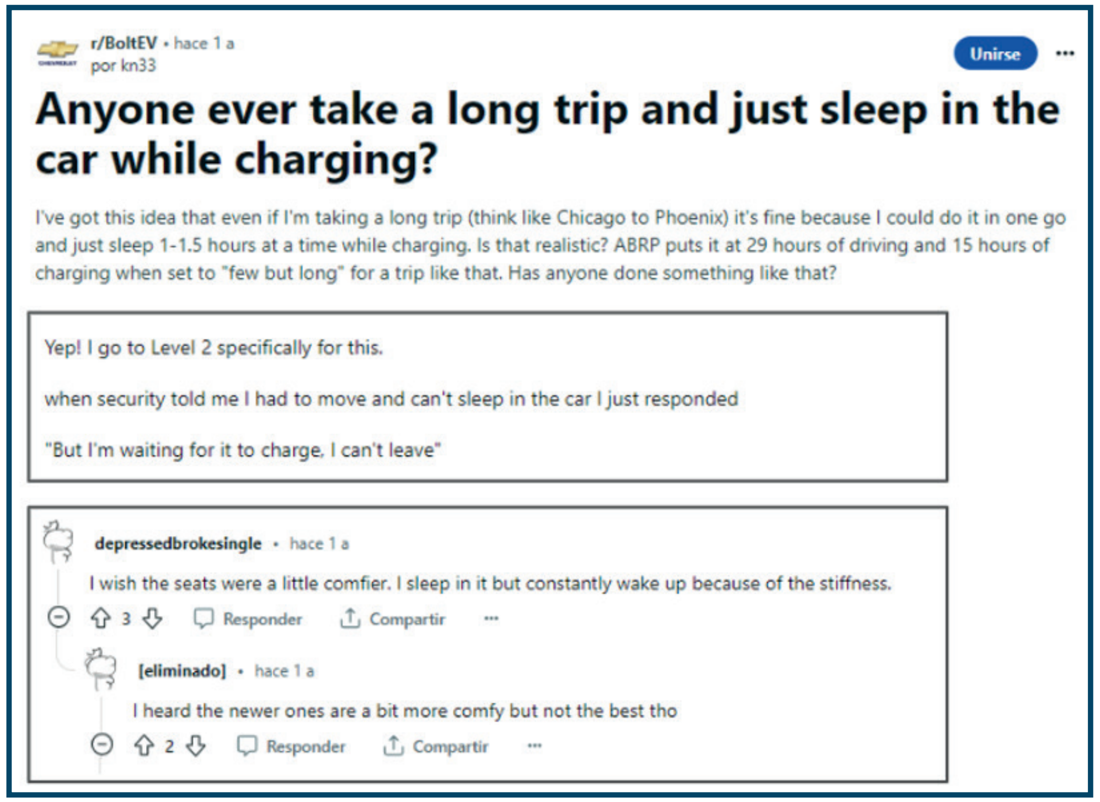


Figure 2.23. Situations where participants would sleep in an AV (Riley, 2023)

2.5.2. Electric Vehicles


r/BoltEV • hace 1 a
por kn33

Unirse

Anyone ever take a long trip and just sleep in the car while charging?

I've got this idea that even if I'm taking a long trip (think like Chicago to Phoenix) it's fine because I could do it in one go and just sleep 1-1.5 hours at a time while charging. Is that realistic? ABRP puts it at 29 hours of driving and 15 hours of charging when set to "few but long" for a trip like that. Has anyone done something like that?

Yep! I go to Level 2 specifically for this.

when security told me I had to move and can't sleep in the car I just responded

"But I'm waiting for it to charge, I can't leave"

depressedbrokesingle • hace 1 a

I wish the seats were a little comfier. I sleep in it but constantly wake up because of the stiffness.

3 Responder Compartir

[eliminado] • hace 1 a

I heard the newer ones are a bit more comfy but not the best tho

2 Responder Compartir

Figure 2.24. Screenshots from blogs where users EV drivers ask if it is feasible to sleep while the EV is charging (Reddit, 2023)

Another user scenario in which BMW studies the possibility of drivers sleeping in the car is while charging their EVs in a public charging station. Regardless of the increment of drivers buying an EV and the amount of them that have to charge in public chargers, no research is done about sleeping while the vehicle is being charged. In order to have a better idea if people would sleep in this situation, the research is done consulting Q&A webpages such as Reddit, or online blogs.

As seen in Figure 2.24, users are not really sure that sleeping while the vehicle is being charged is legally or safe. Another blogger (Sensiba, 2022) mentions sleeping in the vehicle while charging on long road trips in order to recover energy. However, she is mainly worried about safety, privacy and this being against the law. Lastly, she mentions that potential issues for sleeping in a charging EV are very small, but because of these doubts, people do not tend to sleep in their EV while charging.

Sensiba mentions that the main factor for people sleeping while charging the EV is the type of charger. While Level 2 of EV chargers are the most common in Netherlands and Germany (see Figure 2.25) (Netherlands Enterprise Agency, 2023) (Carlier, 2023) can take up to 5 hours to get the car fully charged, Level 3 fast charging only takes 40 minutes to 1 hour for full charge. Drivers mainly opt to stretch their legs and relax in a restaurant while charging in Level 3. However, when charging in Level 2, more users consider taking a short nap.

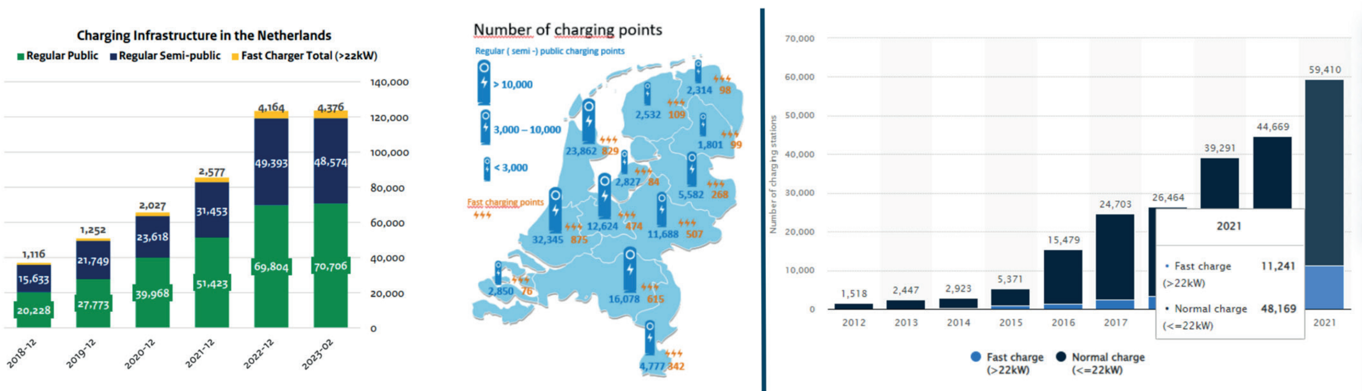


Figure 2.25. amount of Level 2 and 3 chargers in the Netherlands (left) (Netherlands Enterprise Agency, 2023) and in Germany (right) (Carlier, 2023)

Upon evaluating different types of scenarios where the users can take a nap currently or in the future, a summarized scheme (Figure 2.26) is done in order to have a better view of which case is better to focus on.

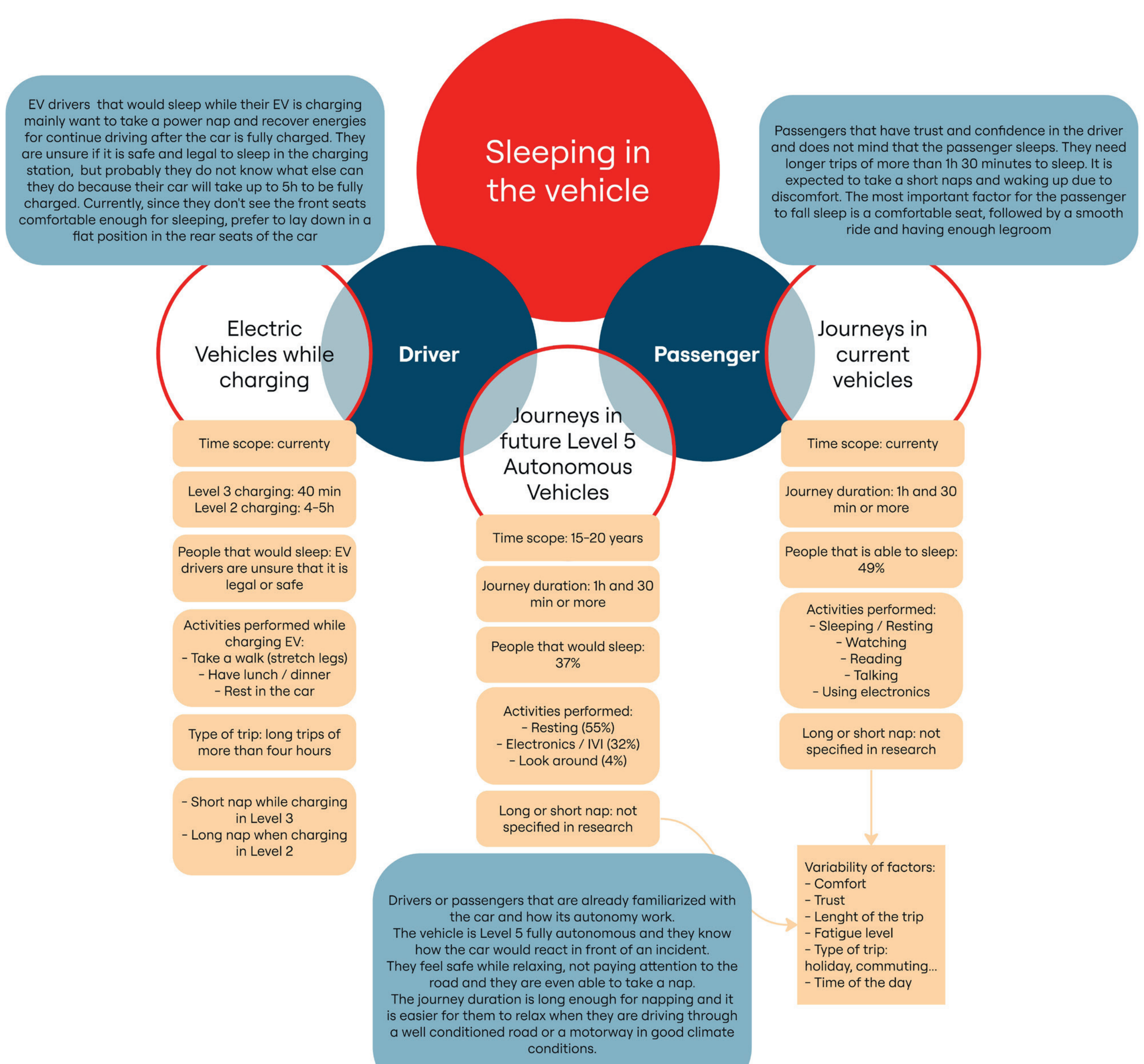


Figure 2.26. Different scenarios in which users would sleep in the vehicle

In terms of sleeping, the seat requirements and features will be similar, no matter the scenario in which the user is sleeping. However, to make the project more specific we will focus closely at sleeping while the vehicle is moving, especially in AVs, which is the main interest of BMW, and see if the design can aim users to sleep in a possible future scenario. Additionally, depending on the area of the redesign that is encountered, it can be discussed if the design would vary depending on the scenario.

2.6. Market research

2.6.1. BMW

BMW's mission statement is "to become the world's leading provider of premium products and premium services for individual mobility" (BMW Group, 2023). The automotive brand is identified for its sport, elegant and high-speed vehicles, as represented in Figure 2.27. BMW's target audience is a diverse group of individuals who share a common appreciation for luxury, performance, and innovation in their vehicles. Although this audience includes both men and women, men tend to make up a slightly larger proportion of BMW's customer base (Tech Drive, 2022, Startup Talk, 2023).

Figure 2.27. Representation of BMW vehicles (Hippo Leasing, 2022)

BMW's commitment to innovation and performance can be seen in their research and studies evaluating improvements for comfort in their seats. A few examples are explained:

One challenge for automotive seats is to reduce weight without compromising on comfort. BMW developed a concept seat from a contoured shell of composite which follows the human body, reducing the need for thick foam. BMW did a weight reduction of more than 50% by using thin profile seats, while increasing legroom for rear passengers. The prototype seat (figure 28) consists of a hard shell with inflatable cushions to fill the gaps between the tallest and shortest persons. (Franz et al., 2011).

Due to sedentary behaviors, BMW developed a new concept, the active seating system. It consists of sensors in the backrest of the back seat of the car that can capture movements of the upper body and makes it possible for the passenger to control a game (Figure 2.29). Mastrigt et al. (2015) evaluated the perception of comfort and discomfort in a 30 minute driving test. Discomfort was low for all activities and participants felt more challenged, fit and refreshed during active seating.

Figure 2.29. Active seating game developed by BM

Figure 2.28. . Prototype of thin profile seat by Franz et al. (2011)

Another example regarding improvement of comfort is the Lightweight massage system. The benefits were noticeable and it was proven not distractive. According to the study, the massage system reduces the muscle activity in the shoulder and upper part musculature related to stress, and increases comfort especially for long distance driving (Franz, Zenk, et al. (2011)

2.6.2. BMW seats

Figure 2.30 shows different BMW seats that have been developed during the last years or are concepts to be developed. Some common aspects among them is the shape of the integrated armrest in the seat that creates a cocooning effect. Another curious characteristic is that some seats do not have an adjustable head restraint (or at least not at first glance, such as the BMW X6 M). In addition, any front seat counts with neck support, and only few rear seats have it. The external armrests of the seats are fixed, and cannot be reclined to adapt it together with the backrest angle. Additionally, the newer the seat is, the thinner it is, reducing weight.

Figure 2.30. last seats and concepts developed by BMW

One of the latest seats developed by BMW is the one in Figure 2.31. This seat has been designed to "offer the ultimate comfort for relaxing". It can be reclined up to 150º into a comfortable reclined position, with the goal of offering the occupants the best possible comfort on longer trips (BMW, 2020). The belt is integrated into the seat to allow total comfort when reclined back. Additionally, the airbag wraps entirely around the occupant providing wraparound protection in the event of an accident.

Even though the seat is designed for offering the ultimate comfort for relaxing in the journey, it has still not been tested with passengers. The discovery of weak points will offer the possibility of improvement and redesign, meeting the wishes of future intended users. Because of this, the quick development of autonomous vehicles, and resting as one of the main activities performed by passengers, the comfort evaluation of the seat is carried through sleeping research.

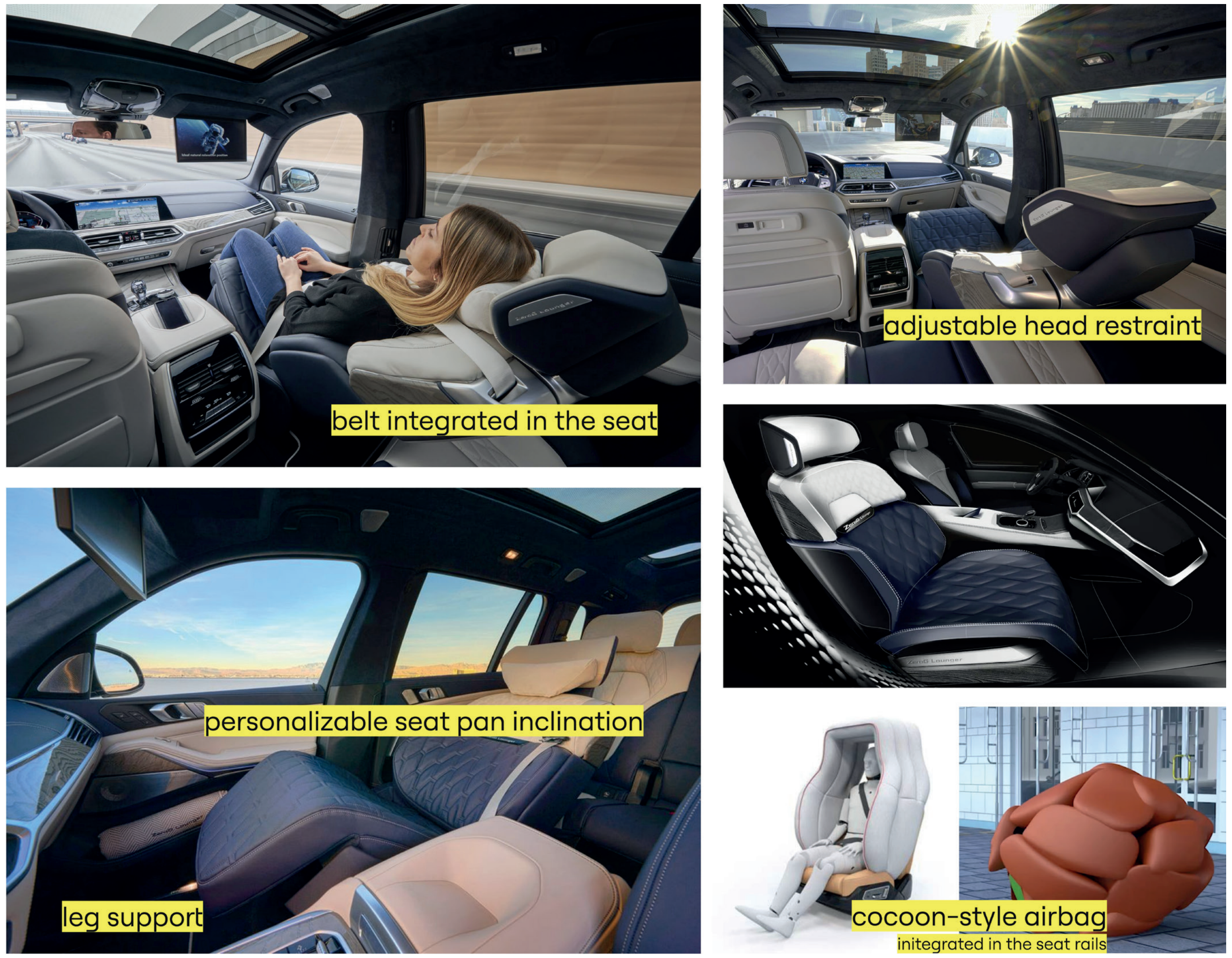


Figure 2.31. Latest seat developed by BMW and for further research

2.6.3. Other seats

To have a better understanding on which is the state of the art in vehicle seats, other automobile brands are analyzed. In order to narrow this analysis, only the main five competitors of BMW are analyzed, being Audi, Mercedes Benz, Porsche, Lexus and Fiat Chrysler (Comparably.com, 2023). Most innovative seats of these brands can be seen in Figure 2.32.

It is becoming a trend to integrate leg support although it is mainly for rear seats. Some of them integrate a foot support attached in the rear area of the front seat. Additionally, since all the seats are integrating a cocooning shape in the area of placing the arms in the backrest, an external headrest that adjusts with the backrest inclination may not be necessary. A new feature that some seats are integrating is the adjustability of the seat pan angle, offering more reclination. Last, even though the most sporty style cars do not offer an adjustable head restraint, almost every other car offers it.

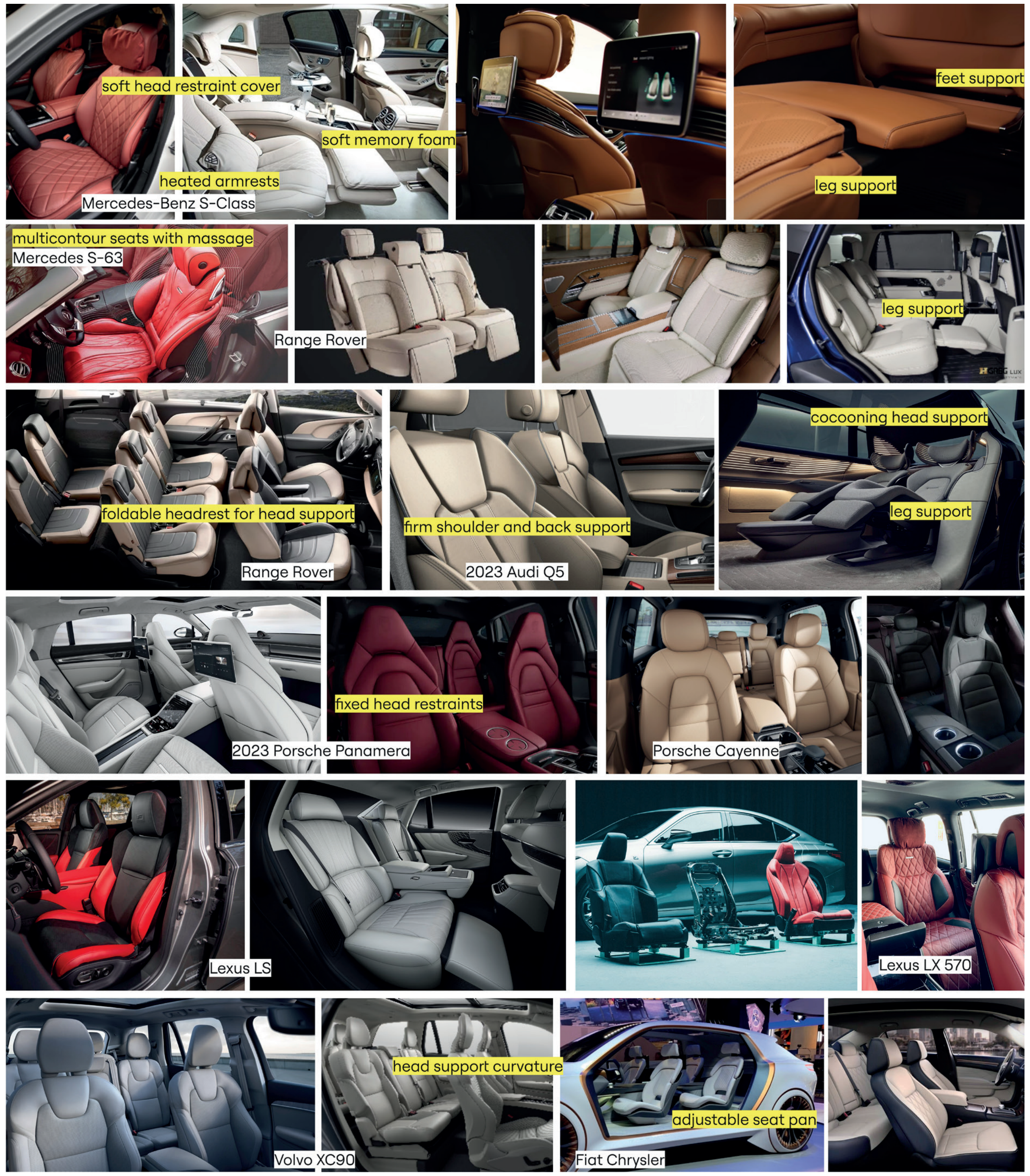


Figure 2.32. Market research seats from brand competitors

2.7. (Sleeping) Comfort evaluation

In order to test the seat developed by BMW, evaluating sleeping comfort is an important consideration, due to the number of occupants that try to sleep during long road trips or overnight journeys. Multitude of studies (such as the ones analysed during chapter 2) have been assessing comfort in car seats over the years. Due to how subjective comfort is and how it varies from person to person, some standardized objective and subjective criteria are commonly analysed for comfort evaluation.

2.7.1. Objective measurement

Even though comfort is a subjective attribute, researchers have focused on developing assessment methods using pressure distribution to assess objectively the seat (dis)comfort (Le et al., 2014). Mergl et al. (2006) mentions that long term discomfort on a seat can be analysed by three indicators: Percentage of load (% load), maximum pressure (Pmax) and pressure gradient (Pressure distribution). However, since discomfort appears approximately 40 minutes after sitting, long testing periods are better to establish the (dis)comfort of a seat (Vink & Hallbeck, 2012).

Objective pressure indicators to a comfortable seat are:

- Lower rates of pressure on the buttocks and higher on the back
- Balanced pressure among buttocks, upper part and lower part of the body
- Seat samples that creates less pressure are related to a higher comfort than those with higher total pressure

Electromyography (EMG) has also been been used to test comfort in different of comfort research (Li et al., 2020; Kuijt-Evers et al., 2017; Franz et al., 2011;...), and have correlated lower EMG amplitudes to more relaxation and comfort. Recent developments of new technologies allow for recording emotions. Thanks to eye tracking data and EEG (electroencephalograph) signals it is possible to build emotion recognition models (Zheng et al., 2014).

Several studies show that micro-movements and fidgeting are an appropriate measure for discomfort. Therefore, posture changes can be defined as an objective measurement of discomfort. As analyzed by Vergara and Page (2002), great changes of posture are an indicator of discomfort, instinctively shifting or changing the posture in an attempt to alleviate discomfort and relieve pressure.

COMFORT WHILE SLEEPING

Polysomnographic (PSG) data analysis has been defined as the golden standard for sleeping evaluations. However, there is limited literature including PSG in the evaluation of sleep in the car context, together with the initial discomfort of wearing electrodes around the head and face. For its analysis, when the total sleep time, slow-wave sleep and REM is higher, the quality of sleep is better (Roach et al., 2018). Caballero-Bruno et al. (2024) evaluated different parameters of the sleep that can be seen in Figure 2.33.

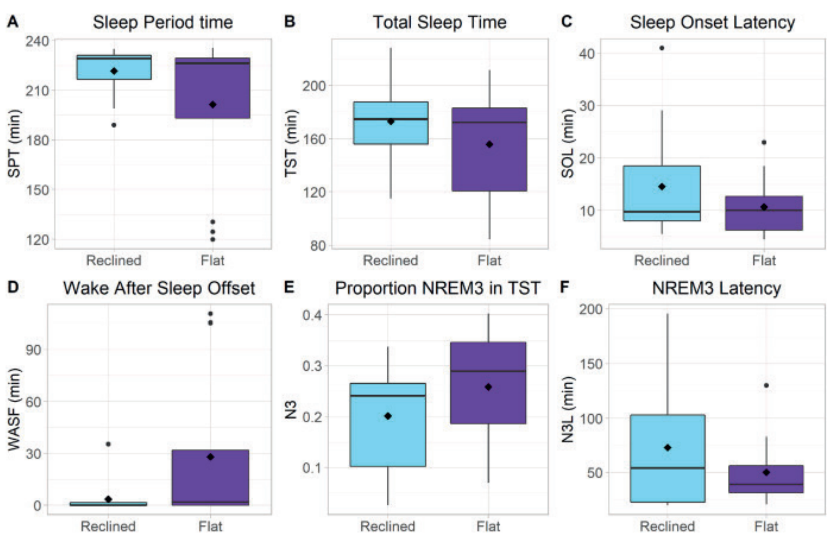


Figure 2.33. Sleep parameter boxplots for reclined and flat sweat conditions gathered by PSG (Caballero-Bruno et al., 2024)

2.7.2. Subjective measurement

In addition to objective measurements and considering that comfort is an individual and subjective concept, questionnaires are an important research method in order to evaluate the subjective feeling of people.

- A common way to evaluate (dis)comfort is applying the 10-point scale, used in different research by BMW (Figure 2.34)
- Porter's seven-point comfort rating scale evaluated different body regions and it is asked to rate discomfort on a scale from 1 to 7, as seen in Figure 2.35 (Porter et al., 2003)

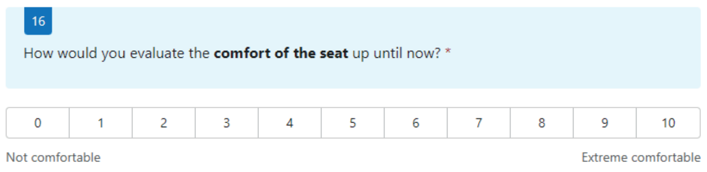


Figure 2.34. 10-point scale example

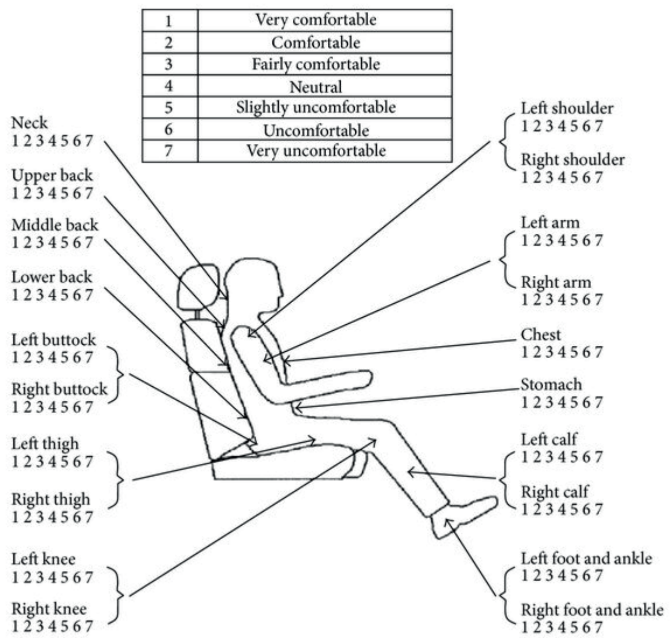


Figure 2.35. Porter's seven-point comfort rating scale (Porter et al., 2003)

- Corlett and bishop discomfort scale (Corlett and Bishop, 1976) is a scale compressed between 0 (no discomfort) and 10 (extreme discomfort) for local body areas (Anjani et al., 2021), as shown in Figure 2.36.

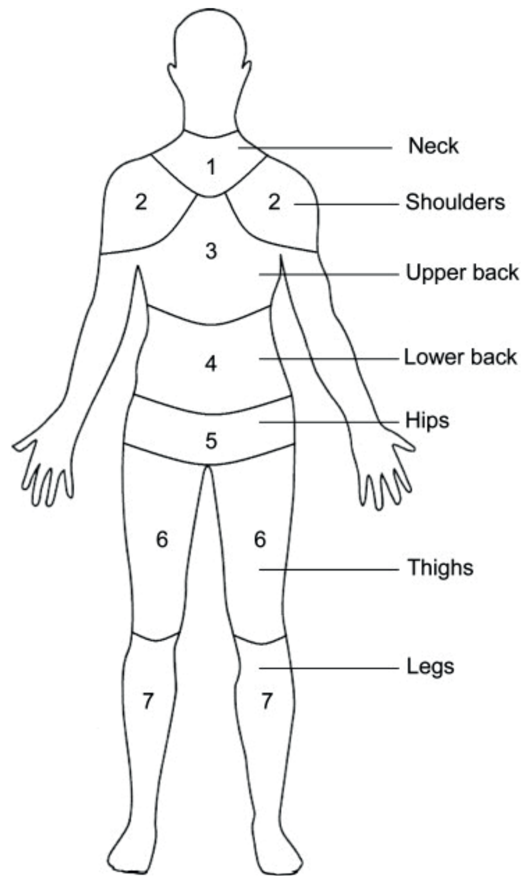


Figure 2.36. Corlett and bishop discomfort scale (Corlett and Bishop, 1976)

Due to time limitations and the goal of the research on evaluating those areas of the seat that produce discomfort, subjective measurement evaluations on comfort will be used towards the participants.

2.8. Conclusions

After analyzing the different factors influencing comfort and discomfort in vehicle seats, key parameters for evaluating seat comfort include the posture, posture changes and the contact areas of the body with the seat. While all areas of the body need to ensure having great contact to be more comfortable, head and neck area and leg area are the ones that tend to suffer more discomfort while sleeping in constrained spaces. The main reason is the design of the sea, because they are not mainly designed for sleeping yet, and there is a limited space in the cabin for the seat.

For the evaluation of the seat, and due to the findings of this chapter, special attention will be given to the head and neck area, and the lower legs and feet, as possible redesign improvements.

- Head/neck area, since when sleeping, it needs to be in contact towards the surface of the seat and be properly supported to avoid undesired and uncomfortable movements.
- Lower legs and feet. On some occasions they are hanging or accommodated without specific support. This creates numbness and slight pain on this area.

In order to evaluate the comfort of the seat, the following considerations can be taken into account:

- Time of sleep and time to fall asleep. The duration of both can estimate how comfortable it is for sleeping.
- Changes of movements. Examining how many movements during sleep offers insights into the adaptability of the seat and its ergonomic aspects.
- Common positions. Identifying common positions adopted during sleep helps to evaluate the user interaction.
- Pressure distribution in back area and seat pan.
- Comfort before and after the nap in two different scenarios: power nap of 30 minutes, and full cycle nap of 90 minutes
- Evaluate the main (dis)comfort differences between a short and long nap
- Main discomfort areas of the seat after sleeping

From the research done in this chapter, and depending on the area of study after testing the seat, some general recommendations are obtained in order to ensure comfort in any seat, as it can be seen in figure 2.37.

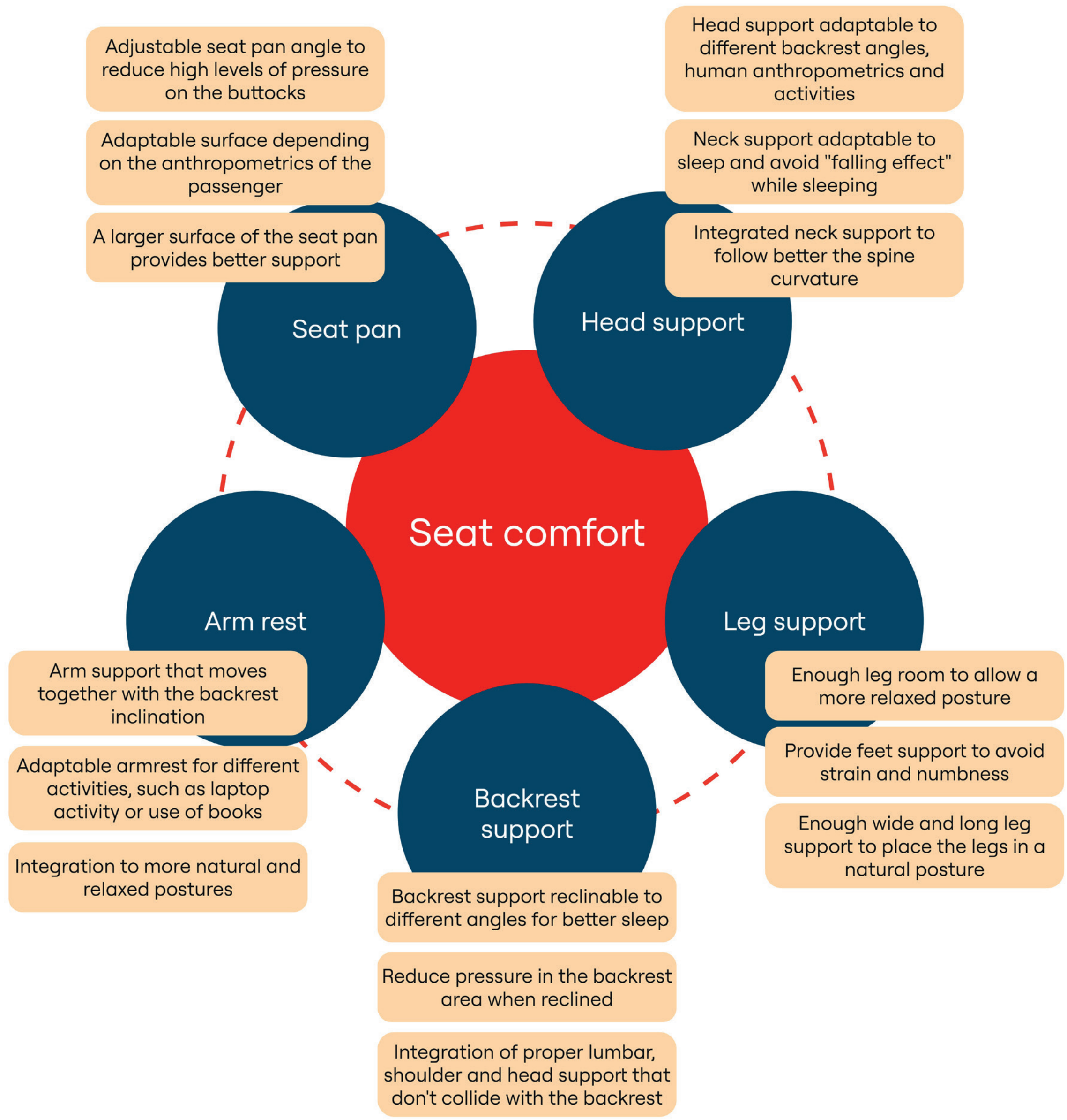


Figure 2.37. General recommendations to ensure comfort in a vehicle seat, extracted from the chapter

3 Sleeping research -and comfort-

In this chapter, it is explained the development and results of the user test realized in order to assess the seat designed and manufactured by BMW. As explained, due to their interests and future possibilities, the test is focused on how comfortable it is to sleep in the seat. Additionally, the goal is to obtain areas in which the seat can be improved for future redesigns.

3.1. Introduction

As mentioned in Chapter 2, the new seat developed by BMW has not been tested yet in terms of comfort for passengers. Because of this and their interest in sleeping during the journey, currently and in the future, the comfort of the seat will be tested by participants after sleeping a certain amount of time.

The sleeping and general comfort will be evaluated in two different seat configurations: backrest angle of 120° and backrest angle of 140°. This was selected from a previous sleeping research, in which sleeping comfort in six different backrest angles were evaluated (110°, 120°, 130°, 140°, 150° and 180°), as seen in Figure 3.1, the main differences in comfort were found between 120° and 140° angles. 140° resulted in the most comfortable overall, more than 150° and 180° (flat position) (Vledder et al., 2024). It is important to mention that the previous research was evaluated with standard seats and not seat cars, and that the duration of the nap was 90 minutes, in order to complete a full sleep cycle.

Therefore, for obtaining significant results and differences in this sleeping research, the backrest angles of 120° and 140° are evaluated. Additionally, the seat pan counts with an angle inclination of 20°, as recommended in previous literature research (Caballero-Bruno et al., 2024). Main dimensions of the seat can be seen in Figure 3.2.

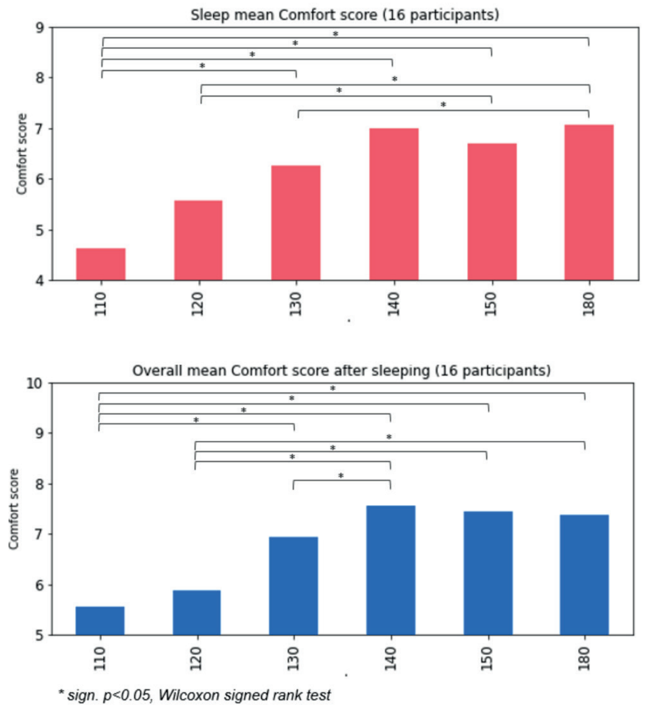


Figure 3.1. Results from 90 minutes sleeping research (Vledder et al., 2024)

Due to the research found regarding the advantages of taking a power nap while driving, the time of the nap for testing the seat is established in 30 minutes.

The user test expects to solve the following research questions:

- What are the main comfort differences between the two seat configurations? (120° and 140° backrest angle)
- Is the seat comfortable enough to take a 30-minute power nap?
- What areas of the seat are comfortable and which ones could be improved?

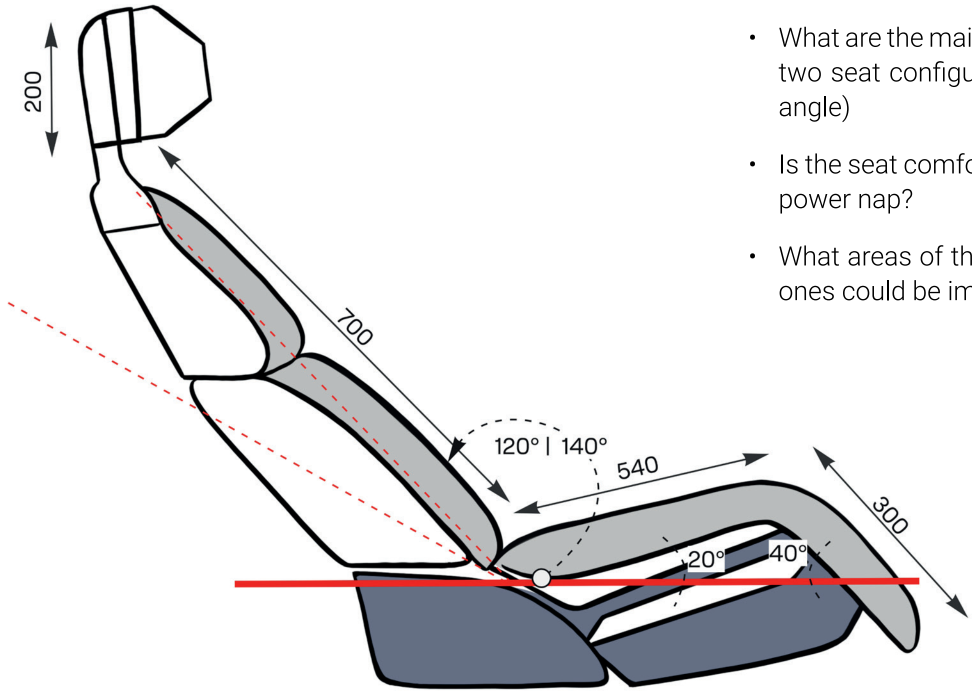


Figure 3.2. Dimensions of BMW seat

3.2. Method

3.2.1. Procedure

The participants recruited for this research had the opportunity to try the new BMW seat and take a power nap in two seat conditions. The seat is integrated in a mock-up of the interior cabin of a car and it's placed in a quiet room, as seen in Figure 3.3. The environment was the same in both conditions, providing a silence room and with the least amount of light possible.The objective of the study is to obtain subjective and objective data for evaluating the comfort of the seat in both conditions and evaluate what areas of the seat can be improved and which ones are comfortable. The participants were joining the experiments two times, in order to sleep in both seat conditions and evaluate at the end the main differences. The participants had some information about the research and what they were going to do, since they were asked not to drink caffeine or stimulant drinks the day of the research. The participants joined individually.

When the participant arrived at the room they were explained with the procedure of the session. First, some general anthropometric measures were taken and then they were asked to take a seat. Before sleeping, they had to fill in a (pre nap) questionnaire regarding comfort and discomfort at that moment. The full questionnaire can be seen in Appendix B. The seat was systematically varied in one of the two configurations, and therefore half of the participants started with a backrest angle of 120º and the other half with 140º (as appear in Figure 3.4) and they were asked not to adjust the seat. Pressure sensors are integrated inside the seat. These are able to record pressure distribution and loads when the participant is seated

Figure 3.3. Set up of the research

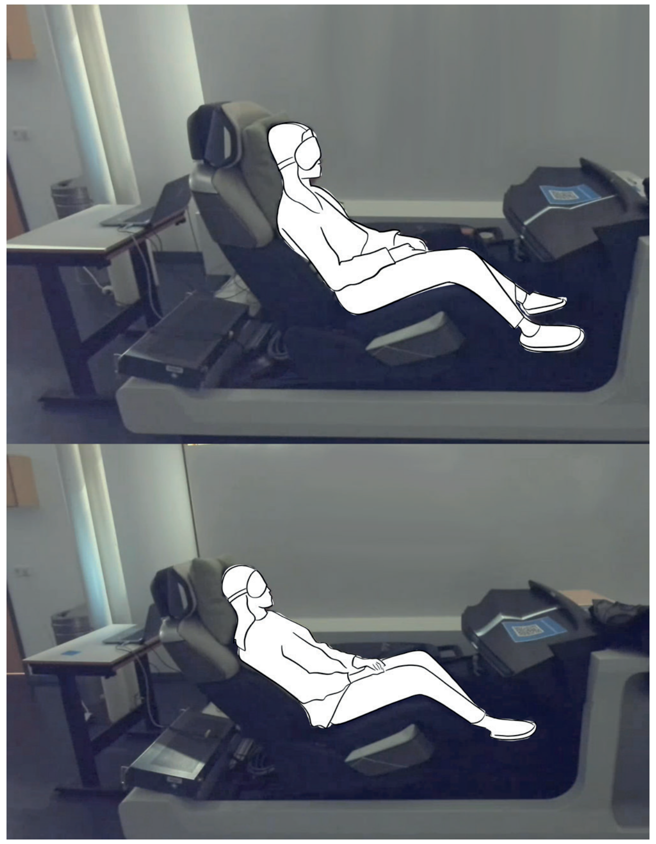


Figure 3.4. Example of a participant sleeping first at 120º (up) and the second time at 140º (down)

After filling in the pre nap questionnaire, they were asked to sleep for half an hour in the seat and if they did not manage, to stay relaxed and to not wake up or use their phones. For the sleeping period, they were able to place themselves in any preferred position and use a small pillow if they needed it. Light appeared to be one of the most influential external factors according to the previous sleeping research. Since it was not feasible to turn the room completely dark in this study, the participants placed a sleeping mask covering their eyes to be more relaxed and avoid distractions. Two participants requested not to use it because they always sleep with light. Since it was asked "How much did the sleeping mask influenced your sleep?" in the questionnaire, it was observed that overall it was helpful to the participants that used it. It facilitated sleeping to most of them.

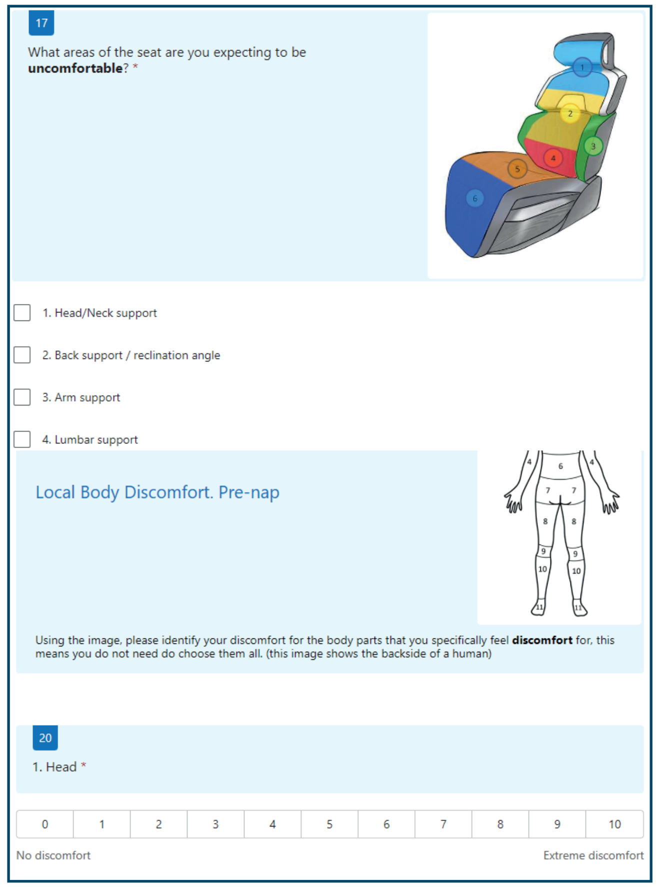
After the nap, the participant was awakened with an alarm of relaxing nature sounds. During the 30-minute nap, the researcher left the room and at the end the researcher returned. Once the participants woke up, they fill in the post-nap questionnaire. At the beggining and end of the research, snacks and drinks are offered.

3.2.2. Measure

The questionnaire collected subjective data regarding (dis)comfort experience, sleeping (dis)comfort and reviews about different areas of the seat (Figure 3.5). The questions had small variations between the pre and post nap, and at the end of the second session, they were asked questions comparing both seat configurations.

The questionnaire was designed based on the findings of Chapter 2.7. A ten-point scale was used several times in order to ask overall comfort/discomfort, sleeping comfort, and comfort of the seat. A figure of the seat differentiating its different parts was provided in order to mark the most uncomfortable areas before and after the sleep. A local body discomfort map was also used to identify body parts that suffered discomfort. Last, a few open-ended questions provided more feedback about how the backrest angle or the head support influenced the sleep. At the end of the second session, they selected in which session experienced more comfort.

During the sleeping, the participants were video recorded through a camera in order to analyse their movements and shift of postures. In addition, the pressure sensors were recording data to an external laptop.



17

What areas of the seat are you expecting to be **uncomfortable**? *

- [ ] 1. Head/Neck support
- [ ] 2. Back support / reclination angle
- [ ] 3. Arm support
- [ ] 4. Lumbar support

Local Body Discomfort. Pre-nap

Using the image, please identify your discomfort for the body parts that you specifically feel **discomfort** for, this means you do not need do choose them all. (this image shows the backside of a human)

20

1. Head *

0	1	2	3	4	5	6	7	8	9	10

No discomfort — Extreme discomfort

Figure 3.5. Questionnaire sample

3.2.3. Apparatus

The equipment shown in Figure 3.6 was used in order to collect all the relevant data from the participants:

- BMW seat. The seat is automatically adjustable thanks to an external laptop in the following configurations: reclinable backrest, reclinable legrest, adjustable headrest height, reclinable seat pan and adaptable upper part of the back support.
- External laptop for adjusting the seat and sensor data recording
- Logitech Camera for participant recording
- Temperature and humidity data recorder
- Fitbit 3. However, it did not provide sleeping data for 30-minute naps.

3.2.4. Participants

A sample of 16 participants, all TU Delft Master students, participated in the research, consisting of eight men and eight women (In Figure 3.7. the anthropometric data is specified). Participants were from different nationalities: Indian (6), Spanish (3), Mexican (2), Italian (2), Dutch (2), and Chinese (1). A simple selection was done previously for recruiting them, discarding those participants that had sleeping problems or illnesses related to sleep. Additionally, it was attempted to choose participants that tend to take naps, were fast sleepers and could sleep easily anywhere.

The time of the test varied according to the availability of the room and the availability of participants. Although it is not the most recommended to take naps after 14:00h, the tests were done in the evening avoiding noises outside of the room. The time slots were 17:00h, 18:15h, 19:30h and 20:30hAll the participants signed an informed consent (Appendix C) and were aware of the data that would be needed from them.

Figure 3.6. Research equipment

Participants [n=16]	Mean	SD
Age (Years)	25,75	2,64
Height (cm)	171,31	10,004
Body weight (kg)	67,40	16,79

Figure 3.7. Anthropometrics from the participants

3.2.5. Stimulus

The research took place in a closed room. The area of the research was enclosed by separation panels to create a more relaxed feeling and avoid distractions. To facilitate sleeping and avoid pain in the neck and head, a pillow was offered in case they wanted to use it.

All participants were really excited in the first session to try the seat and sleep on it due to their innovative features. After sleeping, most of the participants appreciated having 30 minutes of relaxation in the middle of the day and being able to rest. After completing both sessions, participants were rewarded with a 20€ gift voucher.

3.2.6. Data analysis

For analysing the results, all the participants questionnaires were collected into an excel file. Microsoft excel was used for the closed questions, and they were compared between both configurations of backrest angles. The goal is to discover the main differences and show them through data visualization.

These results are as well compared through T-tests. The purpose of this statistical test is to ascertain whether there is statistical evidence that the mean difference between observations in the different outcomes of both backrest configurations is significantly different from zero.

For the open-ended questions, the software Atlas.ti is used. It is a qualitative data analysis used for coding and examining responses. With visualization tools, it can be extracted the most frequently occurring codes and therefore, obtaining relevant data in a rapid extraction.

Last, the analysis of the videos is done manually, observing signs of movement, changes of postures and common signs of sleeping. This is translated into a table comparing both configurations and extracting the most relevant results once all the videos are analysed.

3.2.7. Hypotheses

BMW researchers advised in previous meetings about the discomfort that the headrest provides, since it is really hard and it can not be adaptable. Therefore, inadequate head restraint has been the main assumption regarding possible areas of improvements of the seat.

Since the sleeping research is taking place in a vehicle seat unlike the previous sleeping research, it is expected higher comfort scores for comfort and sleeping quality will be recorded, and lower discomfort rates in both configurations of the seat.

Previously to conducting the research, different experts of seat design tried the seat for only a couple of minutes. Some of the brief and broad feedback that was provided is collected in Figure 3.8. Despite the participants only sat for a couple of minutes without performing any specific activity, the feedback was used as a first basis on what to analyse during the research, and what areas to observe in the video recordings.

Although research shows that discomfort in seats tends to appear after a long period sitting (from minute 35 to 40), it is assumed that with the time for filling in the pre nap questionnaire and sleeping, will be long enough to distinguish uncomfortable areas of the seat and body discomfort.

Figure 3.8. Initial feedback collected of the seat

3.3. Results

3.3.1. General comfort

Analyzing the questionnaire, and answering the question of "Did you manage to sleep the last 30 minutes?", 10 out of 16 participants managed to sleep for both backrest angles. Something to remark is that even though 6 people did not manage to sleep, all participants had a good nap in the 140º backrest angle configuration (see Figure 3.9.), compared to 5 bad naps in 120º. Therefore, despite being unable to sleep, it can be assumed that they were relaxed and resting properly.

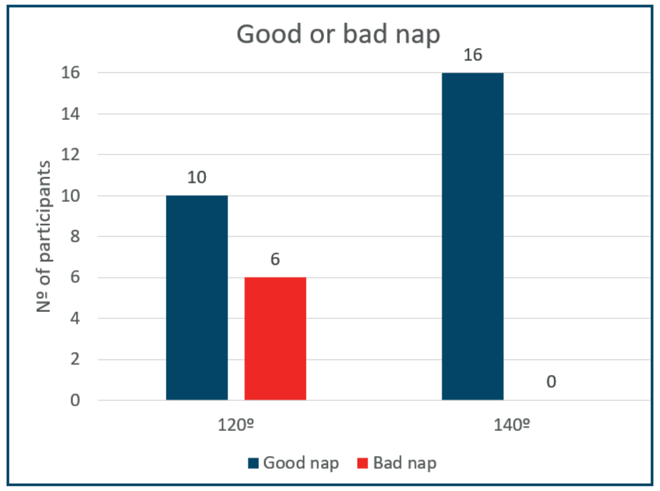


Figure 3.9. Good/bad nap in both configurations

Regarding their sleep quality overall, it can be seen in Figure 3.10. that the main predominant answer is "Fairly good" for both seat configurations, with slightly better sleep quality for 140º.

Figure 3.10. Sleep quality overall

Analysing the sleep, and according to the participants, it takes between 10 to 15 minutes to fall asleep. From Figure 3.11. it can be concluded that people need less time to fall asleep in the 120º backrest angle (mainly 2 to 5 minutes while fewer need 10 to 15 minutes). In the 140º reclination, the majority of participants took from 10 to 15 minutes to fall asleep. The mean time to fall asleep in 120º is 14,86 minutes and for 140º is 14,46 minutes.

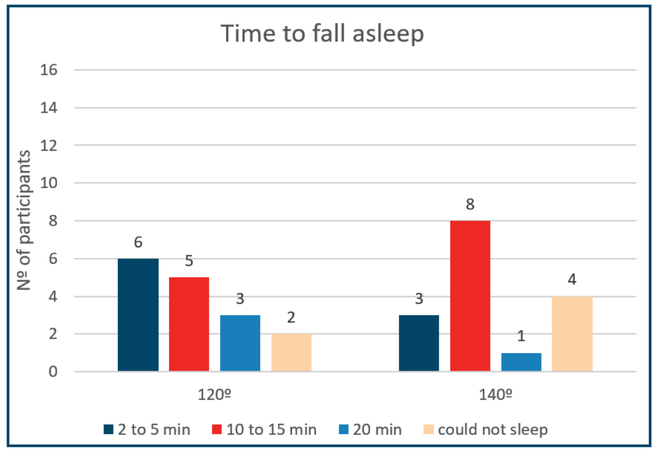


Figure 3.11. Time to fall asleep

Regarding the amount of sleep, it can be seen in Figure 3.12 that participants slept from 15 to more than 20 minutes. The mean amount of sleep for 120º is 12,62 minutes sleeping, and for 140º is 13,66 minutes.

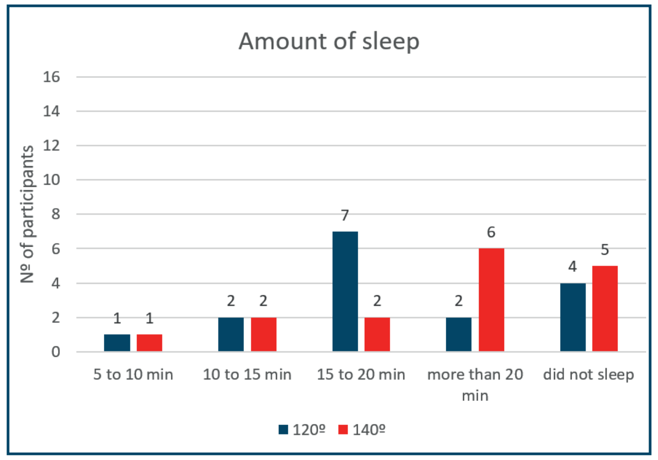


Figure 3.12. Amount of sleep

From the sleep mean comfort, there is a preference of comfort for the 140º backrest configuration. For 120º, the sleep mean is 6,31 out of 10 (standard deviation: 1,88), and for 140: 7,46 out of 10 (SD: 1,45). There is one point of difference between both backrest angles. Regarding the overall discomfort, 3,31 out of 10 (SD: 1,77) for 120º backrest angle, and 2,26 out of 10 (SD 1,72) for 140º (Figure 3.13 and 3.14). Both results are compared with the t-test explained previously. This means that there is statistical evidence (significant differences) between both seat configurations (asterisk * stands for sign. p<0.05) through Wilcoxon signed rank test.

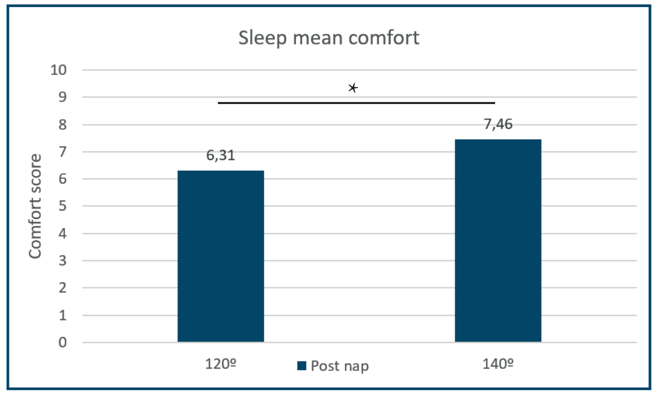


Figure 3.13. Sleep mean comfort
* sign. p<0.05, Wilcoxon signed rank test

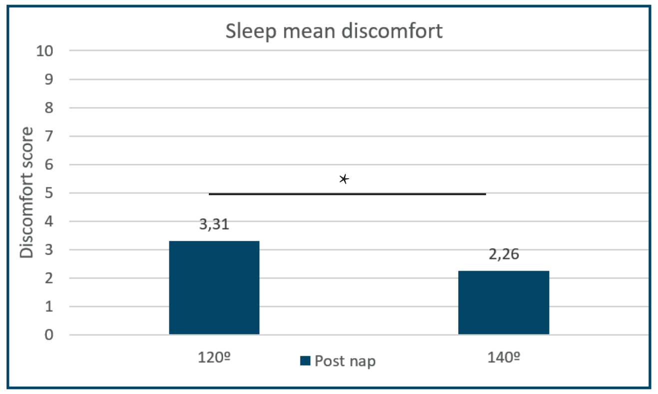


Figure 3.14. Sleep mean discomfort
* sign. p<0.05, Wilcoxon signed rank test

Evaluating the overall mean comfort and discomfort, no significant results can be extracted between both seat configurations (through Wilcoxon signed rank test). As can be seen in Figure 3.15 and 3.16, only the overall mean discomfort between both angles before nap is notorious. It is interesting to mention how the discomfort slightly increases after nap in 120º, while decreases after nap for the seat configuration of 140º.

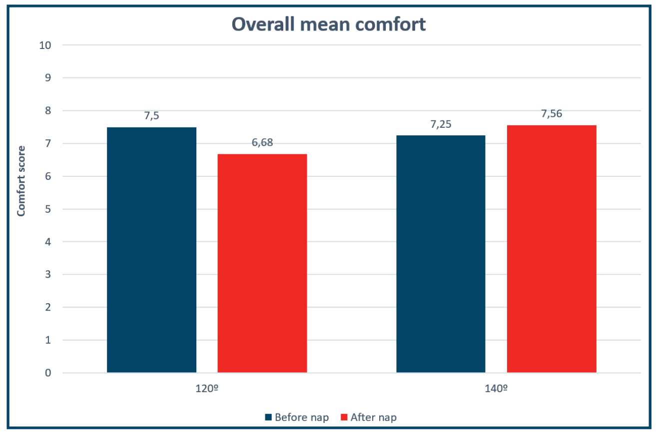


Figure 3.15. Overall mean comfort

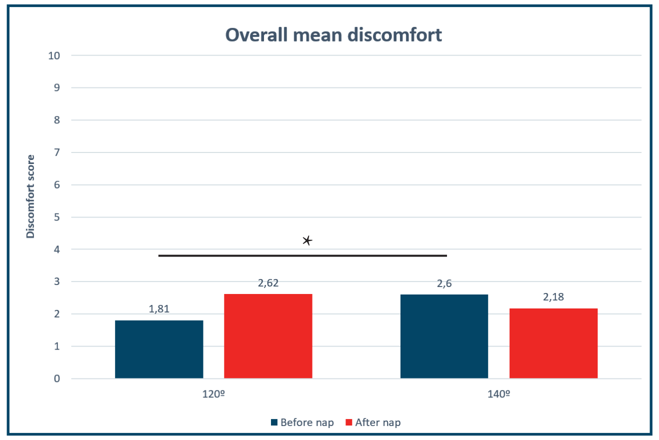


Figure 3.16. Overall mean discomfort
* sign. p<0.05, Wilcoxon signed rank test

3.3.2. Backrest angle

From the question "Which seat configuration do you prefer?", there is a clear preference for the 140º backrest reclination. 81,25% of participants (13 out of 16) prefer this backrest reclination. Regarding the sleeping quality between both configurations, nine participants preferred the 140º reclination, while three participants preferred the 120º backrest angle, and four participants considered both configurations similar regarding their sleeping.

In order to better understand this preference, it is important to analyse the question "Did you experience any difference in discomfort between the first and second session?" The results to the question can be seen in Table 3.1. and Table 3.2.

	120º backrest angle
Pain in head and neck	6
Better support in head and neck	2
Comfort on legs and feet	2
Backrest discomfort and pain	2
No need of pillow	1

Table 3.1. Amount of times that the codes have been repeated for 120º backrest angle

	140º backrest angle
More comfort overall	2
Discomfort in legs and feet	2
Discomfort on head and neck	1
Less movement restriction	1

Table 3.2. Amount of times that the codes have been repeated for 140º backrest angle

One of the reasons for choosing the 140º backrest angle is the pain in head and neck that participants experienced with the 120º backrest angle, together with discomfort in the back area. However, despite being the preferred angle, there are some drawbacks such as discomfort in head and neck, and more discomfort in legs and feet compared to 120º backrest

3.3.3. Seat analysis

In order to answer the research question: "What areas of the seat are comfortable and which ones could be improved?", the following questions are analyzed:

Since almost all the participants had a good nap, for a better explanation it is asked: "Briefly explain why you had a good or a bad nap?". The results can be seen in Table 3.3.

	SQ2-120º	SQ2-140º
Appropriate backrest angle		5
Changes of postures	3	
Comfort from the pillow	1	4
Comfortable seat	3	7
Easiness to sleep	2	3
external noises		1
Lack of adjustment on head support	1	
Lack of footrest	1	
lack of head support	2	1
Lack of sleep		1
Leg pain	1	
Neck pain	7	1
Numbness on the legs	1	
Overall comfort	1	5
Relaxing nap	4	1
Shoulder pain	1	
soft seat		1
Stress and worries		1
Time to fall asleep	1	1

Table 3.3. Codes extracted for question "Why you had a goor or a bad nap?"

The main good nap factors are:

- Appropriate backrest angle
- Comfort from the pillow
- Overall comfortable seat
- Easiness to sleep
- Overall comfort
- Relaxing nap

And as bad nap factors:

- Changes of posture while sleeping
- Neck pain
- Lack of head support
- Leg pain

Figure 3.17. shows an example of an open-ended question answer by a participant and how it is coded.

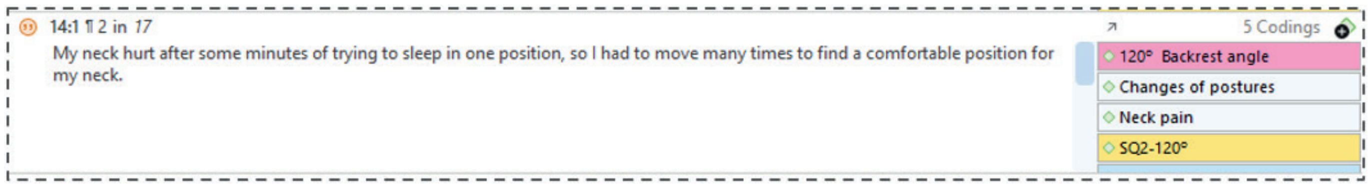


Figure 3.17. Example feedback provided by a participant in question: "Why you had a goor or a bad nap?"

We also asked the participants to describe the nature of your comfort and discomfort. The main reasons are similar to the ones provided in Table 3.3. As for the nature of the comfort, the main mentioned aspect is the favourable shape of the seat, the comfortable back area and the appropriate leg support. Regarding the nature of the discomfort, the most mentioned are the neck pain, lack of head support and the hanging feet.

For a more specific understanding of areas of the seat, it is asked "which areas of the seat are you expecting to be uncomfortable?" before nap, and "which areas were uncomfortable" after nap. The results can be seen in Figure 3.18

It is noticeable that the two main areas of discomfort pre and post nap are the head/neck support and the leg/feet support. Regarding the head/neck support, it can be seen how the discomfort reduces after the nap. This can be due to the possibility of using a pillow for getting better comfort in that area. For the feet and leg support, both angles cause the same discomfort, although the expected discomfort for 140º is lower than the experienced. The other expected areas of discomfort are the arm support and lumbar support, which experienced discomfort resulted lower.

It was asked to evaluate the overall (dis)comfort of the neck, and the results can be seen in Figure 3.19. The mean comfort for 120º is 1,5 (Standard deviation 1,69), and for 140º is 2,75 (standard deviation 1,48). Regarding mean discomfort, for 120 is 7,75 (SD 1,03) and for 140º is 6,75 (SD 0,88).

There is a lot of difference between how low the comfort is rated and how high the discomfort is rated. In both angles the head/neck support is rated relatively negative for comfort and discomfort. It is assumed that the comfort increases, and the discomfort decreases in 140º due to the use of the pillow in that configuration.

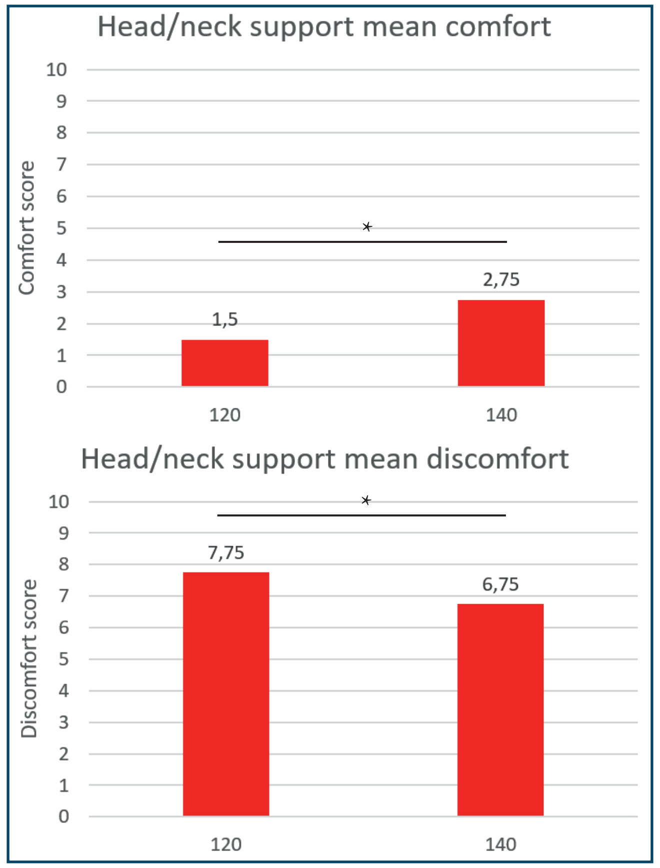


Figure 3.19. Head/neck support mean (dis)comfort
** sign. p<0.05, Wilcoxon signed rank test*

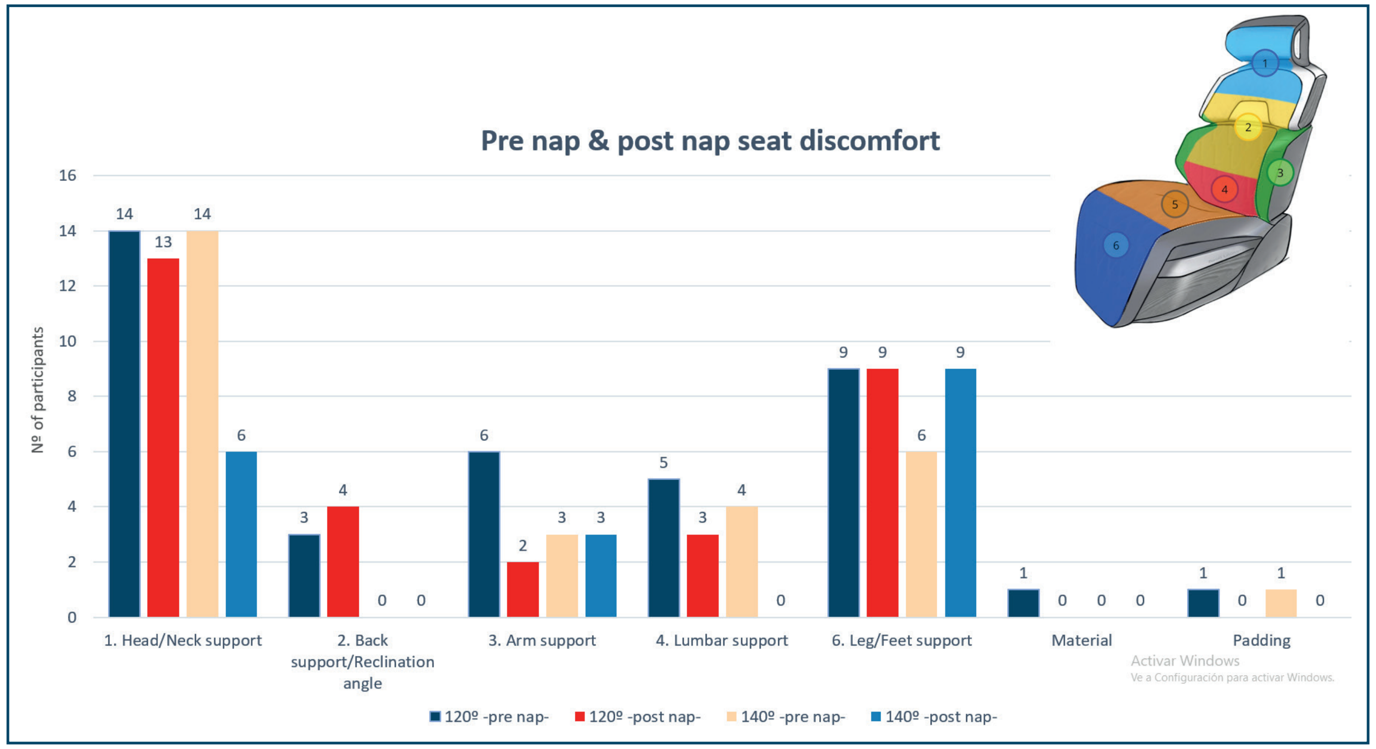


Figure 3.18. Results to the question "Which areas of the seat are you expecting/experienced as uncomfortable?"

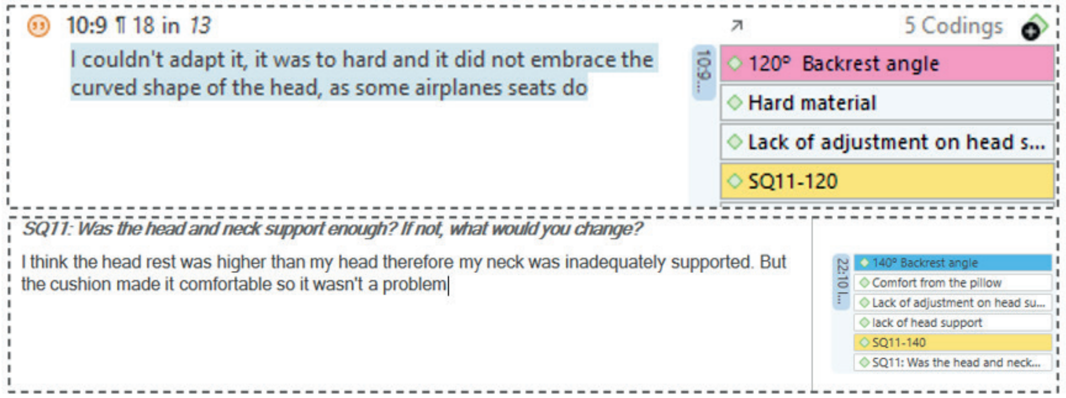


Figure 3.20. Feedback to question "How would you evaluate the head support?"

As an open-ended question, it was asked "How would you evaluate the head support?". Figure 3.20 shows some feedback provided, and the most mentioned aspects can be seen in Table 3.4. The main complaints regarding head support is the lack of adjustment on head support and the lack of head support (neck support and lateral support). As positive aspects, it is mentioned the comfort provided by the pillow.

	SQ11-120	SQ11-140
Comfort from the pillow		5
Hard material	1	
inappropiate support angle	2	2
Lack of adjustment on head su...	6	5
lack of head support	3	6
No ergonomic curvature	1	

Table 3.4. Codes extracted for question "How would you evaluate the head support?"

The second discomfort area has been the leg support. However, regarding (dis)comfort there are not as much differences as there is for the neck support (Figure 3.21). The mean comfort for 120° is 4,12 (SD 3,9), and for 140° is 5,5 (SD 2,72). Regarding mean discomfort, for 120 is 5,35 (SD 3,92) and for 140° is 3,87 (SD2,58).

From the question "How would you evaluate the leg support", the most mentioned attributes can be seen in Table 3.5. The most repeated aspect by participants is the lack of foot support and the pain created due to having the feet hanging.

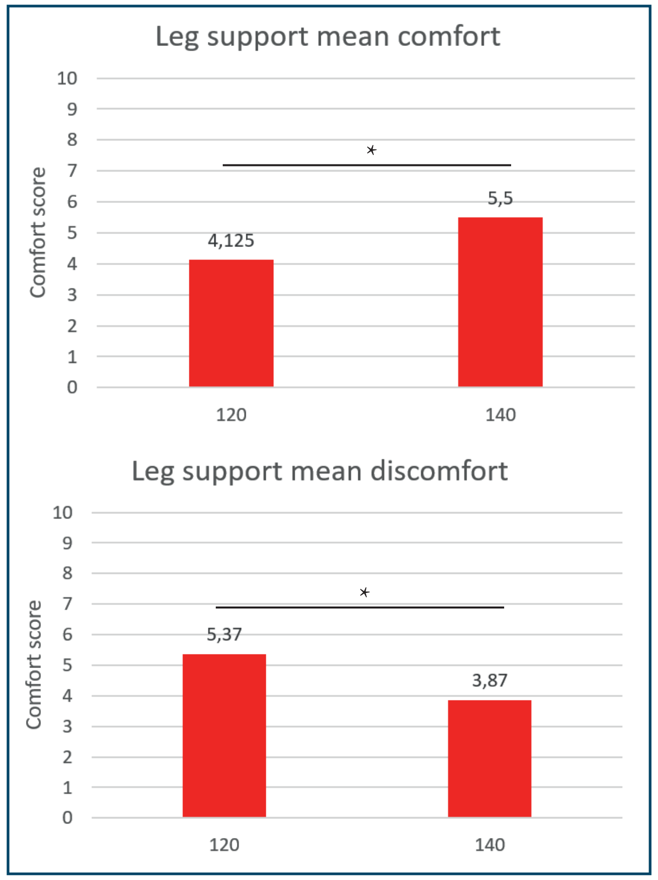


Figure 3.21. Leg support mean (dis)comfort
** sign. p<0.05, Wilcoxon signed rank test*

		SQ8-120 (8)	SQ8-140 (8)
Good leg support	6	2	1
Hanging feet	17	3	5
Lack of feet support	4	2	2
Leg pain	8		1
Leg pressure	1		1
overall discomfort	6	1	
Preference: feet support	7	4	3
Sharp angle between seatpan and leg support	1	1	
Support from lateral cup holder	2	2	
Too high	1	1	

Table 3.5. Codes extracted for question "How would you evaluate the leg support?"

3.3.4. Movement, sleep and posture analysis

In Appendix D can be found the complete analysis. For each participant the number of changes of posture during the session was recorded to check if it is related to discomfort. For each posture it is measured the duration, the use of the pillow, and how the head, arms and legs are placed. From the video recordings it can also be estimated if the participant managed to sleep and during how long.

Most of the participants did not use the pillow in 120° backrest configuration (see Figure 3.22), while four participants used it. From the recordings it can be seen that the ones that use the pillow did not reach the head restraint and placed it to offer more support . From the questionnaire analysis, the main reason for not using the pillow on this inclination is because the pillow pushes the head to the front, since the head support already creates a feeling of pushing forward. On the other hand, in the 140° configuration 10 out of 16 participants used the pillow. From the questionnaire analysis it is mentioned that the head support had a very hard material and otherwise not using it might be uncomfortable.

	use pillow	not use pillow
120°	12participants did not use the pillow in 120	4 participants use the pillow in 120
140°	6 participants did not use the pillow in 140	10 participants use the pillow in 140

Figure 3.22. Use of pillow in different configurations

The amount of times that participants changed postures is similar for both configurations. As it can be seen in Figure 3.23., the most common is no change of posture during the 30-minute nap. Some participants mentioned in the questionnaire that the shape of the seat invited them to assume that posture and that it was very comfortable. The participants that did not change posture, managed to sleep for more than 25 minutes. On the other hand, the participants that made more than five changes of posture did not show any sign of sleeping during the session

	no change of posture	1-2 change of posture	3-4 change of posture	more than 5 change of posture
120	7	2	4	3
140	7	3	5	1

Figure 3.23 . Number of participants that changed postures in both different configurations

Almost all the participants tried first to sleep in a frontal posture and then made small variations on legs, arms or head to make it more comfortable. This is why the changes are minimal in some occasions, while few participants changed directly to a completely different posture. There is a tendency from shorter people to change their posture more frequently and to place themselves into strange positions. On the contrary, taller people tend to place in a frontal posture and not perform any change of posture.

There is a direct relation between the amount of times that participants changed positions and the amount of sleep they got. In figure 3.24. can be seen that more than half of the participants slept for 20 to 30 minutes in both configurations.

In order to check if a participant was sleeping or not, some assumptions were made:

- The head is falling towards the front, sides and back
- The mouth is open
- There is no change of posture or movement at all from arms, legs and head

However, a more objective analysis considering the pressure sensor or PSG data would be necessary to confirm the amount of time the participants were sleeping.

	20 to 30 minutes of sleeping	15 to 20 minutes	unclear or 10 minutes	no signs of sleeping
120	9	4	2	1
140	9	1	3	3

Figure 3.24 . Number of participants and the amount of sleep they had

The last analysis from the video recordings is focused on the head and neck posture, because it is where most changes were seen. Figure 3.25 shows the analysis of the movement of the participant's head while sleeping, and the amount of times it was seen.

Therefore, movements on the head while sleeping and its lack of support is a major issue. It was experienced for almost all the participants and this created discomfort, as it is seen from the questionnaire.

	head falling to the back	head falling to the sides	head falling to the front	no movements thanks to the pillow	no movements
120	3	7	5	0	4
140	4	6	0	3	4

Figure 3.25 . Amount of times specific movements on the head are observed

The main comfort point from the head and neck area was provided thanks to the pillow. However, not all the participants used the pillow and the ones that did, placed it in different ways. Figure 3.26 shows the different ways in which the pillow is used (or not). Participants did not use the pillow in multiple ways, and once they placed it they did not change it.

3.4. Discussion

3.4.1. Good nap

From the results obtained, extracted mainly from the questionnaire and video recordings, it can be extracted that participants were quite comfortable in both configurations during the sessions. However, more comfort is experienced in 140º backrest and the nap was better evaluated, even though few of them did not manage to sleep.

However, in order to answer the research question "Is the seat comfortable enough to take a 30 minute power nap?", focusing on the 30 minutes sleep, more analysis should be done. Although the seat is comfortable and it is possible to have a good nap, more time would be needed in order to have a proper power nap for some participants in order to wake up refreshed and obtain the benefits of short naps. For this, it is worthwhile to consider the amount of time that participants need to fall asleep (more than 10 minutes in most times). However, it should be considered that there were participants that fell asleep almost immediately, and the fact that some participants were not tired enough to sleep in the seat at the research moment. Consider a real scenario, a passenger/driver is up for sleeping because they are already feeling tired.

Pillow position:

120º
- Pillow to support the lateral side of head and neck (1/16)
- Pillow on head, neck and shoulders (3/16)
- No pillow on the head(12/16)
  - No use of pillow (8/12)
  - Pillow between arms (2/12)
  - Hugging the pillow (2/12)

140º
- Pillow on the head, neck and shoulders (9/16)
- Pillow to support the lateral side of head and neck (1/16)
- No pillow on the head (6/16)
  - No use of pillow (3/6)
  - Pillow between arms (2/6)
  - Hugging the pillow (1/6)

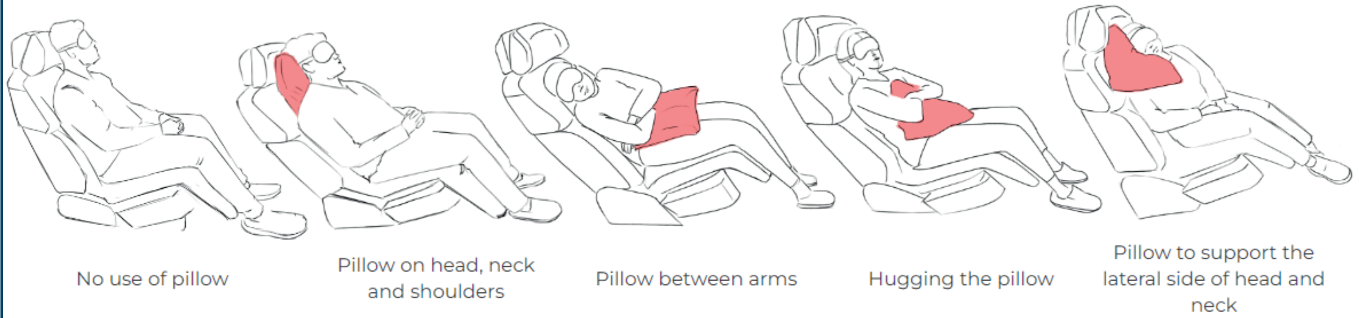


Figure 3.26 . Analysis of pillow position and uses in both seat configurations

3.4.2. Differences between 120º and 140º

Significant differences were found between both backrest angles in terms of sleeping comfort. Although there is a clear preference towards 140º backrest for sleeping. The comfort in both configurations, the amount of time slept and the amount of time to fall asleep are similar between them.

The biggest difference is the use of a pillow in 140º backrest while it was not used for the 120º. It indicates that different angles of headrest are necessary depending on the configuration of the back support, for not having the need of using an external pillow. For 140º, the head falls mostly to the back for the participants that did not use a pillow, due to the empty space created between the shoulders and head.

For the 120º, due to the discomfort of placing a pillow, the hardness of the headrest and the few reclination of the backrest, almost all the participants that fell asleep experienced "head falling effect" towards the side, front and back.

Another difference between both configurations is the experienced comfort regarding the leg support. For 120º, the experienced comfort is higher than in 140º because the feet are not hanging. However, when changing the backrest to a more reclined, the leg support also reclines backwards, causing that the feet of the participants are hanging and the longer the duration, the bigger the strain and numbness.

3.4.3. Posture

Figure 3.27 shows an overview of the most common postures while sleeping in the seat. The most repeated posture is the neutral posture to the front, and most of the participants stayed in that position during the 30 minutes. However, some people slide down for not touching the head support and avoid discomfort (mainly short participants).

On most occasions the arms were placed touching the legs. Some people preferred to cross the arms and others chose to support the arms in the pillow.

3.4.4. The seat and opportunities for redesign

The shape of the seat, materials, padding and lumbar support were evaluated as the main areas of comfort of the seat. Additionally, and in difference at what it was expected, there was no discomfort or complaints regarding the lack of arm support, but participants appreciated the cocooning shape that wraps them and the protrusion of the area for placing the arms.

However, bigger issues can be seen in the area of the head and neck support, followed by the leg support. In Figure 3.28. it can be seen the most comfortable and uncomfortable areas of the seat.

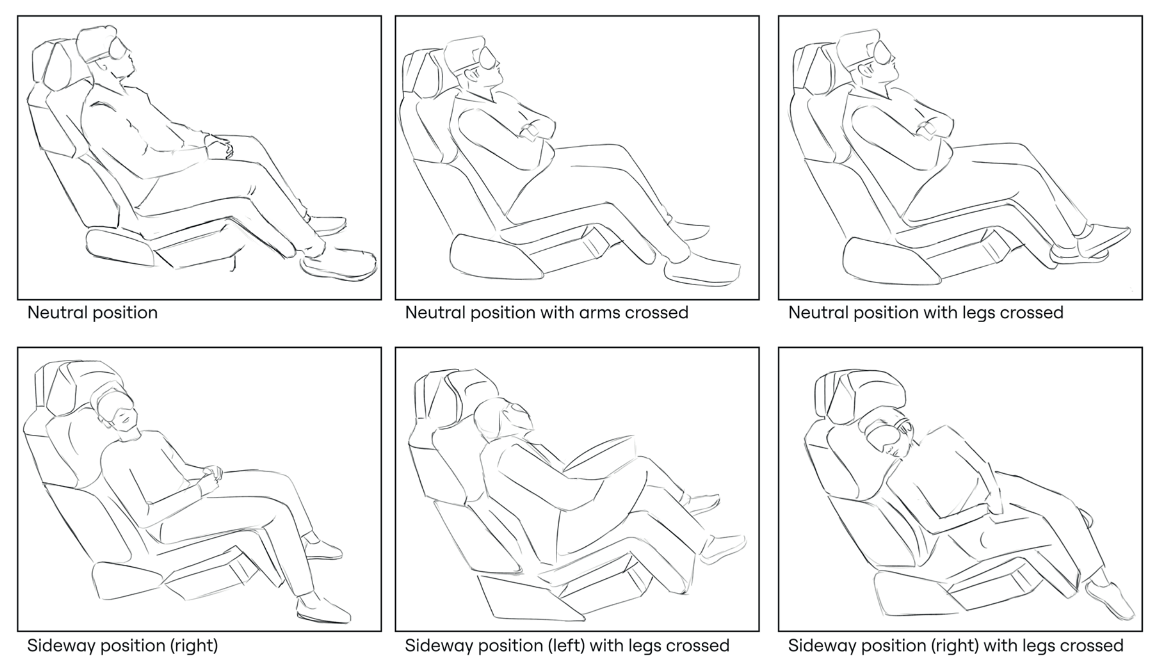


Figure 3.27. Common postures while sleeping in the seat

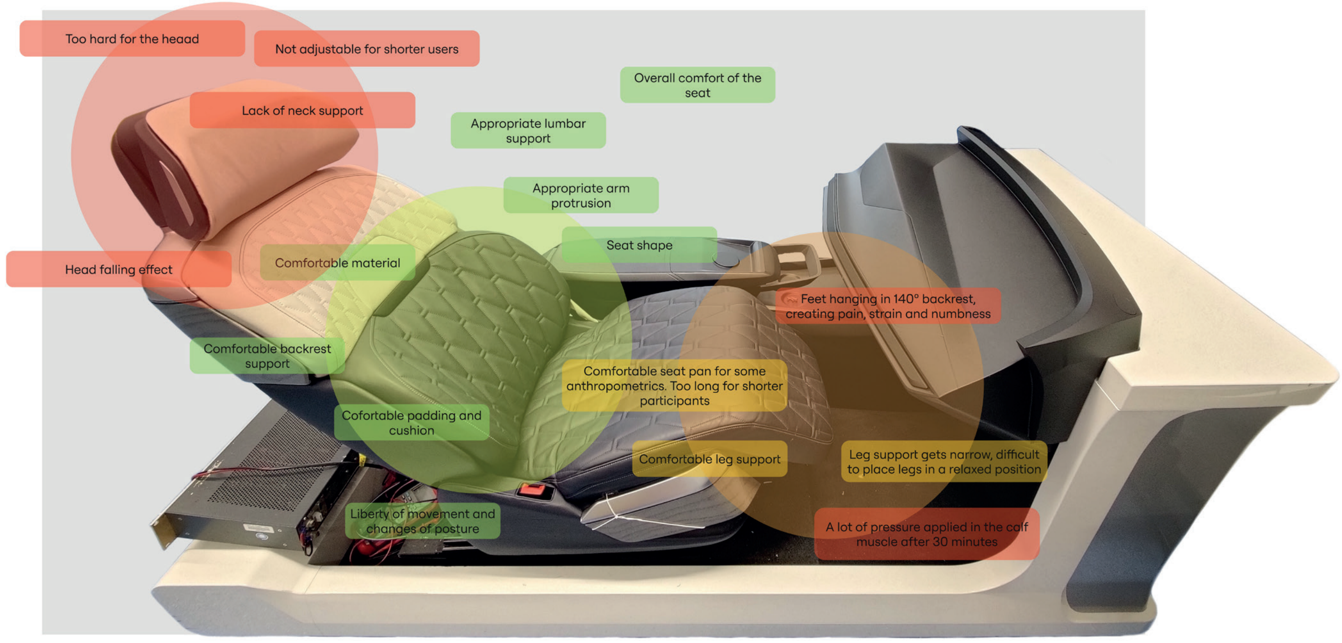


Figure 3.28 . Most comfortable and uncomfortable areas of the seat for a 30-minute nap

Even though the leg support and the lack of a feet support is a negative point mentioned by participants, the lack of adjustable head support that facilitates sleep was mentioned on more occasions by the participants. In the video recordings, it is seen how the head and neck goes through a lot of movement in different participants, since they struggled to place the head in a comfortable position.

Due to the main negative feedback provided for the headrest area, together with the feedback provided by BMW, it is chosen to redesign this area of the seat and make it more user friendly and comfortable to future users.

The current headrest follows few of the design recommendations obtained by the literature research in chapter 2. Currently, it does not follow the curvature of the spine, neck and head. Additionally, it can not be adjustable to differences in anthropometrics and it is not adjustable to different backrest configurations, having the need to use a pillow for 140º backrest but pushing the head towards the front for the 120º backrest. Regarding design recommendations for sleeping, the current seat does not prevent the falling head effect that happens when the passenger is sleeping, and it does not provide enough lateral support for relaxing the head and neck. Last, there is a lack of neck support, creating an empty space between the shoulders and the head, that leads the head to fall backwards when relaxed and causing neck pain.

Because of these reasons, the head restraint of the current seat can be improved, trying to positively fulfil the aspects mentioned previously, and redesigning a new integrated head restraint for the BMW seat, with a focus on sleeping.

3.4.5. Further research

After the analysis and selection of the weakest point of the seat for further redesign, more research with a focus on the head and neck support of the seat would be necessary in order to develop the most effective design.

Research regarding the appropriate angle between the neck and the head should be done, as well as recommended shapes and materials for the design of a neck support. Ergonomics considerations for developing an adjustable headrest for different anthropometrics need to be considered, and take into consideration the current regulations and safety standards for the development of a head restraint that can be integrated in current vehicles. Last, it is important to find the current state of the art regarding head restraints, neck supports and travel pillows.

3.5. Conclusion

After performing and analysing the results the sleeping research in which 16 participants evaluated the seat, the main outcomes of the research are:

- There is significant preference towards the 140º backrest angle against 120º backrest.
- The seat is comfortable enough for sleeping, taking into consideration that some users fell asleep after few minutes. However, more time would be needed in order to have an appropriate power nap considering the time it takes to fall asleep.
- There is a preference of using the pillow in 140º, and not for the 120º backrest angle, since it pushes too much the head forward.
- The need of a pillow in a more reclined angle shows a need of improving the head and neck support.
- Head/neck support was the most uncomfortable area of the seat. Additionally, the body areas of head and neck were evaluated with significant higher discomfort in comparison with other body areas.
- Proper neck/head support is needed in order to ensure higher ratings on sleeping comfort, and avoid pain on this area of the body.

Additionally, it is necessary to analyse the comfort of the seat during a longer nap of at least 60 to 90 minutes, and see if discomfort increases during time, if there are more changes of postures and if people would manage to sleep the whole period. Bigger differences between both seat configurations could be obtained.

For a more complete evaluation of the seat, evaluating the seat while performing different activities apart from sleeping would provide new insights, new discomfort areas and probably new requirements. For instance, an assumption obtained from the literature research is that for active seating (activities such as working with the laptop, reading a book or use the phone), an arm rest would be appreciated for facilitating the activity, even though it is not necessary for sleeping.

Last, as mentioned previously, based on this research, one of the most interesting focus points for future redesign is the head and neck support area of the seat. Improving the current head support is the main goal for the second part of the project.

4 Headrests -considerations and analysis-

From the previous chapter, it is chosen to propose a redesign for the current seat. Therefore, this chapter explains the design recommendations and what considerations need to be taken into account for the development of an appropriate head restraint or head support comfortable for sleeping.

4.1. Design considerations

According to The Royal Society for the Prevention of Accidents (2018), head restraints are an automotive safety feature, attached or integrated in the top of each seat to limit the rearward movement of the adult occupant's head, in a collision, to prevent or mitigate whiplash or injury to the cervical vertebrae. It will also reduce the amount of time it takes the head to initially contact the head restraint. They have been mandatory in all vehicle seats since the latest 1960.

In order to be effective, the head restraint should be adjusted properly to either the driver or passenger, as it can be seen in Figure 4.1.

- The top of the head restraint is as high as the top of the passenger's head
- The position of the head restraint must be as close to the rear of the head as possible

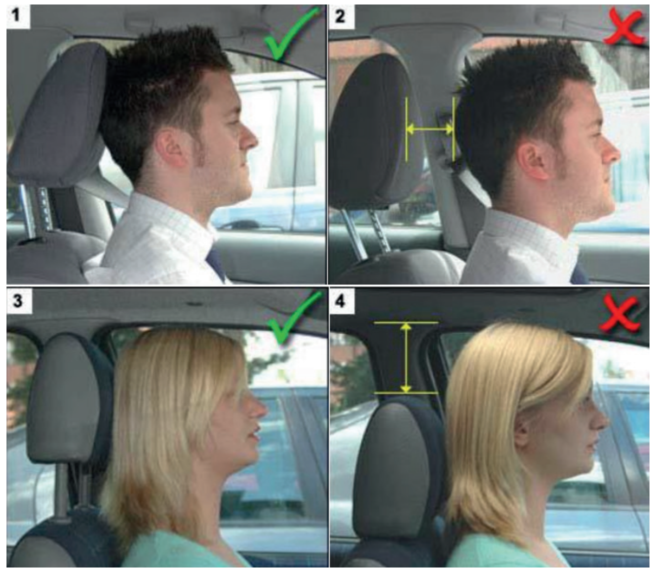


Figure 4.1. How to adjust a head restraint (The Royal Society for the Prevention of Accidents (2018)

4.1.1. Types of head restraints

The main components of a Head Restraint is the head rest and the neck rest. While the head rest is compulsory and is mainly meant for safety, the neck rest is often forgotten in the design of the seats and its functionality is mainly providing comfort (Franz et al., 2011). There are two types of head restraints: the integrated and the adjustable. Within the adjustable, there are three types (Figure 4.2.) depending on the degree of headrest movement (Wikipedia, 2022).

- Two-way headrest: only the height of the headrest can be adjusted. These are the most popular and used currently.
- Four-way headrest: it can be adjustable in height and in angle reclination of the headrest.
- Six-way headrest: mainly used in the aircraft industry. Not only can be adjusted in height and angle reclination, but also adapt to the width to the head.

Figure 4.2. Examples of adjustable head restraints

4.1.2. Recommendations from literature research

It is important to follow the design recommendation from Chapter 2 regarding that the seat should support the natural curve of the spine. According to Delleman et al. (2004), a "neutral position" is preferably for the body, meaning that the angles should be in the "rest" position of a joint, where the muscles are not stretched. Considering the natural curves in the vertebral column, the cervical curvature that connects with the head should be in a natural position (Figure 4.3.)

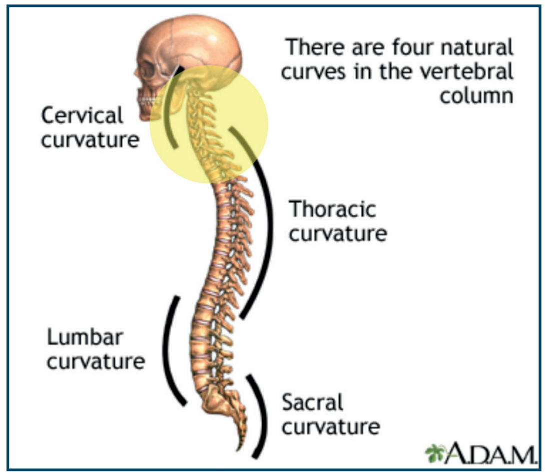


Figure 4.3. Four natural curves in the vertebral column (MedLine, 2023)

Bouwens et al. (2017) defined three main axes of the head in which a pillow or neck support would be affected (figure 4.4.). In order to provide the least possible discomfort, the head and neck support should avoid as much movement as possible in any of those three axes while sleeping. Regarding the rotation on the Y axis, biomechanical studies have indicated that the head achieves best balance when rotated 20º backward (Staarink, 2007).

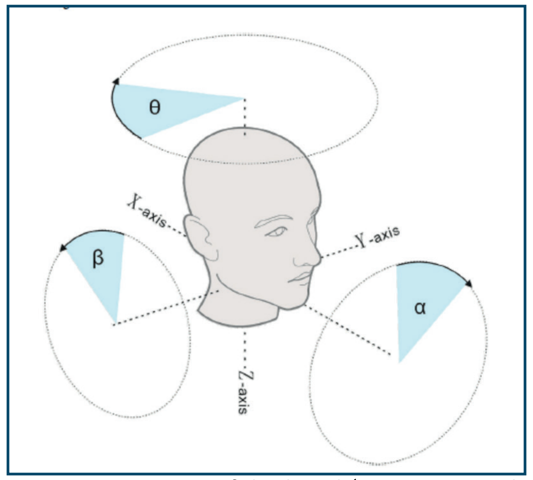


Figure 4.4. Main axes of the head (Bouwens et al., 2017)

For getting the best balance, the physiological range of the curvature of the neck should be considered. According to Bouwens et al. (2017), the tragus and seventh cervical should create an angle between 40,6º and 43,7 degrees (Figure 4.5).

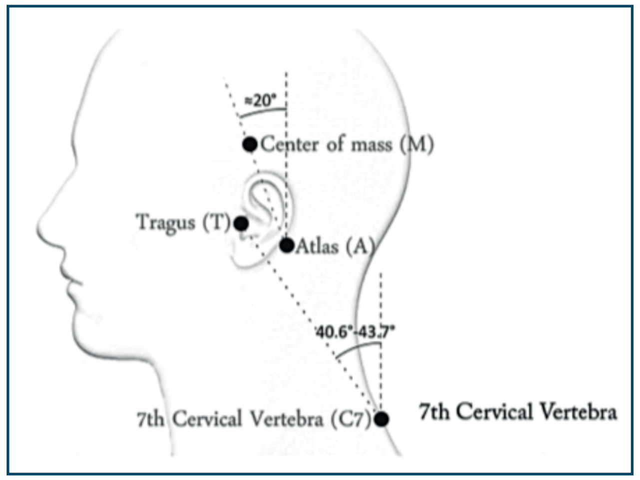


Figure 4.5. Desired angle between the tragus and seventh cervical (Bouwens et al., 2017)

In figure 4.6.it can be seen how in both configurations it is difficult to maintain the recommended angle of 40 to 43º. For 120º, the angle is too low, pushing the head more forward than recommended. For 140º, the angle is higher than the recommended, making the head to fall backwards due to the lack of head support, creating an empty space in the area of neck and head.

As a recommendation for future neck supports and travel pillow, the paper mentions a design that restricts the head movements in yaw, pitch and roll directions with a socially accepted appearance.

They also found that experienced comfort is highest for travel pillows that restrict head movements in all directions in order to maintain a neutral posture. (Table 4.1). Discomfort experience is predicted by observing the number of participants' in-seat movements: more movements resulted in higher experienced discomfort *(Bouwens et al., 2017).*

From the pillows that were tested in Table 4.1, the Embrace sleep collar was the one with lowest number of head movements and the one that caused the least discomfort, while the inflatable travel rest caused the most discomfort and the highest number of head movements.

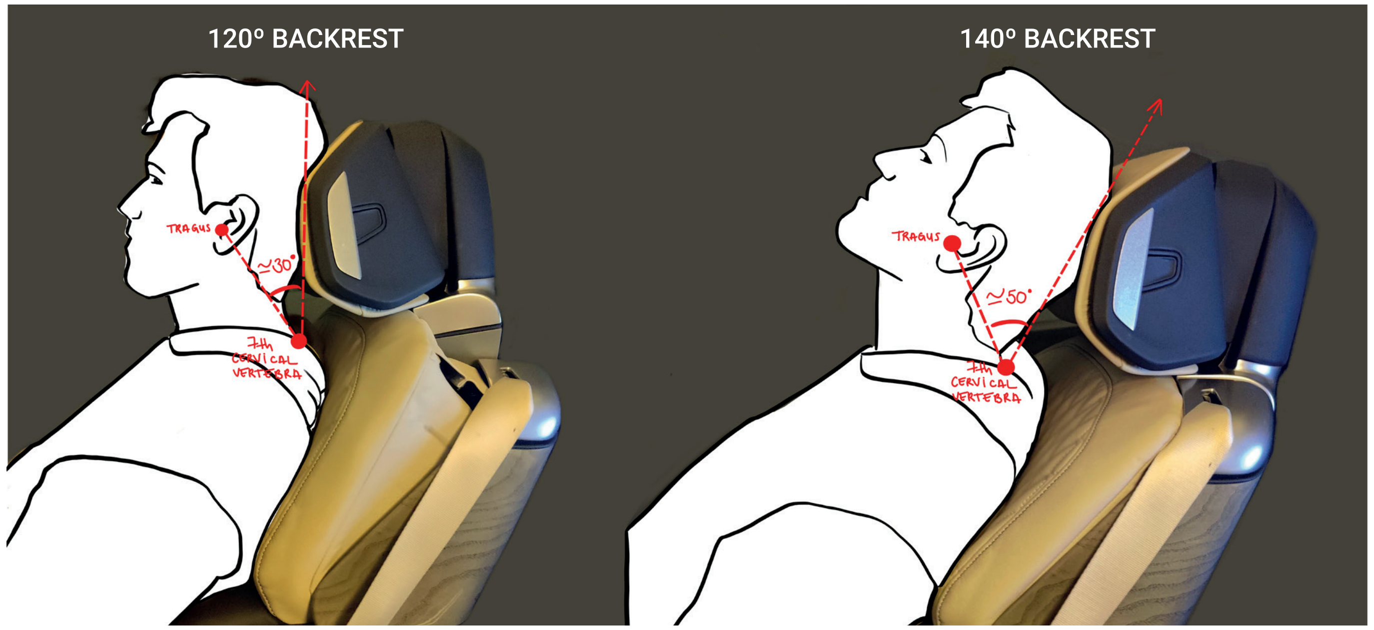
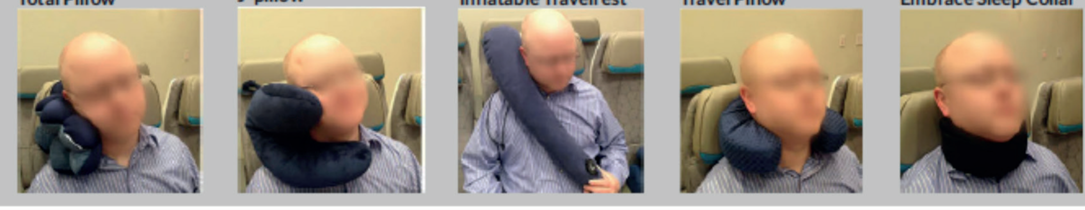


Figure 4.6. Neck curvature range in BMW seat for both backrest configurations



	Total Pillow	J-pillow	Inflatable Travelrest	Carex Memory Foam Travel Pillow	Embrace Sleep Collar
Restricts yaw	+	+	+	+	+
Restricts roll	+	+	+	+	+
Restricts pitch	–	+	–	–	+

Table 4.1. Five head neck supports with different restrictions in head movement. The least discomfort experienced being the "Embrace Sleep Collar" (Bouwens et al., 2017)

Another important consideration when designing the headrest, apart from the shape, is the padding and cushioning, as it is mainly in direct contact with the head, neck and face and they are not covered by clothing (Franz et al., 2012). In their study, it is estimated the maximum pressure between head and headrest with the lower discomfort score per region (Table 4.2).

Additionally, Franz et al. (2012) found for a car seat that approximately 80% of passengers appreciate neck support, while 20% did not. The headrest with neck support should be suitable for tall and small people with different neck size, therefore the neck support and head support created and tested were made height adjustable (Figure 4.7).

Figure 4.7. Headrest with neck support in different positions (Franz et al., 2012)

Body region	Condition	Maximum pressure	Material
Head	lower pressure = bigger discomfort	1,8 kPa - 3,7 kPa	firm foam for the back side of the head
Neck	increasing pressure = bigger discomfort	< 1 kPa	soft foam
Shoulder	average pressure = lower discomfort	2 kPa - 7,6 kPa	firm to extra firm

Table 4.2. Estimated pressure per body area and appropiate material (Franz et al., 2012)

4.2. State of the art

4.2.1. Regulations

With the restriction of compulsory head restraints in vehicle seats since 1969 established by the U.S. National Highway Traffic Safety Administration (The Royal Society for the Prevention of Accidents, 2018), all head restraints must meet the following two standards in terms of performance, design and construction:

- During a forward acceleration of at least 8g on the seat supporting structure, the rearward angular displacement of the head reference line shall be limited to 45º from the torso reference line
- Head restraints must be at least 700mm above the seating reference point in their highest position and not deflect more than 100mm. The lateral width of the head restraint must not be less than 171mm for individual seats (Figure 4.8). The head restraint must withstand a load of maximum 890N.

Additionally, all head restraints must accomplish the Whiplash protection system, which is a protection against whiplash injuries, including the neck extension moment and head acceleration. The test procedures involve simulating rear-end collisions and measuring the forces exerted on the head and neck to determine the risk of injury.

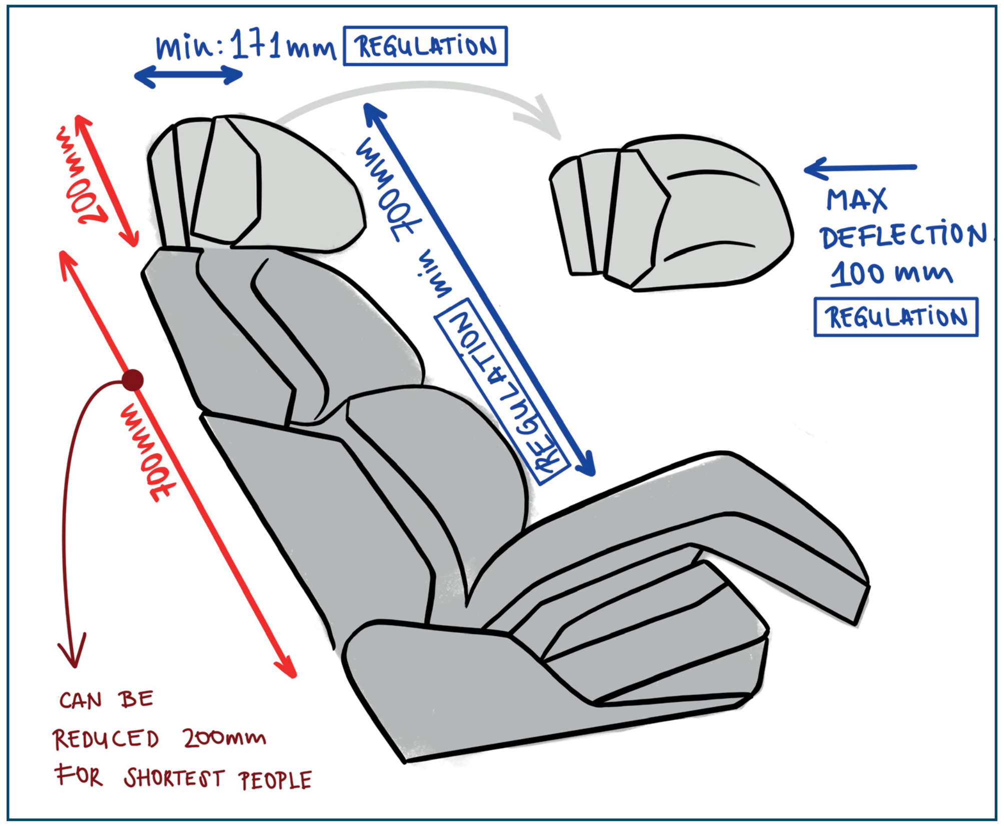


Figure 4.8. Head restraint regulations extracted to BMW seat (in blue the regulations, and in red, the current measures of hte seat)

4.2.2. Headrests in the market

To have a better idea of the current products in the market that helps sleeping while traveling, a board of travel pillows and best headrests designed has been developed in figure 4.9.

From the research, following considerations can be taken into account for the redesign phase:

- » Comfort increases with the integration of pillows with chin support because this avoids the "falling head effect"
- » Pillows with more restrictions in head, neck and chin are evaluated more comfortable
- » Pillows that allow to shape them depending on the body shape allow more adaptability to the user needs than the conventional ones
- » Soft materials such as cotton or velvet are commonly used because they will have direct contact with the body area
- » For neck adjustability, simple and easy to use mechanism are commonly used, such as velcro or straps.
- » According to The New York Times (2024), the ones that restrict movements are the highest in comfort evaluation

Figure 4.9. Headrests and travel pillows in the market

4.2.3. Head restraints in seat vehicles and aircrafts

In order to integrate and develop a travel pillow embedded in the seat, a deeper study of current head restraints integrated in seat vehicles and seat aircrafts is done (Figure 4.10). It is analysed some of the brands that invest more in seat innovation and design, innovations in the field and latest concepts developed.

From this study, following design recommendations can be taken into account:

- Consideration of six-way head restraints because they provide more adaptability to the user
- Integration of a neck support in the headrest for improving sleeping
- Foldable head and neck support such as the ones integrated in aircraft seats
- Follow the aesthetics and shape of the current seat for a seamless integration
- Adaptable head support in height and adjustable to different neck and head sizes

Figure 4.10. Head restraints in seat vehicles and aircrafts

4.3. Ergonomic considerations

4.3.1. Anthropometric variations

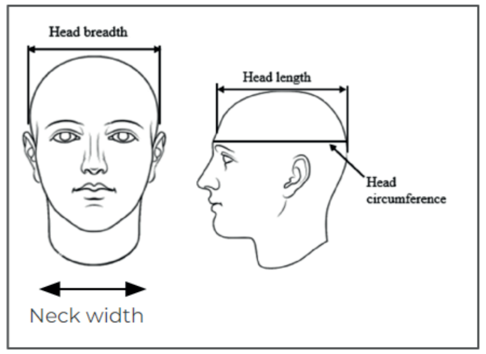
From the previous market research, it will be considered an adaptable head support for different heights, and also adjustable to different neck and head sizes. From this requirement, it will be considered different anthropometric measurements related to the area of the head and neck.

All the anthropometric data mentioned following (in mm) has been retrieved from "Anthropometric data of the population Spanish labor" (Carmana, 2001), "Anthropometric data among four Asian countries" (Abdrahman, 2018) and "DINED Anthropometric database (Dutch population from 20 to 60 years old). The reason of selecting these data is the variations encountered between Dutch population, known for being the tallest population in the world (Business Insider Nederland, 2019), against countries in Southeast Asia, known as the shortest population (Business Insider Nederland, 2019).

NECK AND HEAD BREADTH

Considering the requirement of adjustability of the support for head and neck, variations in head and neck sizes among individuals require accommodating different dimensions. Adequate support for various head and neck sizes is essential for comfort.

Figure 4.11. shows the measures grabbed for each variable. Measures for P05 have been obtained from female Asian anthropometric data, while measures for P95 are obtained from male Dutch anthropometric data. This way allows the adaptability of the product to wider range of population. P50 results in the combination of both Dutch and Asian anthropometric data.



Neck width → neck support adjustment

P05	P50	P95
98	135	173

Head length → head support adjustment

P05	P50	P95
173	190	212

Head breadth → head restraint size

P05	P50	P95
132	146	168

Figure 4.11. Anthropometric data that will be considered for the redesign of the head support (mm). Retrieved from DINED Anthropometric Database (2023) and Abdrahman (2018)

H-POINT

The H-point represents the hip joints location and is a key reference for determining the seating posture. Depending on the seat configuration (mainly on the backrest seat reclination), the distance between the H-point and the top of the head on the same person will vary. Being the higher the reclination, the lower the point of the top of the head. Therefore, in order to calculate this distance, the sitting height from the H-point has been calculated with the BMW seat, with a backrest angle of 140º. This was done by measuring first the participant from its hip to the top of the head. Then, that measure was compared with the H-point height, measured from the hip of the participant placed in the 140º backrest seat to the tallest point of the head placed in the seat. The bigger is the backrest angle, more will be the difference between sitting-height of the participant and the sitting height of the participant considering the H-point.

For more useful results and due to limitations on participants, two users with different anthropometrics have been used (a Spanish male with P95 height regarding the Spanish population database, and a female with P50 height regarding Asian population database) . Ideally, this should be analysed from a P05 Asian female and a P95 Dutch male.

Figure 4.12. shows the results and variations between sitting height and sitting height considering the H-point of the seat.

» The results indicate that the head restraint of the seat should reach at least a distance of 661mm (lower if considering P05 of Asian female population) from the H-point to the tallest point of the head restraint. However, in the current seat, the minimum distance from seat pan to the lowest point of the head restraint is 700mm.

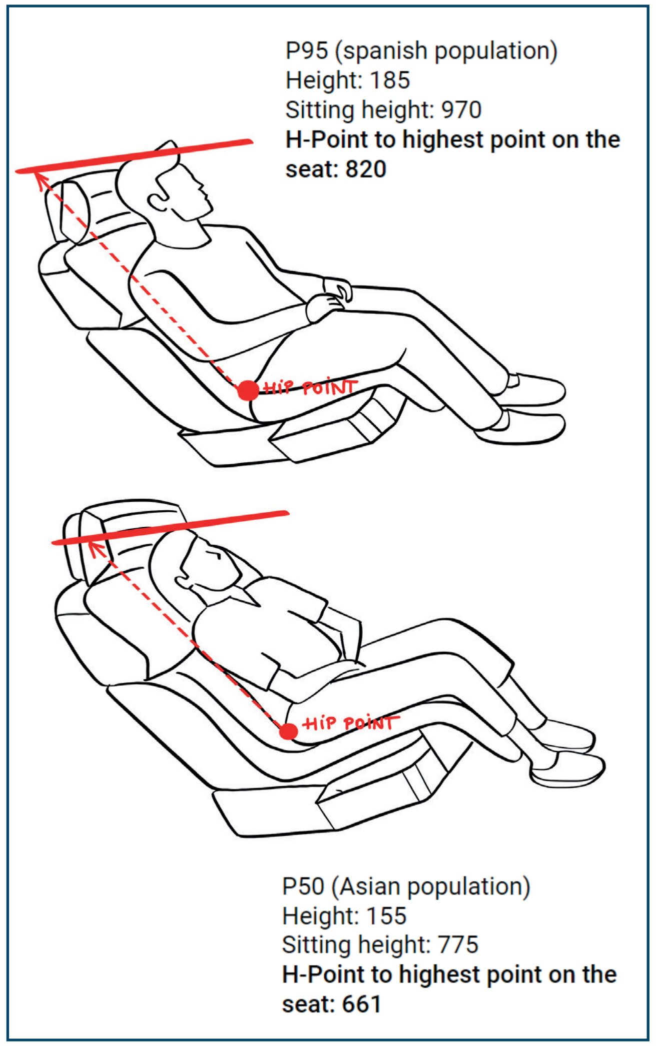


Figure 4.12. H-point variations in two different user groups

Additionally, it is also important to consider the "7th cervical point sitting" measure, in order to determine where should be placed the head support. This measure was only found in "Anthropometric data of the population Spanish labor" (Carmona, 2001). (Figure 4.13). Depending on how it is adjusted the support, different percentiles will be considered.

7th cervical point sitting

P05	P50	P95
549	631	746

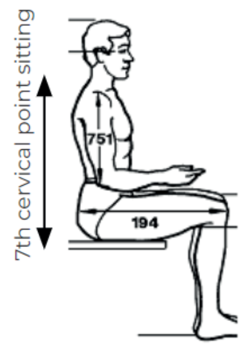


Figure 4.13. 7th cervical point sitting (Carmona, 2001)

4.4. Conclusions

Considering the regulations of the head restraints, the backseat height can be reduced in order to place the head restraint in a lower position and have a higher height range. This way, shorter people will be able to reach the head restraint without being uncomfortable. If not, the head support should be adaptable to lower heights. The main developments on head supports are integrated in seat aircrafts. They can adjust in height and supports the head with foldable mechanisms.

From literature research, a better neck and head support should be necessary in order to maintain a comfortable angle between the tragus and the 7th cervical vertebra. From the observations, the desired angle of 40º can't be obtained in any of both configurations. Therefore, there is a preference from the users that reach the head support of using a pillow.

In Figure 4.14, different insights from the chapter will be considered as requirements for further redesign.

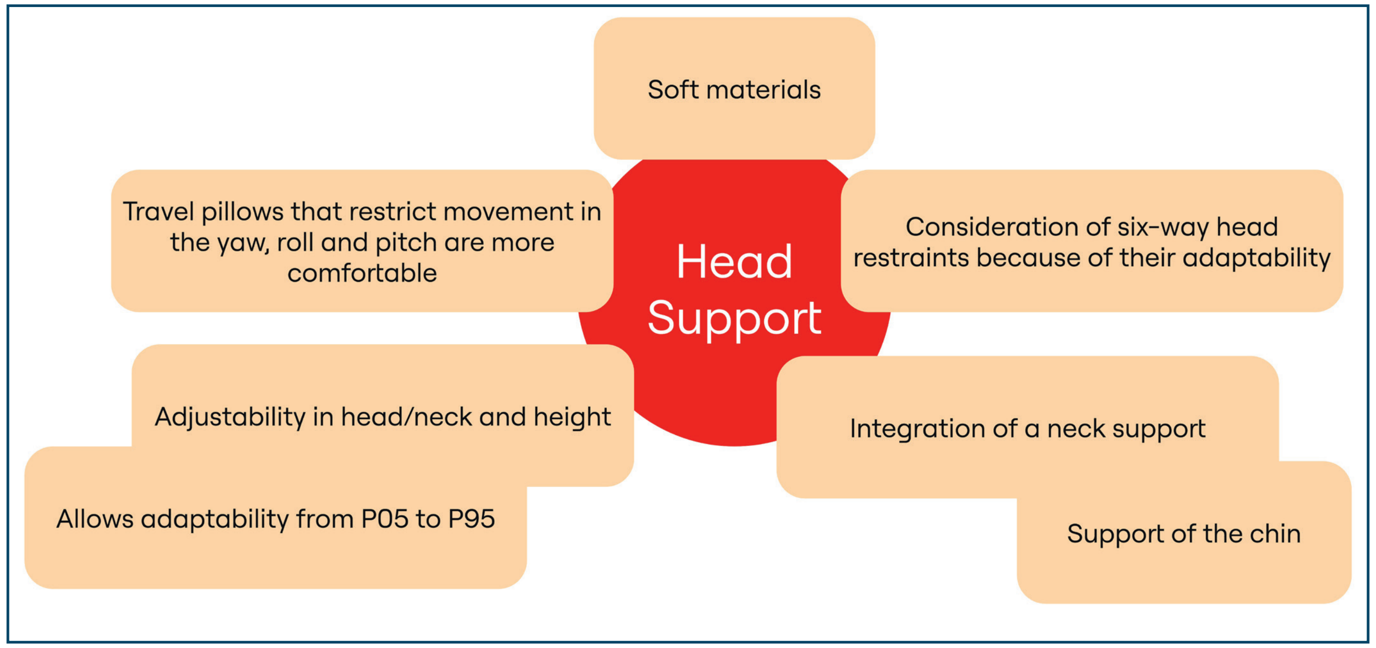


Figure 4.14. Main insights from the chapter as design recommendations

5 Ideation & Development

For the ideation phase, different steps have been followed, first, a design vision has been developed following the ViP method, and a more concrete design goal has been established. From that, a list or requirements is stablished extracted from the previous chapters for the design. Last, the first ideas are shown and explained.

5.1. Design Vision

To develop a vision statement, the ViP method explained in Chapter 1.4. was followed. First, the current product and interaction with it is deconstructed in Figure 5.1. Then, it is defined a possible future within the new product, by stablishing the design domain, identifying relevant context factors, and clustering these by creating relationships between them.

A wide variety of context factors were collected from different disciplines (environmental science, material science, user behaviour, regulations) extracted from the previous research, and have been clustered in different factors in Figure 5.2.

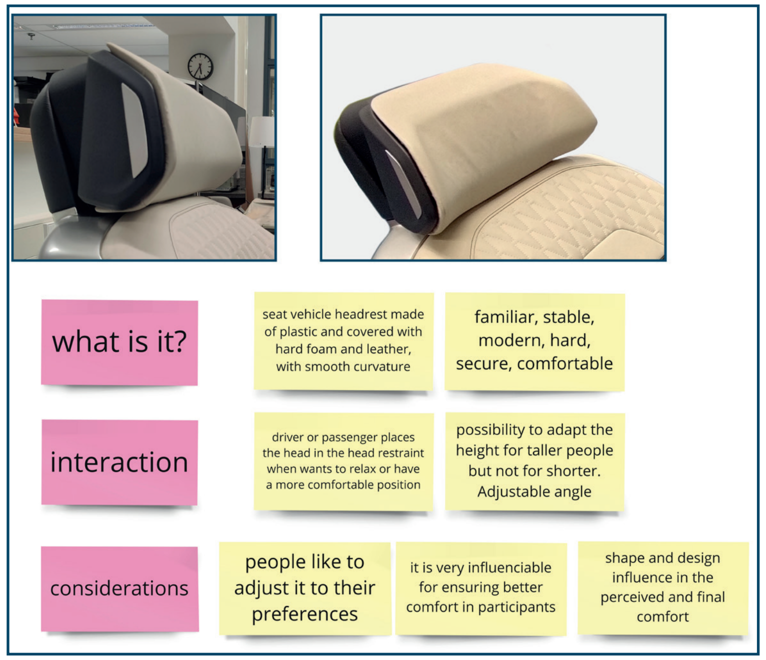


Figure 5.1. Deconstruction of current product

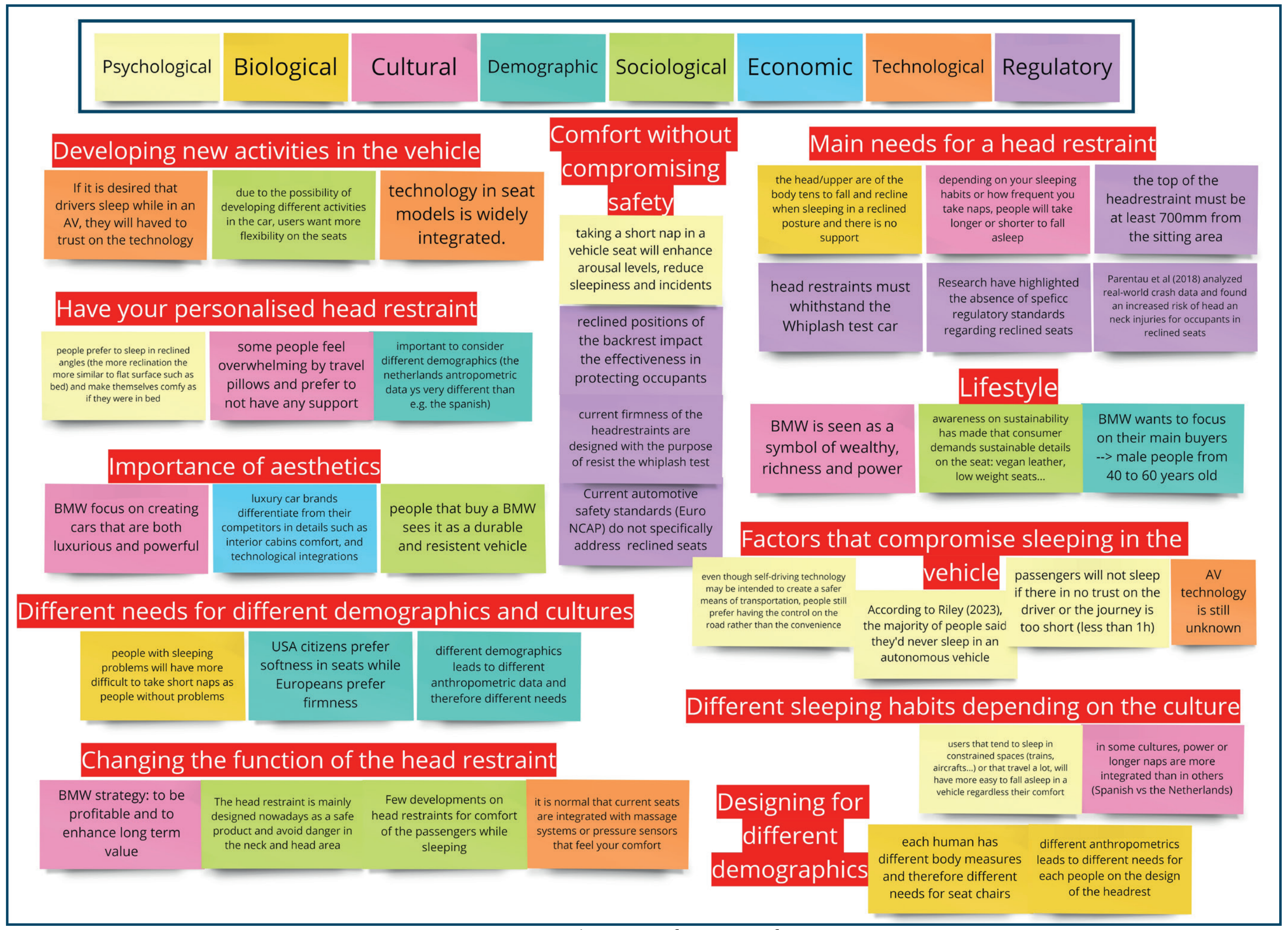


Figure 5.2. Clusters of context factors

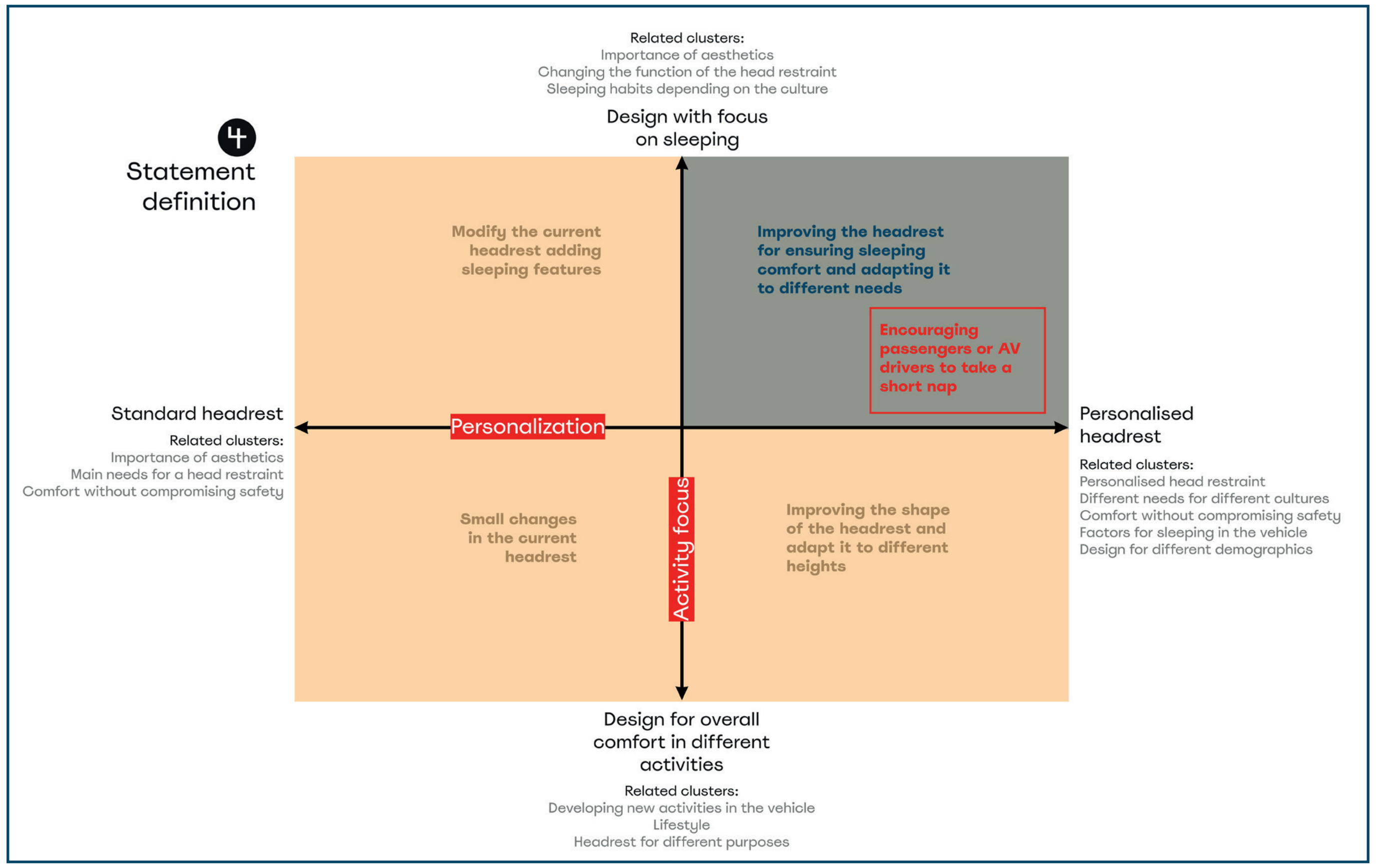


Figure 5.3. Context factor matrix

By plotting the clusters, two main separations could be done in order to choose the direction of the design (Figure 5.3). On the axis the following opposites where plotted:

- Design of a headrest focusing on the sleeping comfort, or design for improving the comfort overall and fort different activities
- Design a personalized headrest, focusing on different cultures, demographics and needs, or develop a more standardized headrest.

However, due to the needs observed in the user test, combined with the interest of BMW in improving the comfort for sleeping, the main problem of the seat is the lack of possibilities to adapt it to different users. Because of that, designing a personalized headrest with a focus on sleeping is the main objective of the design.

All things considered, the following vision statement in Figure 5.4 was created.

For a better understanding of the vision, the following moodboard of Figure 5.5 is created for having in mind the ultimate goal of the future design.

Improving sleeping comfort in automobile seats and enhancing the journey by **redesigning the head restraint**, developing an **adjustable head and neck support that adapts to different user's needs**, ensuring among others a restful sleep

what do I want to achieve

means

goal

Figure 5.4. Vision statement

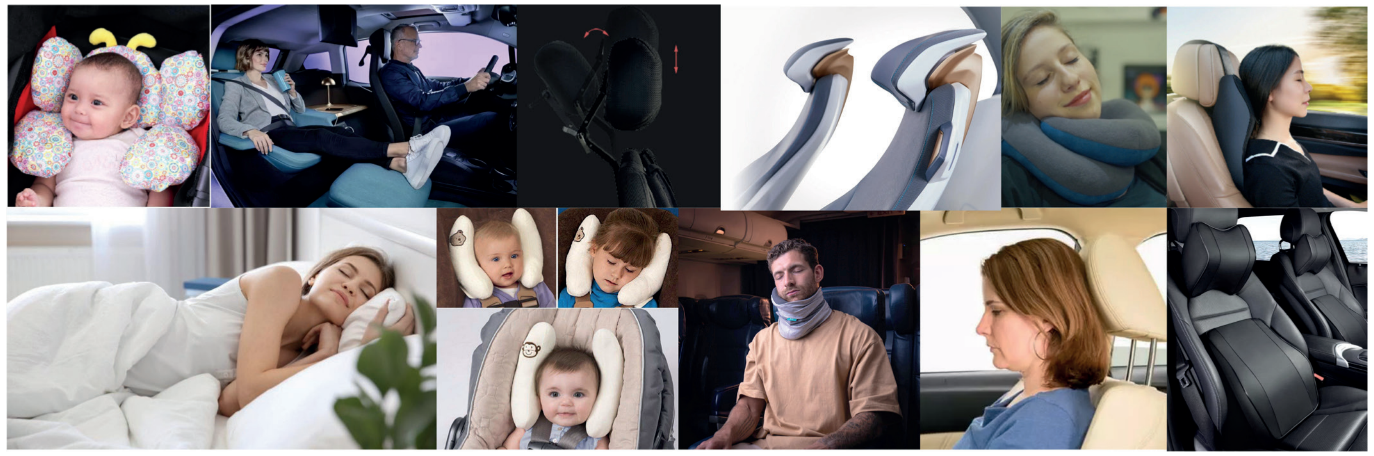


Figure 5.5. Vision moodboard

5.2. Design Goal

From the design vision, a more measurable and specific goal for the rest of the project should be done. For this, the SMART framework is used, developing a design goal that is Specific, Measurable, Achievable, Relevant and Time-bound (ProductPlan, 2022):

The goal is to redesign the headrest of BMW current seat considering future autonomous vehicles and current passengers, in order to improve the sleeping comfort and the time they take to fall asleep.

Therefore, it is necessary to develop an adjustable headrest to the height, neck shape and head width of the users, while following all head restraint regulations.

The idea is that proper support in the upper area of the body, while avoiding falling head effect, will improve sleeping comfort over time.

5.3. List of requirements

All data obtained from the analysis phase, observations from the sleeping test and further research has been combined in a list of requirements for the design of the head support. The full list of requirements can be seen in Appendix G. However, the most important criteria has been selected for having it present during the ideation and concept development.

SLEEP

- The design enables changes of posture while sleeping

SLEEP AND SHAPE

- The design should support the head while sleeping, avoiding "falling head effect"

FUNCTIONALITY

- Head restraint should be adjustable in height and width of neck and head. The range is determined by the anthropometric measures obtained in Chapter 4.3.
    - * Ideally, neck support should be adjusted from 98mm to 173mm and head support should adjust from 132 to 168mm.
    - * Height adjustment should have a range of 200mm, considering the H-point sitting measured in the seat.
- The headrest should be comfortable for different postures

- The headrest is intuitive to use for the occupants
- The design improves comfort when sleeping for long periods of time
- The design should offer a 360º support on the area of the neck and support part of the head/face

SAFETY

- The design follows the current head restraint regulations

AESTHETICS

- The design can be easily integrated in the current seat
- The perception of comfort is integrated in the seat

ERGONOMICS

- The design considers the anthropometric variability of users
- The design follows the natural curvatures of the spine, neck and head

5.4. First ideas

As analysed in chapter 3 and 4, the head restraint of the current seat is the main discomfort problem in order to have a better sleeping. However, improving the comfort of the head and neck support can be achieved in two different ways: by changing the current head restraint system and adding a more adequate one, or by implementing a travel pillow into the seat, without the need of making further changes to the current seat. Both options are analysed in Figure 5.6. in order to choose the best one for the current seat.

As analysed in chapter 3 and 4, the head restraint of the current seat is the main discomfort problem in order to have a better sleeping. However, improving the comfort of the head and neck support can be achieved in two different ways: by changing the current head restraint system and adding a more adequate one, or by implementing a travel pillow into the seat, without the need of making further changes to the current seat. Both options are analysed in Figure 5.6 in order to choose the best one for the current seat.

The pros are analysed in green while the cons are analysed in red. After studying both possibilities, and due to the limitations of the project, it is chosen to develop an external pillow that can be added into the current seat, without the need of making additional changes to it.

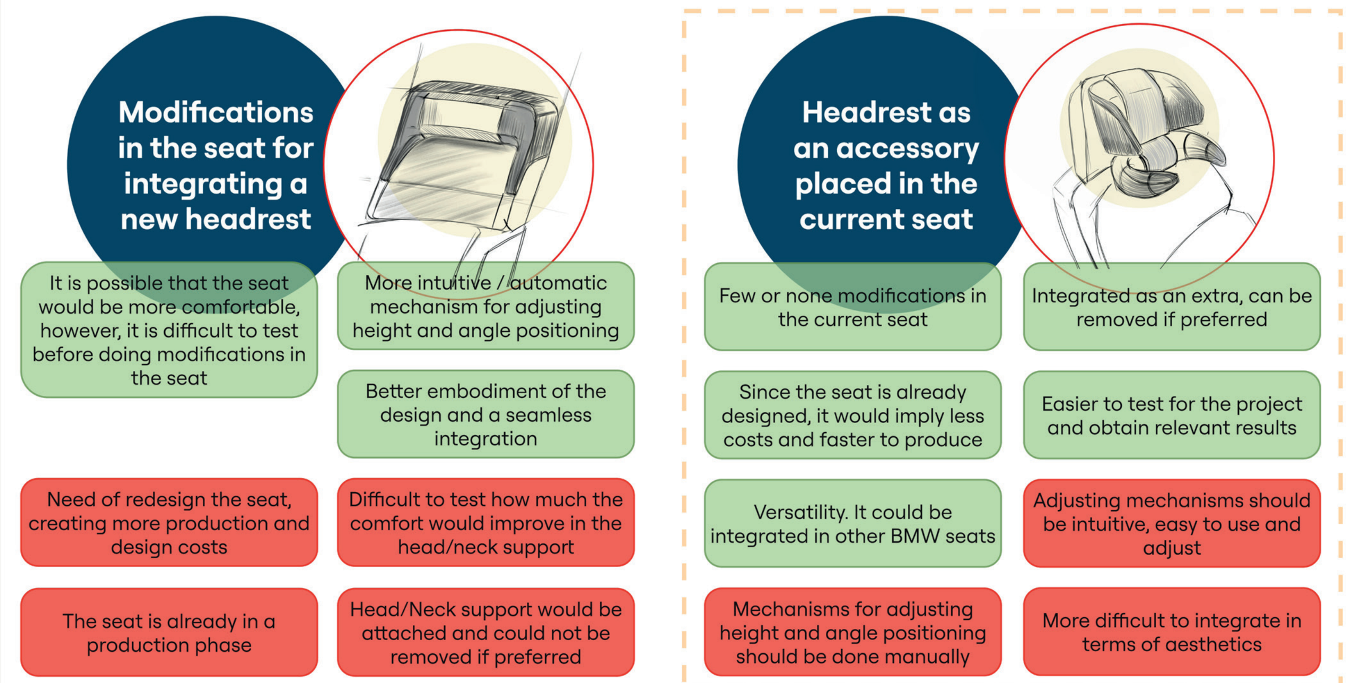


Figure 5.6. Pros and cons: different posibilites of integrating the head support

The main reasons for this choice is the current development and production of the seat. Designing a separate headrest as an accessory is more cost effective than having to modify existing seats or having to produce new ones with the proposed requirements, reducing production costs.

An external headrest increases versatility to use it across different seat models and car types. Additionally, it could be adapted in different vehicles seat without the need of modifying them.

External pillows that are added to car seats are widely seen in the market. They are usually easy to install and remove. A detachable headrest gives the option of adding it when preferred without affecting the entire seat, increasing the ease of maintenance and can be easily replaced.

Lastly, an accessory headrest minimizes changes to the entire seat assembly. Therefore, the seat's safety feature won't be affected.

For the development of the external head restraint, different areas of the design should be considered separately for the development of a better head support, already mentioned in the List of Requirements. First, from the requirements, and due to the time scope of the project, the head restraint design should consider:

- Adjustability in:
  - Neck and head width
  - Angle of reclination of the head restraint
  - Height
- Allow posture variations
- Not being uncomfortable when not sleeping

Appendix F shows two mindmappings developed for a better overview of different considerations regarding the different areas of the head support. For a better clarity in the design process, the adjustability of the head restraint has been studied separately. It offers iterating and refining each aspect of the design independently, giving more importance to the ones that will mostly affect the comfort of the user. In the following sections, each area is explained in detail.

5.4.1. Head and neck support shape for sleeping

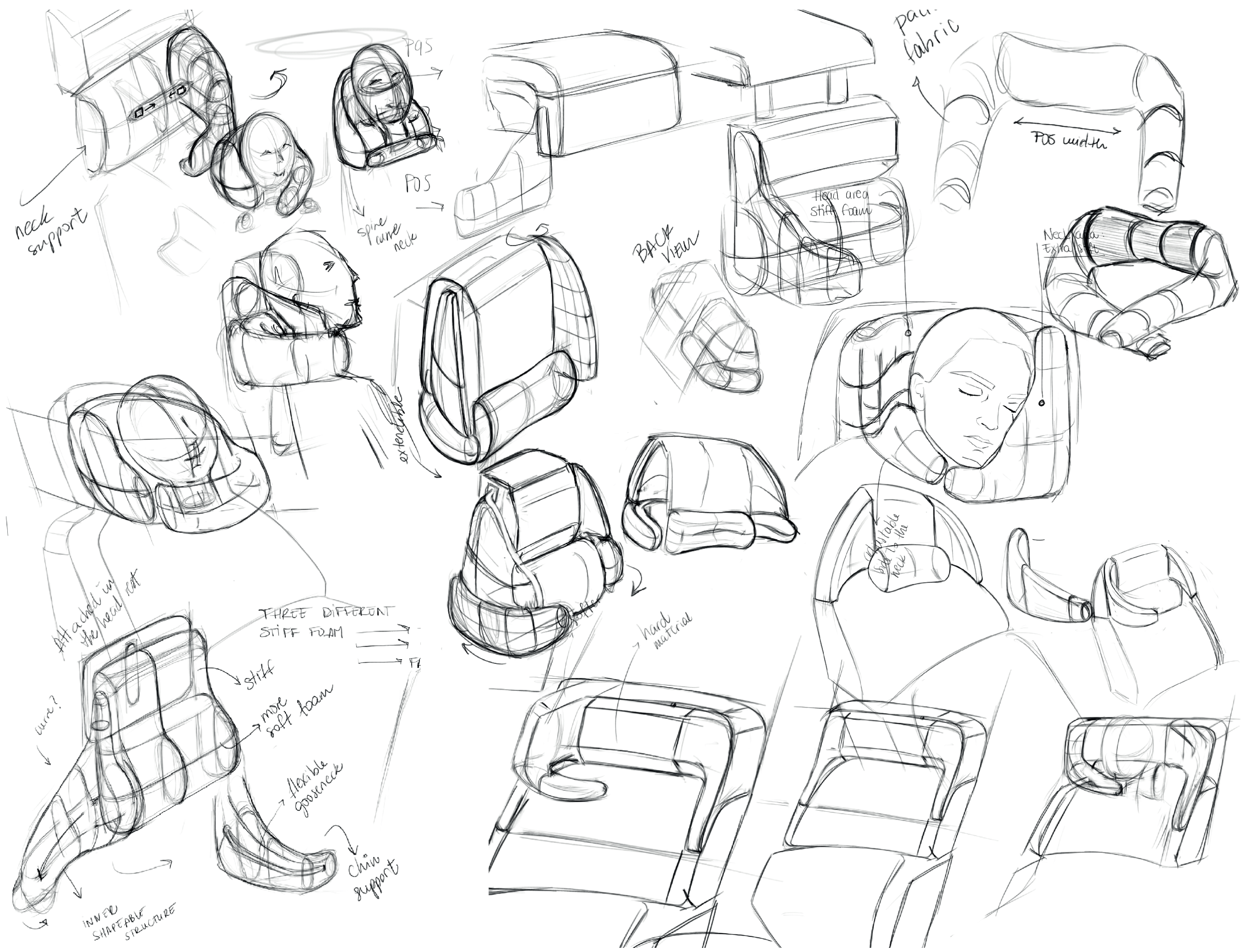


Figure 5.7. Initial ideation sketches

The first aspect of study is the adjustability of the concept considering the head and neck. This was one of the main problems observed in the sleeping study, since participants woke up during the nap due to the lack of support in head and neck. Figure 5.7. shows initial sketches done for this requirement.

IDEA 1

The first idea (Figure 5.8) is to integrate extended wings at the lateral sides of the head by using thorough sliding mechanisms that can adapt to the width of the neck and the head. The wings can be extended (when not using them) or foldable for placing these around the neck with hidden hinges inside the wings. This idea offers an adjustable system for differences in anthropometrics. However, there should be a sliding mechanisms incorporated in both wings, which makes it difficult to hide them and therefore dangerous for the user.

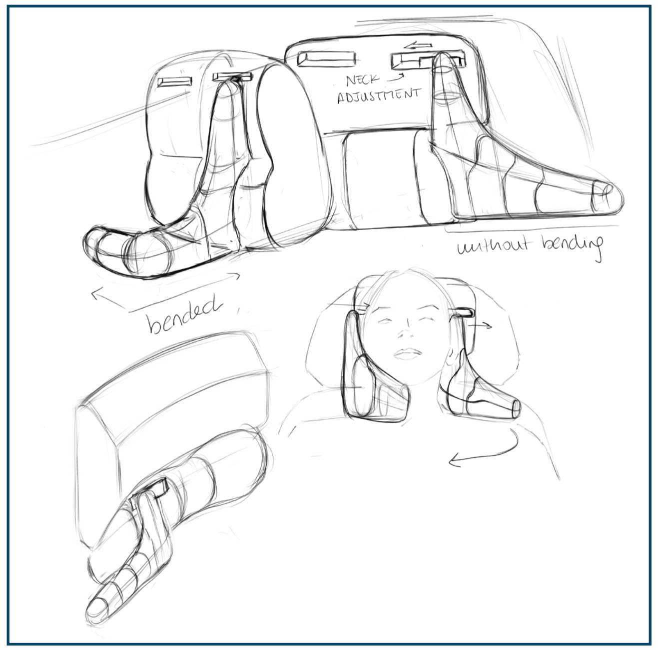


Figure 5.8. Idea 1. Foldable wings with sliding mechanisms

IDEA 2

The second idea (Figure 5.9) consists of integrating a massage system in the neck support area while having light foldable wings that can be wrapped around the neck area and tight together to develop a neck support. As shown in the literature research, it has been proven that comfort improves with massage systems in the neck and back area when sitting for long periods of time. However, the benefits have not been tested while sleeping and it might disturb the user when trying to sleep.

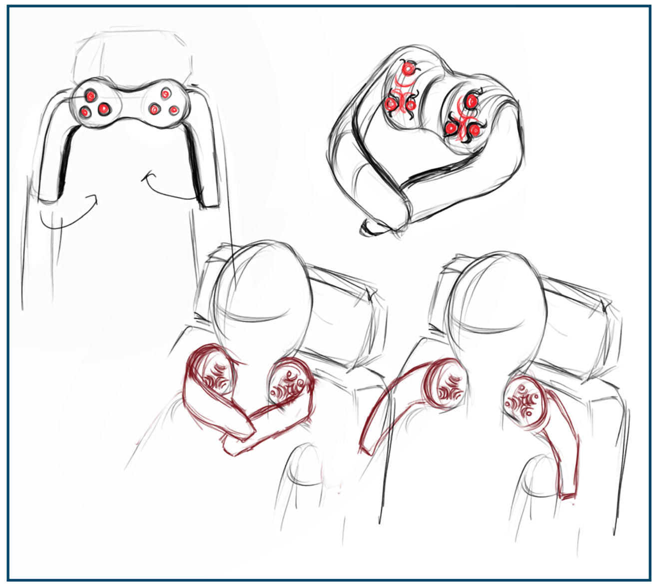


Figure 5.9. Idea 2. Massage system in neck support

IDEA 3

The third idea (Figure 5.10) is to integrate extended wings from the head support laterals, that can be folded with a flexible tube or "gooseneck" around the neck, and adding an additional rear neck support. The design would count with less components and hidden mechanisms, and the lateral wings allow adjustability of the neck and head width. The idea can follow the shape of the current seat making it easy and aesthetic to integrate. However, when using the wings can create an oppressing effect since it covers a great area of the head.

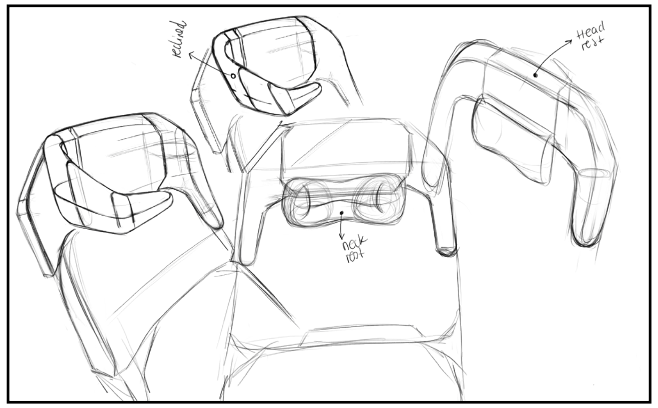


Figure 5.10. Idea 3. Foldable extended wings from the head support

IDEA 4

The fourth idea (Figure 5.11) is similar to the previous one, but the area of the head support is divided from the neck support. The user can choose to use the headrest or the neck rest and the internal flexible tube allows adjusting the wings to the preferred width. However, the mechanism and the shape should be tested for comfort and not create discomfort while not using it.

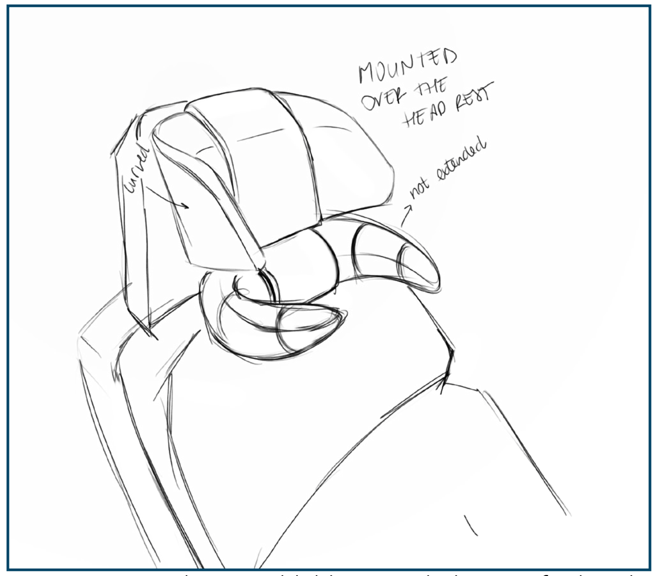


Figure 5.11. Idea 4. Foldable extended wings for head and neck support

5.4.2. Concept selection

All the four concepts are evaluated using a Harris profile (consists of a visual representation of the strengths and weakness of the ideas, based on a number of criteria and representing this visually (Delft Design Guide, 2020)). The criteria are based on the list of requirements in Chapter 5.3, choosing the 10 ones considered most important for the selection of the shape of the product with a focus on the support for head and neck support. The criteria are focused on functionality for comfort sleeping, shape integration into the seat and ergonomics. The Harris profile can be seen in Figure 5.12.

Due to the lack of previous user testing of the ideas and further development of them, the scores of some criteria are made subjectively, considering research done previously, current products in the market and reviews, and thinking on their functionality in a real scenario.

	Idea 1				Idea 2				Idea 3				Idea 4			
Requirements	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2
The design is easily integrated in the current seat	■	■				■					■	■			■	■
Neck and head support can be adjustable to different anthropometrics			■	■			■				■	■			■	■
The design has an aesthetic appearance similar to the seat	■	■				■				■				■		
Mechanisms can be integrated easily in the concept within the time scope	■	■			■	■					■				■	
The design adapts to the shape of the seat and does not take more than the necessary space			■	■			■				■				■	
The shape of the headrest is not overwhelming when folded and different postures are allowed			■	■		■				■					■	■
The design avoids falling effect while sleeping			■				■	■			■	■			■	
The mechanisms integrated are safe, easy and intuitive to use	■	■					■				■	■			■	■
The design enables easy repairability and cleaning of the product		■					■				■				■	
The design supports the head and neck equally and provides comfortable placement of them			■	■			■				■				■	

Figure 5.12. Harris Profile for selection of the idea

In terms of integration within the seat, idea 3 and 4 can be integrated better due to the lack of complex mechanisms such as idea 1 or a massage system in idea 2. For the head and neck support criteria, idea 2 is the one that offers less support in the head. Regarding the aesthetics similar to the seat, all the ideas are graded negative since it is necessary a further prototyping and integration in the seat to check their aesthetics, since all 4 imply adding extra material to the seat. However, 1 and due to the amount of visible mechanisms is the worst graded. For the same reason, when evaluating the mechanisms in each idea, it is also the worst graded since the mechanisms will not be hidden. For adaptability to the shape of the seat, idea 3 and 4 are the best graded since they offer more variability of shape for adapting them to the current seat.

The shape of the headrest is also analysed when folded and if it offers different postures without being overwhelming. Idea 2 is evaluated negatively since both wings of the neck support need to be attached and would block from moving to different postures, and idea 3 offers the same grading because it covers both face, head and neck. However, regarding avoidance of falling effect when sleeping, idea 2 and 3 are expected to fulfill this the best since they cover all the neck area. In terms of safety of mechanisms and easy of use, idea 1 is the worst graded since are visible and idea 3 and 4 are better graded because the lateral wings can be fixed while in idea 2 both wings need to be attached. Finally, for support of head and neck and comfortable placement, all ideas should be tested for comfort evaluation, but all 4 are designed for supporting the head and neck.

Taking a visual look at the Harris profile, idea 3 and 4 have better scores compared to idea 1 and 2. These ideas have similar structures for folding the wings that provide head and neck support, but the main difference is that in idea 4 it is possible to fold the head or the neck support, while in idea 3, both areas are combined.

Since from the evaluation both ideas have similar weights, both are chosen for further development, prototyping and user testing in order to check which shape provides more comfort for sleeping and for placing the head and neck in a relaxed position,

5.4.3. User test, concept shape

After choosing both idea 3 and 4 for further development, a short user test was set up in order to define which shape and system for placing head and neck was more comfortable, and if the comfort was improved by adding the extra head support instead of the current design.

Two fast and low fidelity prototypes were made (Figure 5.13 and Figure 5.14) from the previous ideas 3 and 4.

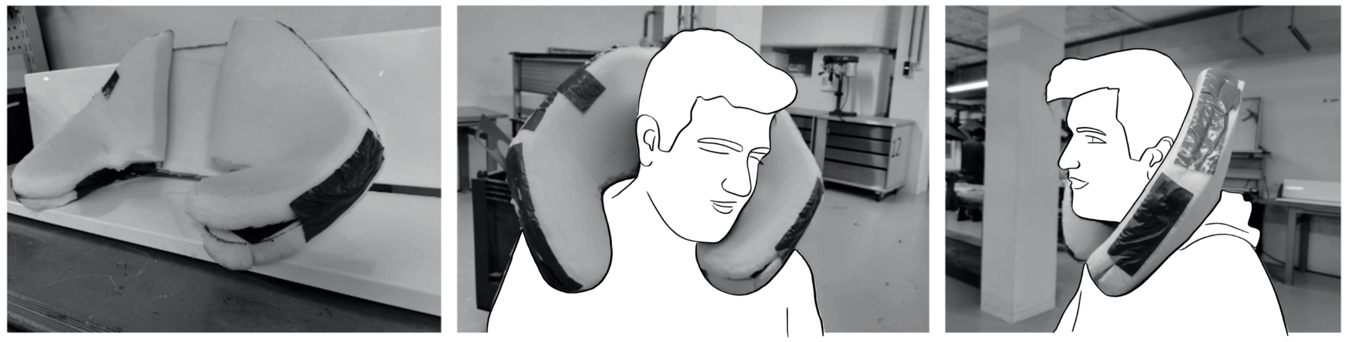


Figure 5.13. Prototype idea 3

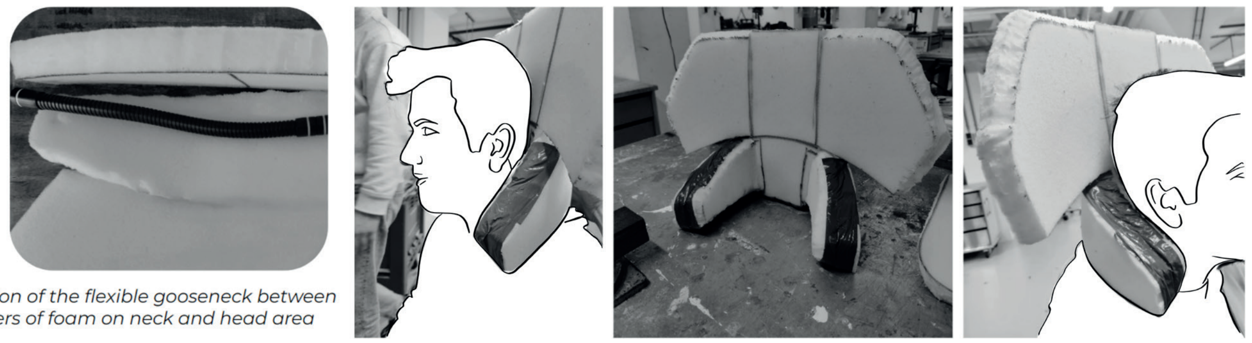


Figure 5.14. Prototype idea 4

The test was performed in the same seat in which the sleeping research was done, and the prototypes of the head support were added to the seat by tape to the current head restraint. Since the main motivation for the user test is to check the shape of the head support and select which one is more comfortable, height or angle adjustment were not tested.

Five participants were involved in the test, all between the age of 20 to 25. (3 female and 2 male). Additionally, all participants had already participated in the 30 minutes sleeping research. The backrest angle varied independently of the participants, being two times 120º and three times 140º. The participants were asked to relax in the seat for 20 minutes (figure 5.15) and to watch a video on their phones. During the first 10 minutes they tried one of the two head supports, and the head support was changed for the last 10 minutes. After experiencing both headrests, they were asked to score the comfort of each of them on a scale from 1 to 10, being 1 not comfortable and 10 very comfortable. Additionally they were asked to evaluate how easy and how intuitive it was to use the headrests and to fold the wings and accommodate them to the desired area. Other questions about what could be improved in the shape of the headrest or adjustment of the sides were done. The complete questionnaire can be found in Appendix G.

From the results and the question "Which headrest do you prefer for sleeping?" four out of five participants preferred concept 2 (headrest with separation from neck and head), and only one participant preferred concept 1 (headrest and neck support united). Some of the main insights for the preference of concept 2 was "the possibility to bend the headrest, the neck support or both if preferred", the shape felt more comfortable and natural for the head and neck, or that when not being used, it was more comfortable. Regarding concept 1, it was mentioned that when not using it, "the lateral sides that bend are uncomfortable in the back" and three participants mentioned that when bent, it covers too much the face and the neck and can be overwhelming. Some of the main insights can be found in figure 5.16.

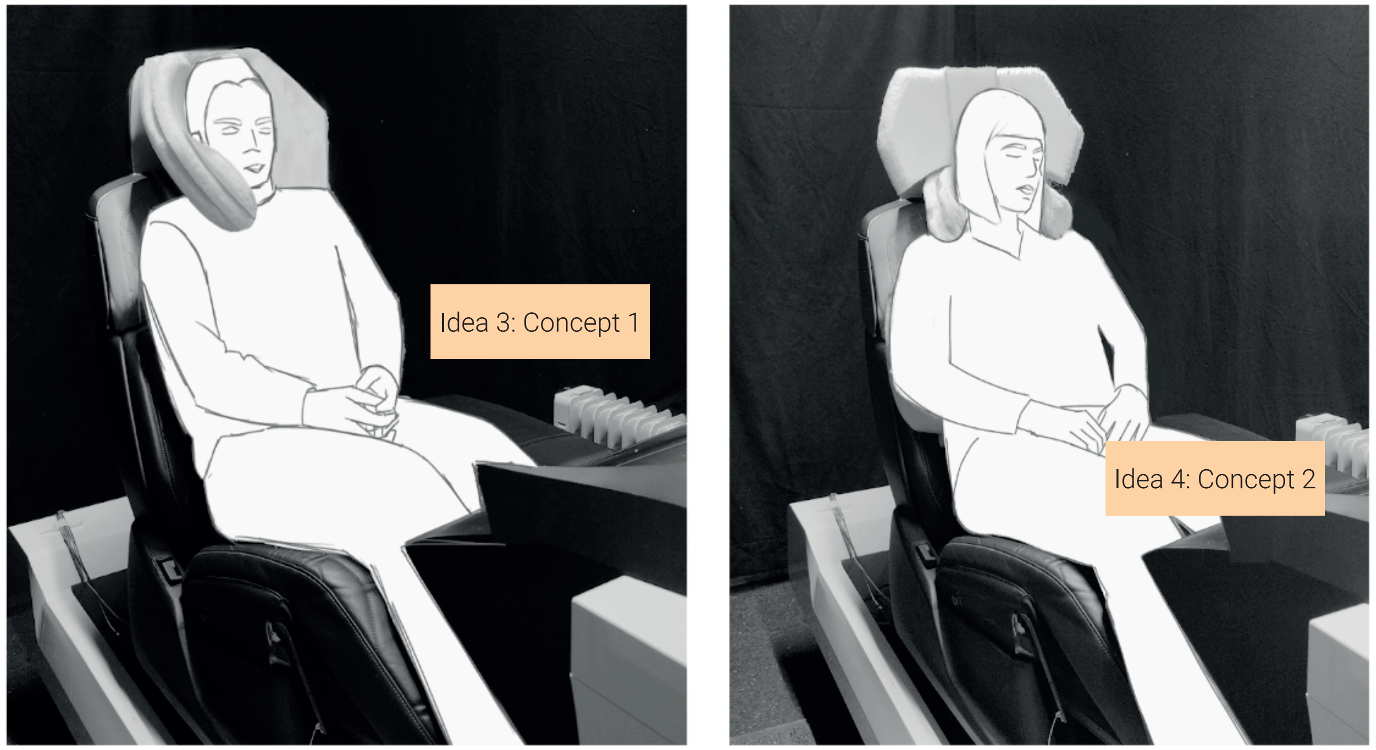
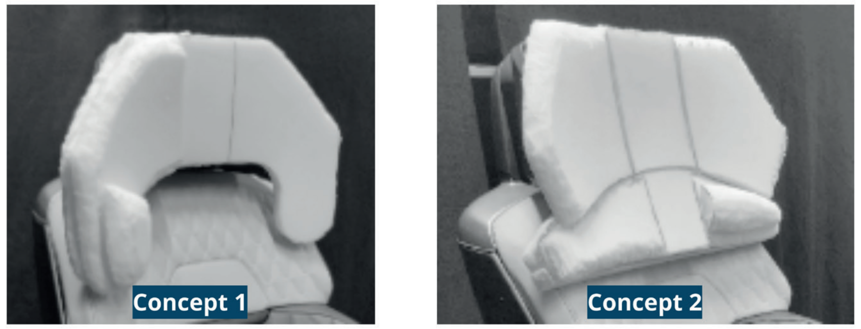


Figure 5.15. Participants testing Concept 1 (left) and Concept 2 (right)



"It supports the head and neck with a comfortable shape"

"The neck support when bended hold my chin as a travel pillow"

"The edges crash with by back so it makes it annoying when not using it"

"It can be a bit overwhelming when I bend both wings"

"I don't like to have support on the area of the face so I like that I can only bend the neck support"

"I prefer the shape of this neck support as it bends better to my neck"

"It already improves comfort even without bending it"

"It does not cover all the neck and does not support the chin so maybe by head still falls down when sleeping"

Figure 5.16. Insights from participants regarding both concepts

From the mean comfort of both headrests, concept 2 is graded with higher comfort than concept 1 (Figure 5.17). However, all five participants prefer to relax and sleep with any of both headrests rather than without the headrest. Regarding the question "How intuitive it is to adjust the headrest and bend it" it was mentioned that more information was needed regarding that it was possible to bend, but once it is explained how, all participants could bend it without problem.

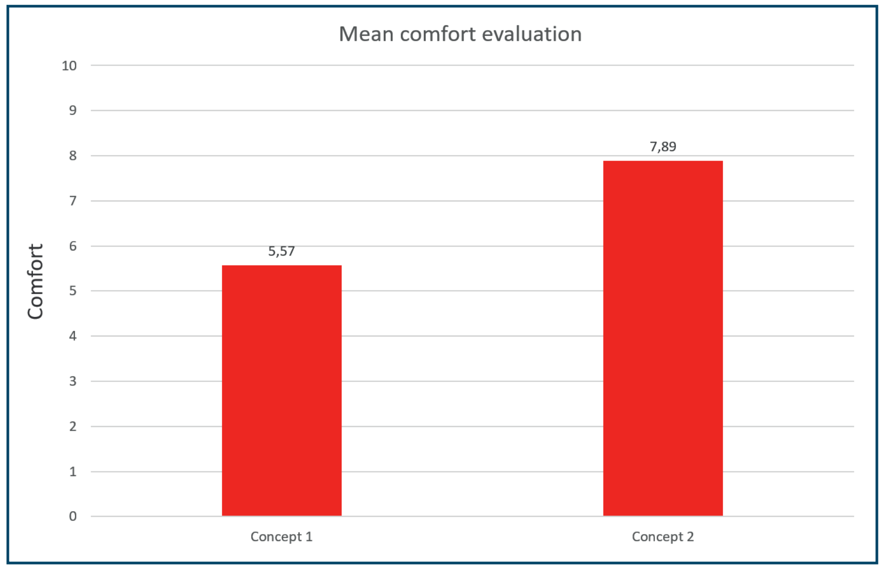


Figure 5.17. Mean comfort of both concepts, being 0 not comfortable and 10 very comfortable

DESIGN OPPORTUNITIES

FOR CONCEPT 1 (Figure 5.18)

- Placing the wings of the head support more inclined to avoid discomfort on shoulders
- Adding a small neck support
- Place the interior structure united from one extreme to another for a better bending, and not only the extremes, as it was done for the user test

FOR CONCEPT 2 (and further development) (Figure 5.19)

- For a more intuitive use on how to bend the headrest, make a distinction between the area that is fixed and the part that can be adjusted, in terms of material, colours or shape.
- For an easier bending of the wings, fix the middle area of the head support to the seat so when wanting to adjust the neck support, it is easier to grab both laterals.
- Design the neck support in a way that when it is not being used, creates contact with the shoulders without making it uncomfortable.
- The interior structure or "gooseneck" needs to support the weight and be able to deform in one direction for adjusting to head and neck.
- For 140º, reclining the headrest upwards could improve comfort avoiding that the head is too much reclined (further testing would be needed)
- Size can be reduced. There is too much space left from the upper part of the head till the highest part of the headrest.
- None of the concepts would prevent the "falling head effect" when sleeping in a 120º backrest reclination, since the wings do not cover the chin area. Making the wings of the neck support longer would imply worse integration of the design.

Concept 2 is preferred by participants due to the opportunity of bending either the head support or the neck support depending on the preference, and because the head support once adjusted, felt more natural. Therefore, this shape will be further developed and tested.

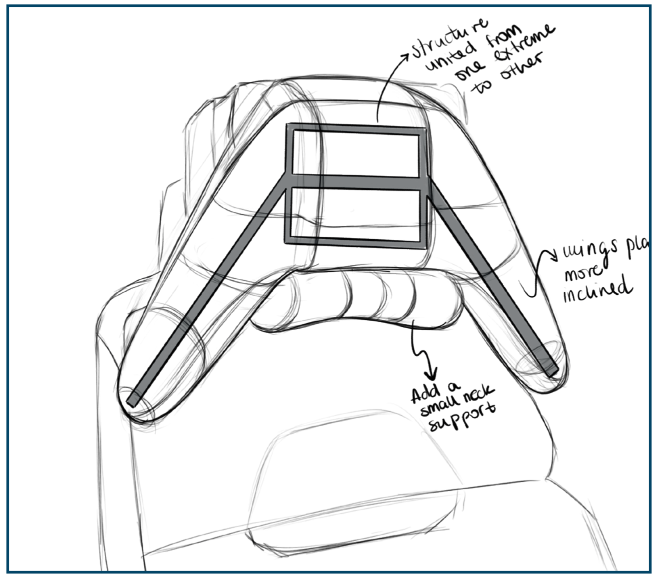


Figure 5.18. Design opportunities for Concept 1

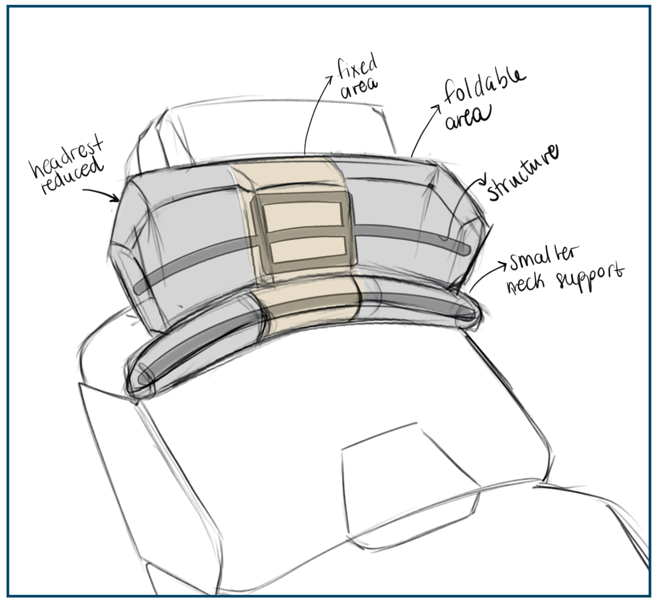


Figure 5.19. Design opportunities for Concept 2

5.4.4. Height adjustment

Once the design shape of the product is defined, it is important to focus on one of the main issues from the sleeping research: most of the participants were uncomfortable since they could not adjust the head support to their desired height, and in most of the cases, the head support was placed too high for their stature.

Taking into account that the head support would be attached to the current seat as an accessory, some requirements need to be taken into account for developing a height adjustment that fits to the design.

- Height adjustment will be done manually. In the current seat, the head support can be adjusted higher for taller people but not for short people. This adjustment is done automatically. For the ease and simplicity of the design, and since it is not integrated in the seat, the adjustment needs to be done manually.
- The height adjustment needs to be intuitive for the user. When doing the first sleeping research, some participants tried to place the headrest to the height of their heads, but this was not possible. From the design, it should be clear for the users that the height can be adjusted.
- The integrated mechanism should be easy and comfortable to use. It needs to be considered what type of mechanisms are integrated currently for the adjustment on seats and try to adapt them to our design. Additionally, it should not involve extra effort for the user, since they want to be relaxed.
- The mechanism should be resistant. It needs to resist the force and weight of the head and neck area that will be supported by the design.
- It needs to be safe for the user. Dangerous mechanisms must be hidden.
- Lastly, the design should be adjustable for different heights.

Some initial ideas are developed:

USE OF MAGNETIC BUTTONS / VELCRO

As seen in figure 5.20, the idea consists in integrating magnetic buttons in different heights on a plate attached to the seat, and when it is desired to adjust the height, remove the design and place it on the desired level of the buttons. However, the concept implies removing each time the head support from its place and having to put it again in the desired adjustment. This would not be comfortable to the user since might not be intuitive

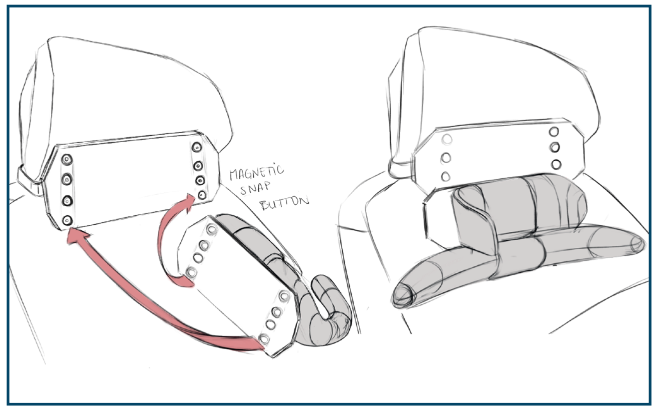


Figure 5.20. Use of magnetic snap buttons

Similar idea to the previous one is the use of velcro for placing the headrest in the desired height of the plate attached to the seat. However, the working mechanism is similar and velcro wears out after some uses and would not stick anymore.

POSITION RATCHET MECHANISM

Current head restraints integrate this mechanism in order to adjust the height. By pressing a button, the height can be adjusted to 3 to 4 different levels. Figure 5.21 shows how the mechanism would be integrated. However, it can be difficult to integrate in an external headrest.

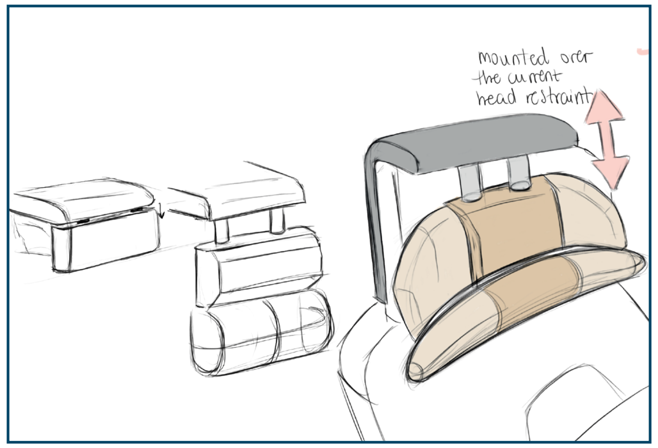


Figure 5.21. Use a position ratchet mechanism

FLEXIBLE GOOSENECK

Integration of flexible wire that can mould to the desired height. As seen in Figure 5.22, it will allow the movement of the head support to different directions. However, it is a visible mechanism that might not be easy to handle.

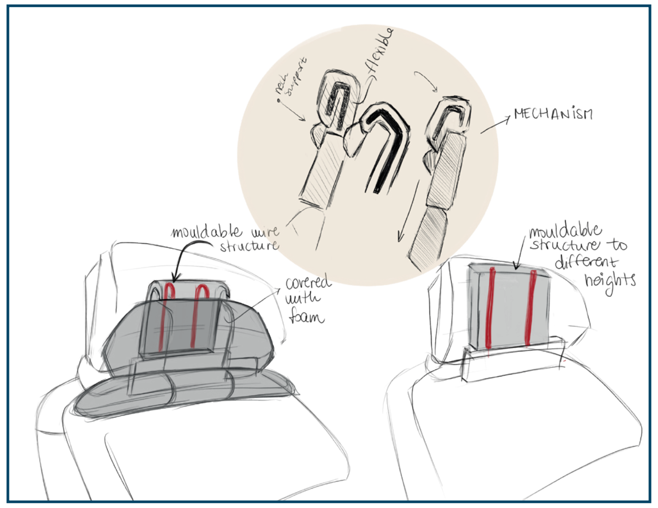


Figure 5.22. Use of a flexible wire

TELESCOPIC POLES

One of the main requirements was offering a mechanism that could be adjusted to shorter and taller users. From this, it is considered a new mechanism based on the working of selfie sticks and the use of telescoping mechanisms. Figure 5.23 shows the main idea and how it works.

The main concept consists in integrating a plate that is attached to the current seat, and attach to it two telescopic poles with rotary mechanisms that allow adjusting the design lower or higher. Even though the main idea would do the desired function, more development is needed in order to integrate it to the design in a functional and aesthetic way.

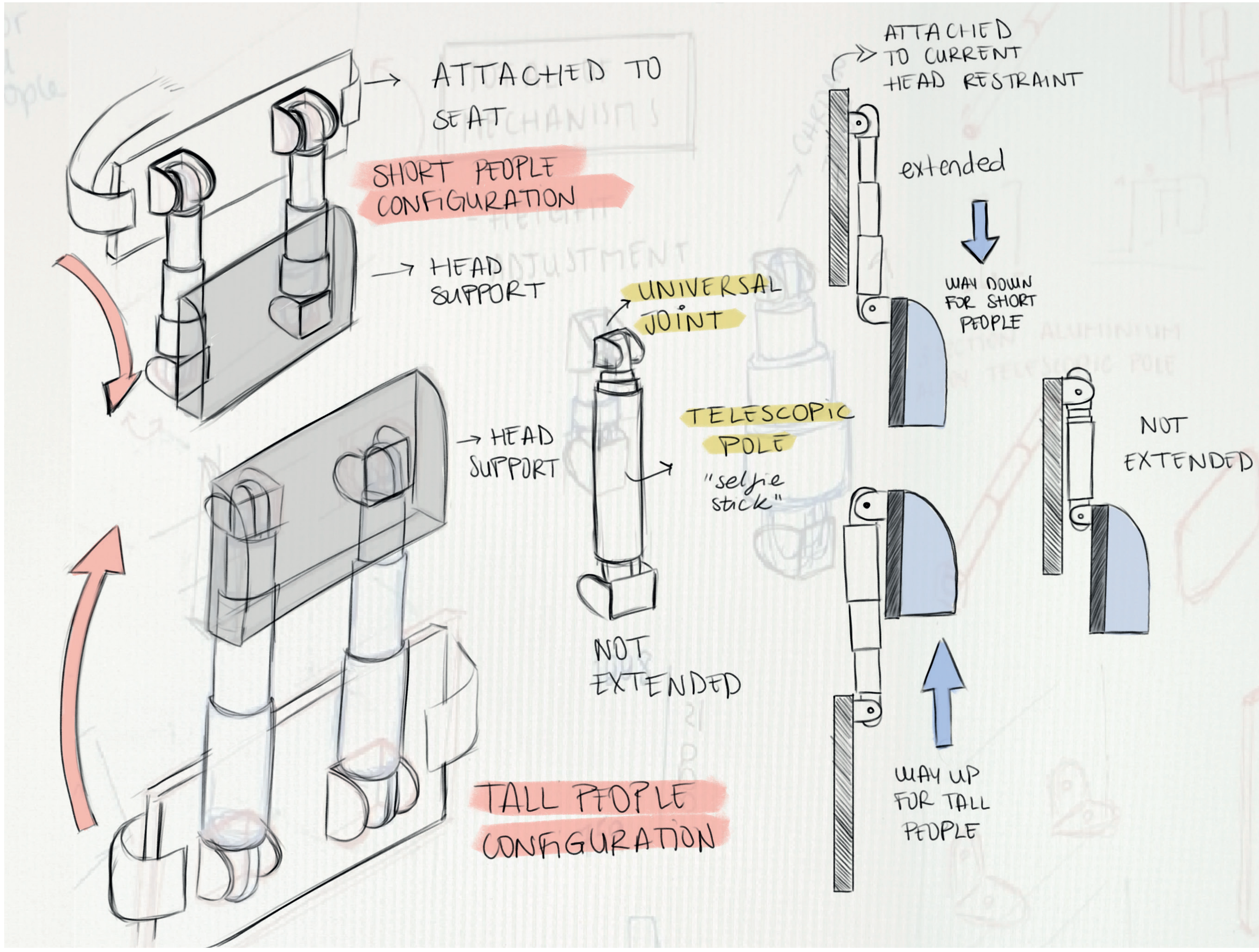


Figure 5.23. Integration of telescopic poles

5.4.5. Head support angle reclination

A problem observed in the sleeping research, and supported by literature research, is the need for reclination on the head support when laying down in an angle reclination of 140º or more for in-vehicle entertainment or sleeping. Due to this, most of the participants in the sleeping research added a pillow to the head restraint to add the desired reclination. To avoid the pillow, it can be considered adjusting the angle of the head support.

The main idea is to integrate a ratchet mechanism (currently integrated in the 4-ways head restraint systems) in order to adjust the headrest angle in different backrest configurations (Figure 5.24)

Another possibility in the adjustment on the reclination through the mechanism chosen for varying the height. The universal joints together with the telescopic poles can adapt to the desired angle (Figure 5.25). However, it should be tested if the mechanism can withstand the force stablished by the user when lying down.

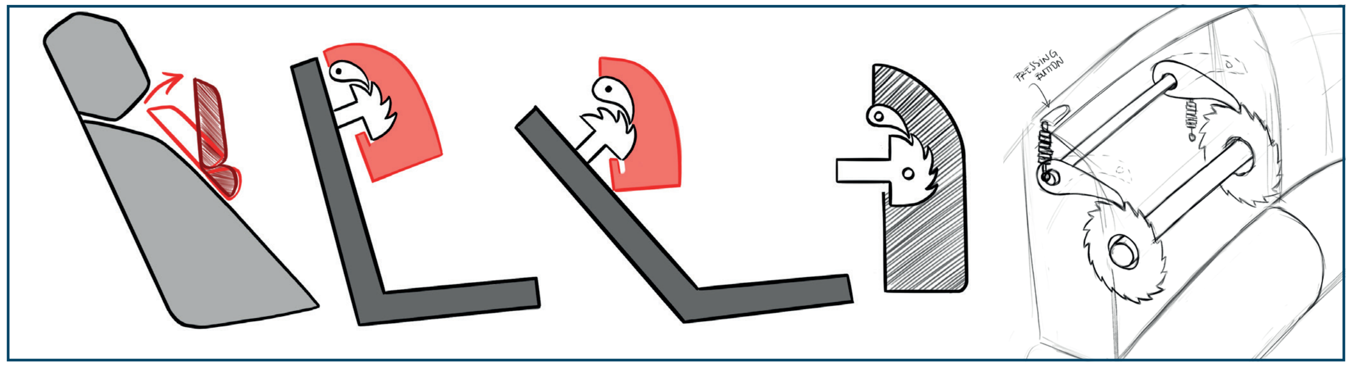


Figure 5.24. Angle adjustment with ratchet mechanism

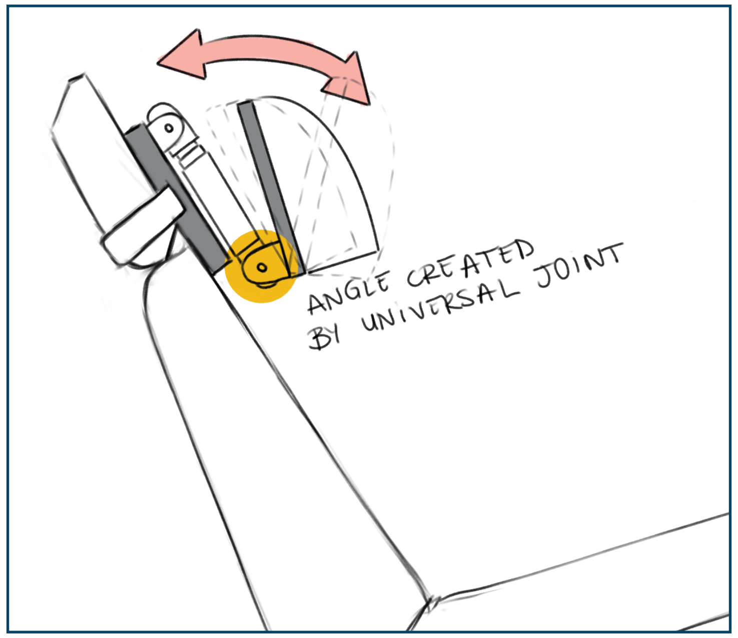


Figure 5.25. Angle adjustment with telescopic and universal joints

5.4.6. Foldable wings

From testing the shape in the user test, it was discovered that a better internal structure for folding and unfolding the wings was necessary. Otherwise, the flexible wire would not move in the desired direction. In order to solve this, a structure that covers all the support is created, as can be seen in Figure 5.26

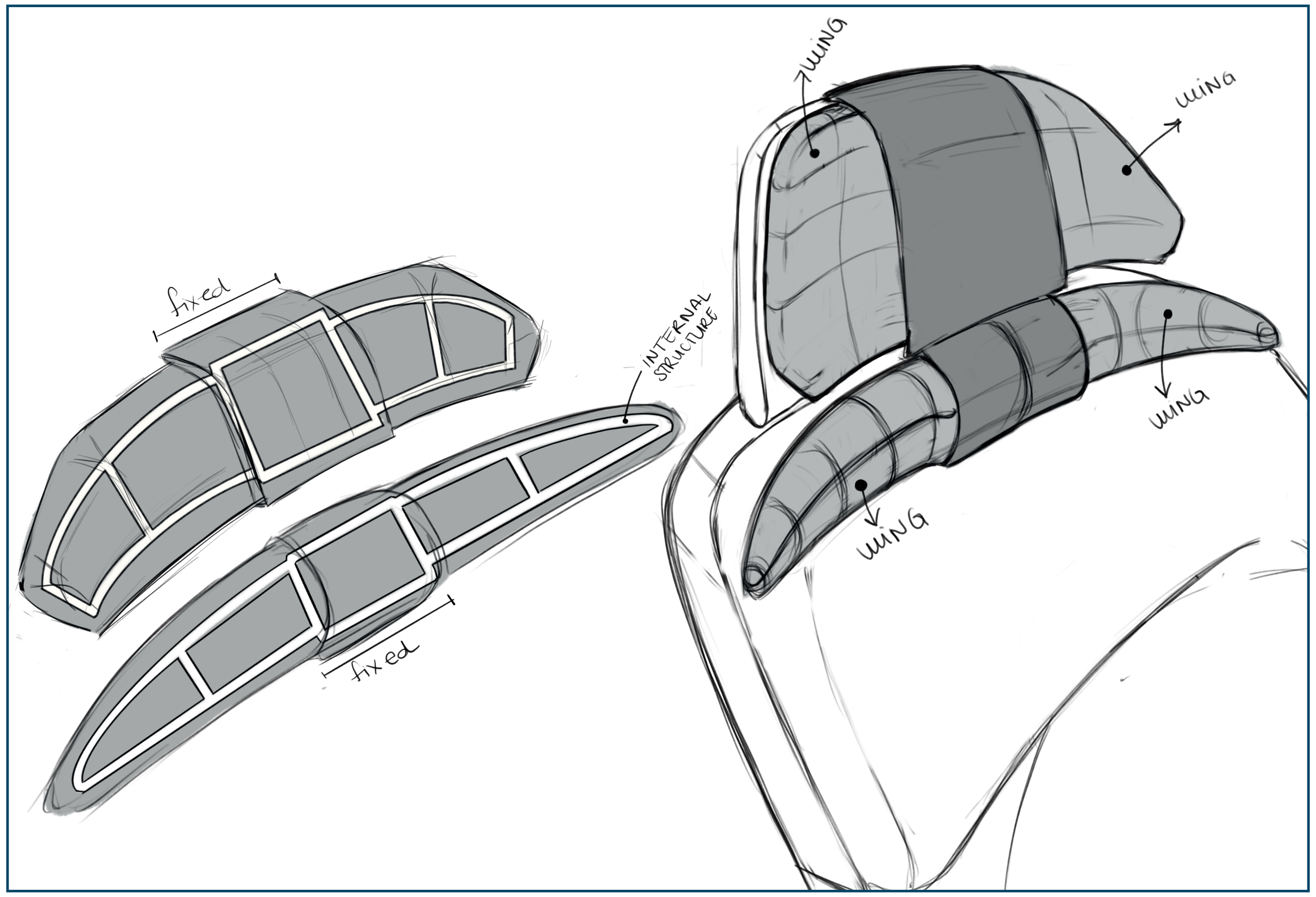


Figure 5.26. Foldable wings and structure

5.5. Conclusion

In this phase, the design has been selected between different ideation processes and prototypes. The final shape of the product has been chosen through a short user test and from there, different mechanisms have been studied in order to meet with the requirements proposed at the beginning of the chapter. This choices will be further developed and explained in the next chapter.

6 Final design

This chapter provides a comprehensive overview of the final design, encompassing different aspects such as final dimensions, integration in the seat, and explanation of final mechanisms. Additionally, it is explained the different prototypes and variations developed for offering the most functional design.

Comfy Neck

Nap on the way

In this chapter, it will be described in detail the final design proposed for improving the comfort while sleeping in the BMW seat. From the aspects discussed in the previous chapter, Comfy Neck is a travel pillow designed specifically for the needs of the ultimate seat comfort designed by BMW. The seat is designed for offering the maximum comfort for sleeping on the road in current vehicles and future AVs. As this has been tested and confirmed from the sleeping research, Comfy Neck improves the sleeping experience for having a nap without neck discomfort.

The main issue of the current seat is the lack of neck support in combination with the hardness of the current head restraint. The main objective of the design is to solve this problem by developing a neck support that embraces the main area of the neck and a head support for providing cushioning. The objective is avoiding undesired movements of the head while sleeping, but also allow to place the head and neck in the most desired position.

The design (Figure 6.1) consists of two main parts, the head support and the neck support. Both are adjustable according to the needs of the user, and they can be bent to the width of their head and neck. To provide a better integration with the seat, the neck support provides two protrusions at its extremes, in order to provide chin support and more restrictions in head movement if the use prefers.

Figure 6.1.: Final design

6.1. Neck and head adjustment

The development of an adjustable head and neck support was the main objective of the design. The final measures have been conditioned from the current measures of the head restraint (Figure 6.2), and the ergonomics measures described in Chapter 4.3.

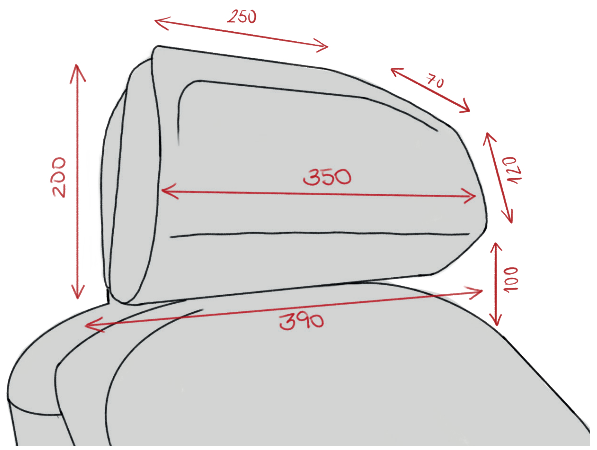


Figure 6.2. Measures of BMW head restraint

6.1.1. Head support

Initially, the head support was designed to embrace the width of the head with the integration of two lateral wings that support the lateral side of the head and cheek. However, it looked big and not seamlessly integrated in the seat, as seen in Figure 6.3

Figure 6.3. First prototype integrated in the seat

In order to offer a better integration, the head support was reduced significantly, from 550mm wide to 400mm (same width as the current head support). Additionally, the shape also varies, providing a similar rectangular shape as the one in the head restraint. Figure 6.4 shows an overview of the final dimensions (in mm) of the head support.

From reducing the size of the head support, some modifications were done in terms of functionality:

- The head support no longer counts with a fixed part for placing the head. Now, all the support can be bent.
- When bent, it does not cover the lateral side of the face, but still provides support the head.
- Since the fixed part is removed, the head support provides tilting towards the laterals while supporting the head (Figure 6.5). It needs to be tested if this is preferred by users or not.

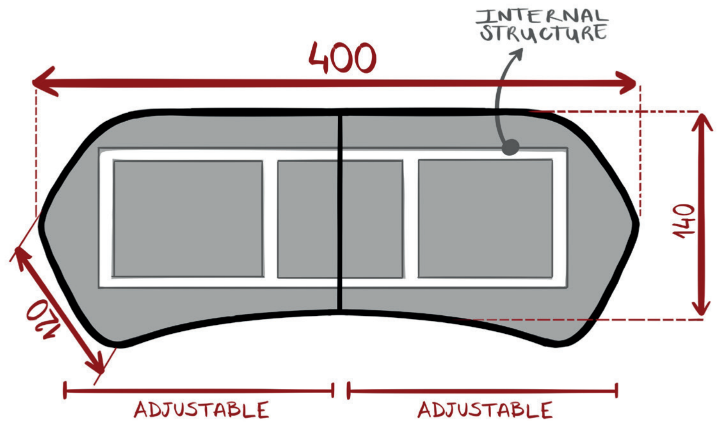


Figure 6.4. Head support measures

Figure 6.5. Tilting of head support

6.1.2. Neck support

As seen previously in Figure 6.6, the neck support would embrace the whole neck, providing support to the chin. However, this design was too big when adapting it to the seat. The size of the neck support was also reduced from 600mm to 450mm.

However, from this reduction, the neck support is not long enough for embracing the neck considering the anthropometrics from P05 to P95.

Since it is considered an important requirement for improving the sleeping comfort, two lateral protrusions are included in the neck support. These are attached to the neck support and if they want to be used for supporitng the whole neck, they can be dettached and joined together (Figure 6.6).

Figure 6.7 shows the final measures of the neck support.

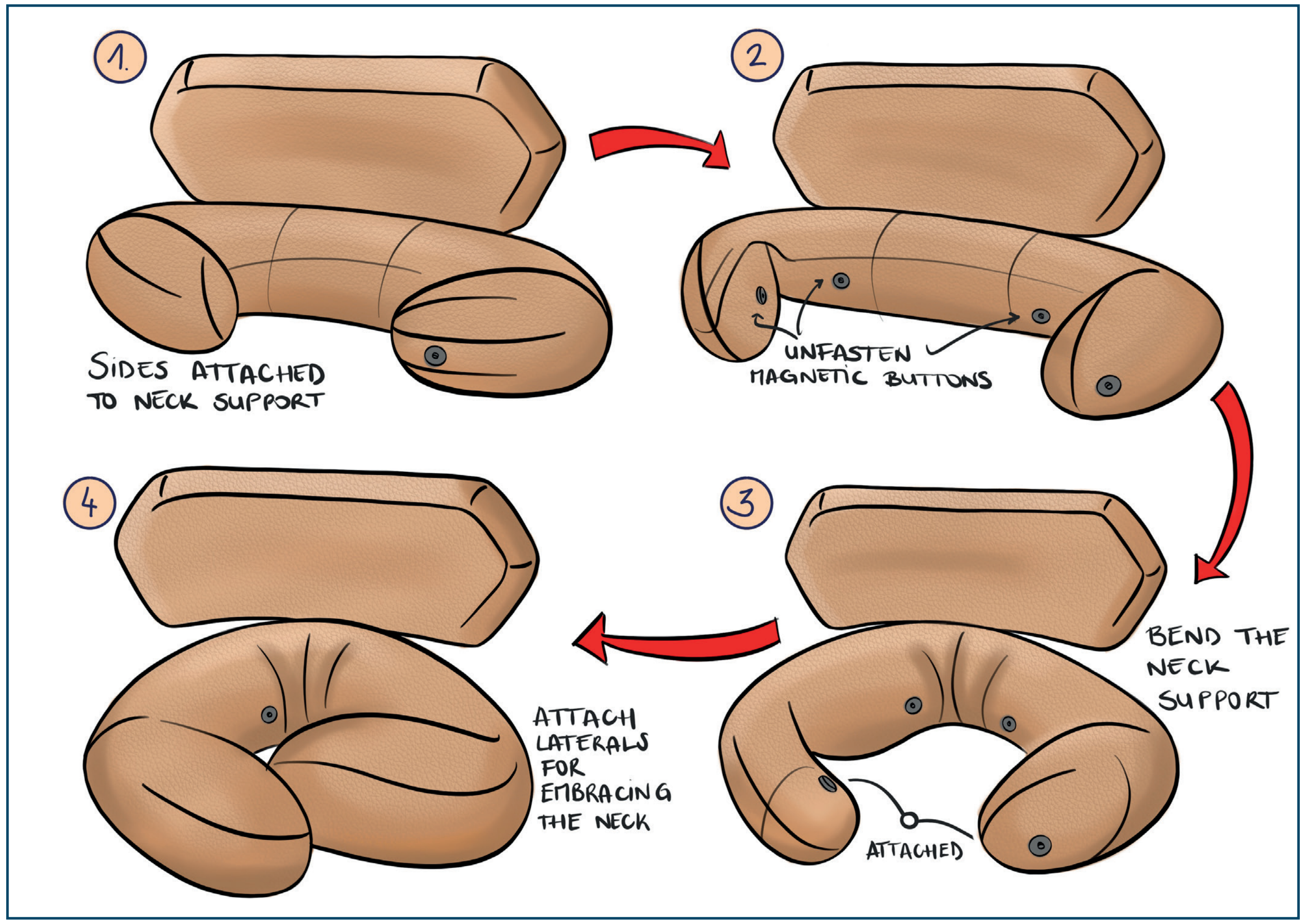


Figure 6.6. Explanation of dettachable lateral wings

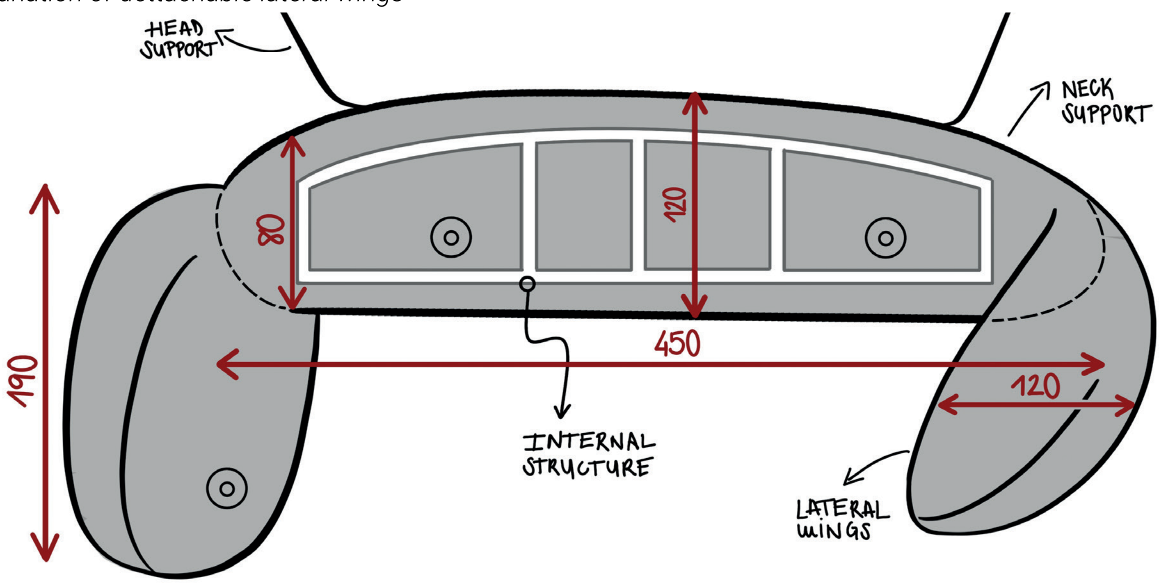


Figure 6.7. Neck support measures

6.1.3. Integrated mechanism

The integrated mechanism is a flexible gooseneck that goes from one extreme to the other. After testing diffe-rent types of flexible mechanisms that can keep fixed (figure 6.8) and checking which one bends better, inte-grating a thick wire works the best. Some of the rea-sons are:

- Light weight: after trying different types of flexible goosenecks or supports, all of them were quite heavy compared with the weight of the foam, making the head and neck support to fall. Thick, hard wire adjusts easily when integrated in the foam.
- Obtaining the desired curvature. Due to the thickness of other mechanisms, they could not provide the desired bended and the curvature was limited by its thickness, without adapting to the shape of the head or neck.
- User friendly: Although it is sturdy, the wires remain stable enough for the users to place the head or neck and not vary the curvature of it. It is easy to bend and shape without excessive force.
- Durability and stability. The simplicity of the mechanism and being hidden inside the foam, makes it a safe and durable mechanism difficult to break.

The wire structure (3mm thickness) is integrated in the middle of the foam, as seen in Figure 6.9. The structure is created in order to bend easier the foam in the desi-red direction.

Figure 6.8. Flexible materials for bending the neck and head

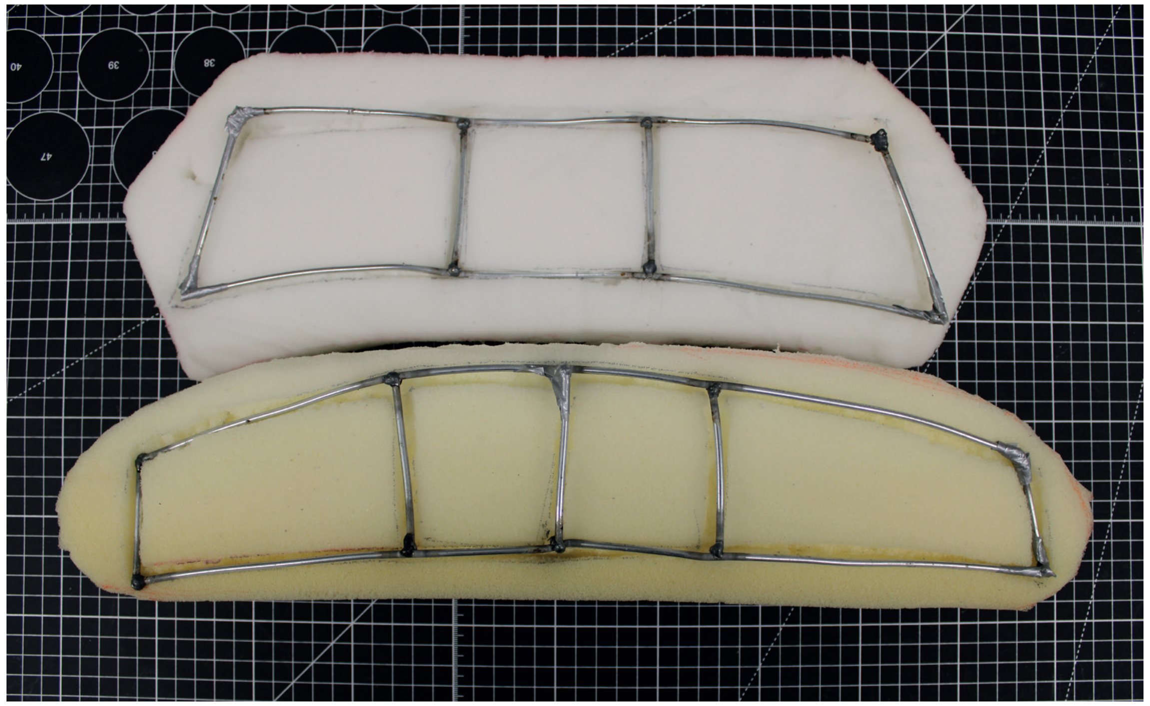


Figure 6.9. Integration of the wire in the design

6.2. Height adjustment mechanism

Due to the requirements and needs for a better design, a mechanism with a manual adjustment for adjusting the height of the support is selected.

The designed mechanism for adjusting the height of the support to different anthropometrics is integrating two telescopic poles (commonly used in selfie sticks). The poles allow adjusting the height by contracting or lengthening them (figure 6.10).

One extreme of the poles is attached to the plate that is fastened to the head restraint of the seat. The other extreme of the poles is attached to the designed product. Figure 6.11 shows how the mechanism works. Since the head support is attached to the start of the current head restraint of the BMW seat, it is necessary that the telescopic poles can be expanded downward for short users, but also upward, for tall users. This can be obtained by adding rotatory universal joints at the extremes of the telescopic poles (Figure 6.11), allowing turning in 180º the head support and making it adjustable for bigger percentiles.

In order to avoid a relevant gap between the mechanism in a downward position and in an upward position, a compact telescopic pole is needed.

For increasing the stability of the head support on the seat, two telescopic poles with a distance of 60mm among them are integrated.

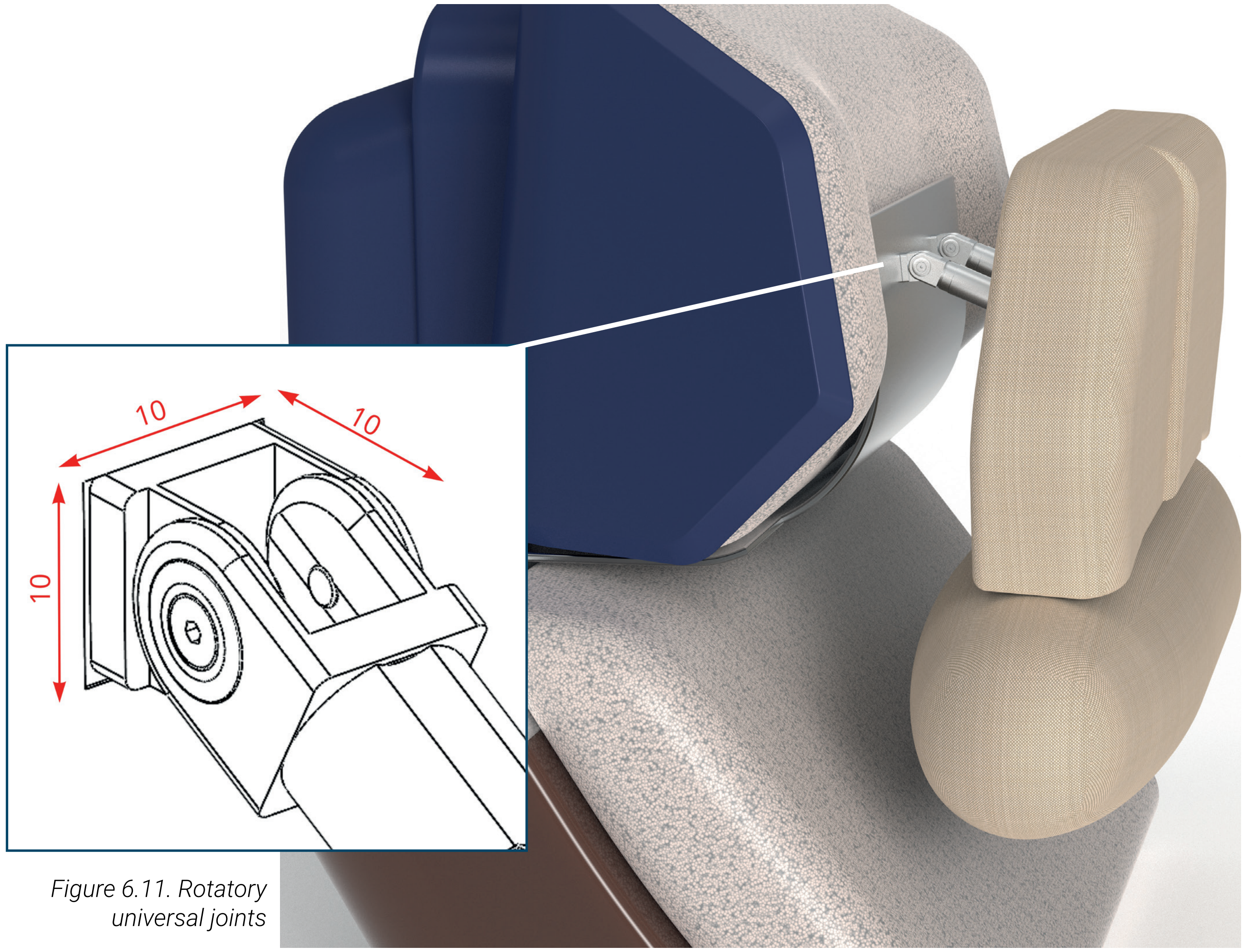


Figure 6.11. Rotatory universal joints

Figure 6.10. Different height adjustments of the design

As shown in Figure 6.12, the taller position would reach the neck support at 750 from the sitting point, considering that the backrest of the seat measures 700mm. From the anthropometric measures of 7th cervical point sitting, this would reach P95 anthropometrics.

The same occurs considering P05 and the adjustment for short people.

The desired total range between the lowest position and the tallest position is 300mm, as seen in Figure 6.13. This measure is obtained from the difference between

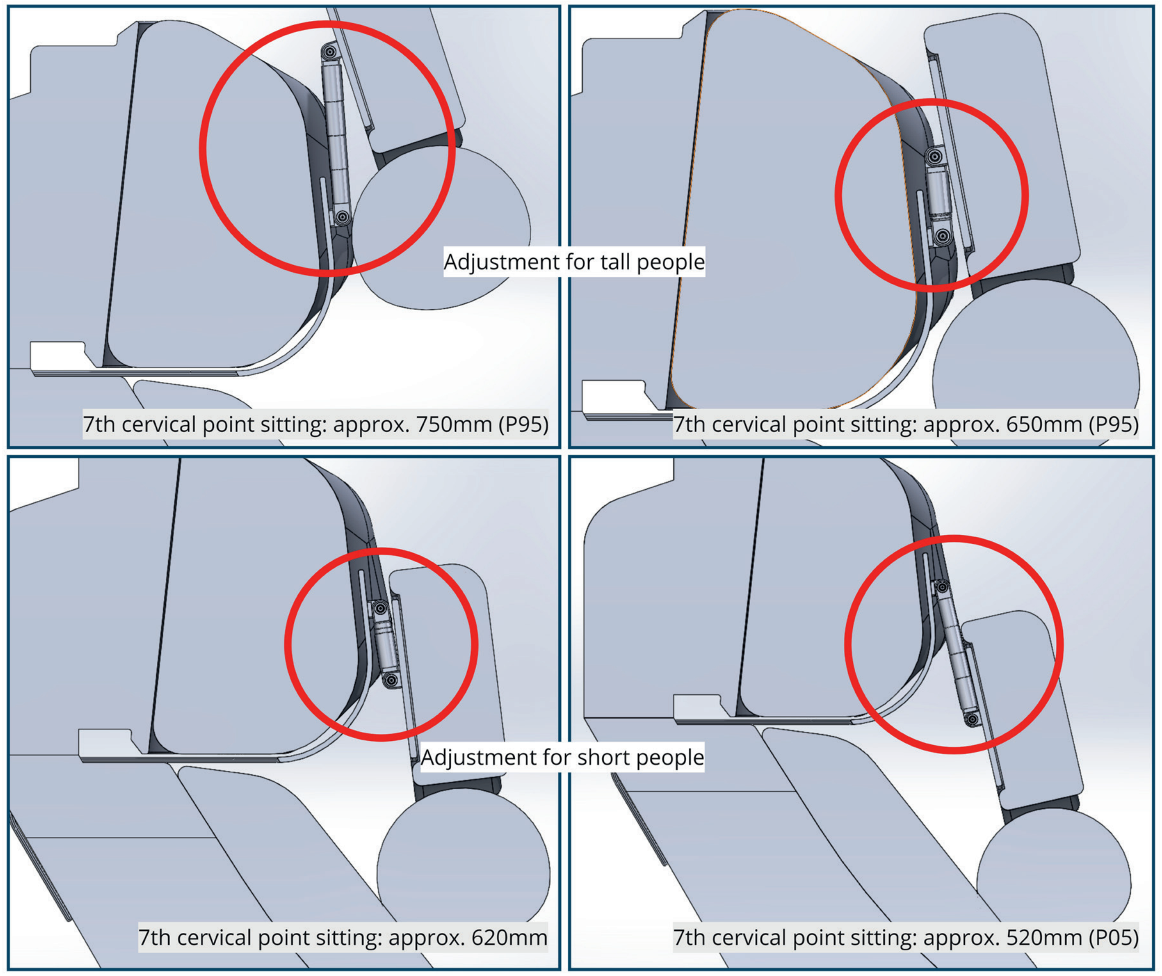


Figure 6.12. Working mechanism of the height adjustment

Figure 6.13. Difference between lowest and tallest position

P05 and P95 measures for "7th cervical point sitting" in Chapter 4.3.

The development of this mechanism allows, among others:

- Offer a wide range of height adjustments, being able to lower it, putting it up and down in an intuitive and easy way to different comfort preferences.
- Customization, allowing multidirectional movement. Not only vertical movement in two directions, but also angular changes. It should be tested if this mechanism is strong enough for changing the angle of the head support when desired.
- Easy to use, as it is a common and not dangerous mechanism (used widely in trekking poles, selfie sticks, tripods...), being therefore intuitive.
- Sturdiness and stability, providing stability and durability by allowing smooth movement while maintaining their structure.
- Space optimization, as the telescopic poles can be compacted when not in use.
- Adaptability to different seats

Another consideration is the mechanism visible to the users for adjusting the support. Although this is not dangerous to use, aesthetically, it is not the best solution.

Possible ideas in order to hide the mechanism are integrating a case or cover that expands and retracts with the use of the telescopic poles. Another solution is to cover the telescopic poles with elastic fabric when the support is in the lowest/tallest position. A cover with this material can retract or fold away as the poles extend, maintaining a streamlined appearance.

6.3. Integration in the seat

For integrating the mechanism and therefore the design in the seat, it is proposed a plate that follows the shape of the head resitraint. It joins the height mechanism to the seat by placing it in the upper part of the backrest, as seen in Figure 6.14.

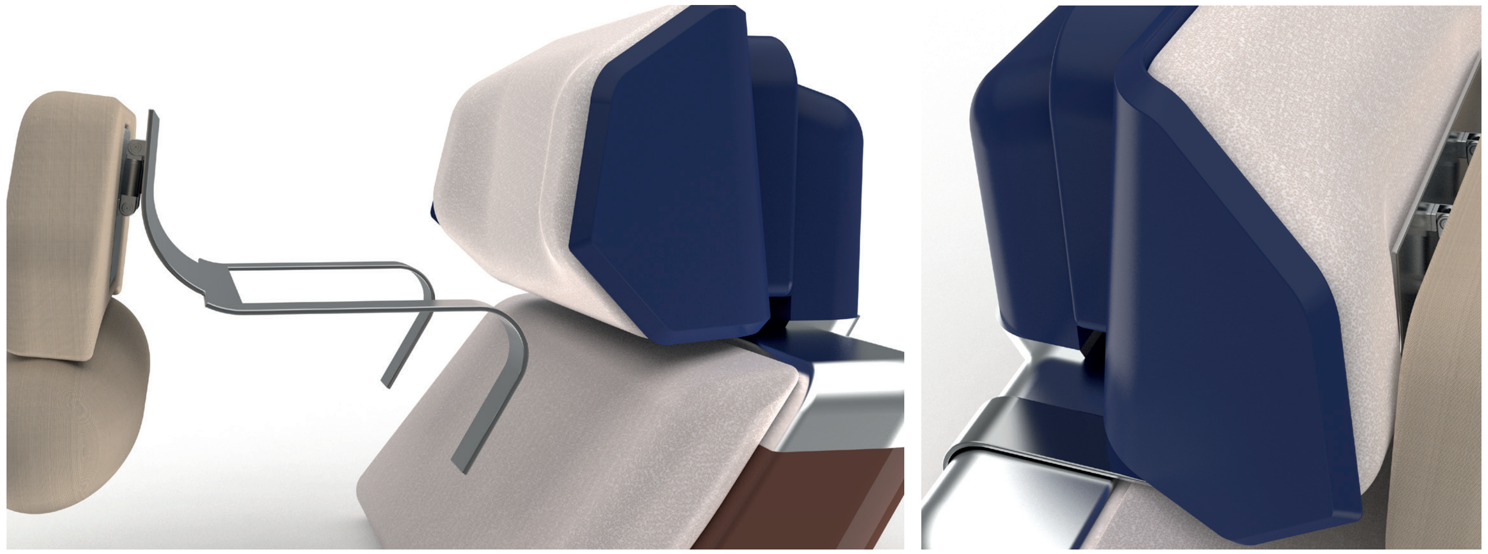


Figure 6.14. Integration in the seat proposal

6.4. Prototype

A prototype of the design is developed in order to test its integration in the seat and check if it improves the sleeping comfort.

First iterations of the design (Figure 6.15) were made regarding shape and measures for the head and neck support. However, these were too big and did not adjust to the current BMW seat.

From these iterations, the idea of angle adjustment of the head support was discarded. The head support already offers the necessary reclination for obtaining the desired curvature on the neck (Figure 6.16)

Final prototype is executed smaller and easy to adapt to the seat. The internal wire structure allows bending without difficult both parts of the support to the preferred shape. The integration of the height mechanism is added but with a bigger telestopic pole and joint due to prototype limitations (Figure 6.17)

6.4.1. Materials

The prototype consists on two different types of foam. The hardness of the foam is obtained from the literature research phase. It is stablished a harder foam for the area of the head and a soft foam for the area in contact with the neck and cheeks. Therefore, the head support counts with a hard foam, and the neck support with soft foam.

For the cover, it is used soft natural cotton, commonly used in travel pillows and neck supports. Initially it was tested the use of leather, due to its use for the seat. However, as seen in Figure 6.15, it is too hard to bend and it is not soft for placing the head and neck. Additionally, since the design bends, it creates notorious wrinkles.

For enabling a better bending, elastic fabric (Figure 6.17) is used in the rear part of the head and neck support.

Figure 6.15. First prototype iterations

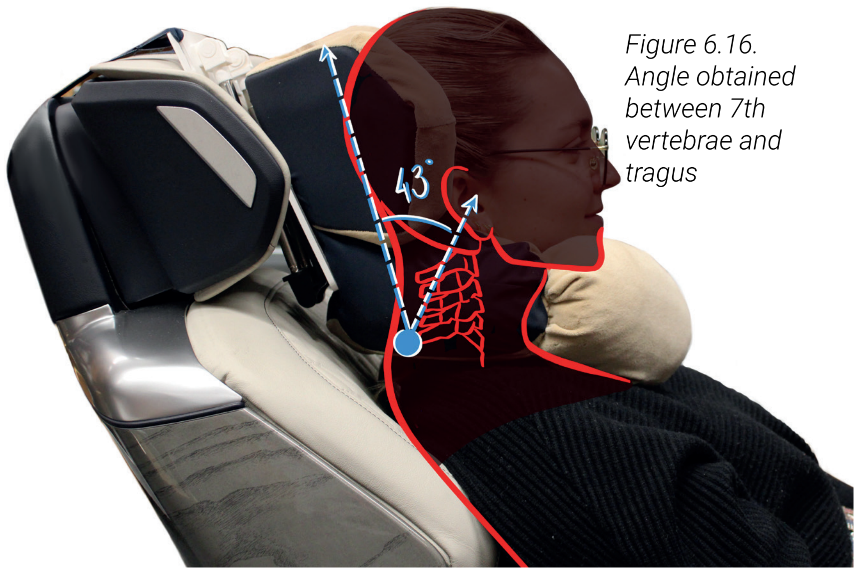


Figure 6.16. Angle obtained between 7th vertebrae and tragus

Figure 6.17. Height adjustment mechanism prototype

Figure 6.18. Prototype without bending

Figure 6.19. Prototype with neck support folded

Figure 6.20. Prototype with neck and head support folded

7 Design validation

This chapter is focused on validating the developed design in the BMW test, in order to test if the overall comfort and sleeping quality improves with the design. First it is integrated pressure sensors in the design in order to obtain more objective results, calculating the pressure distribution. The user test is performed with ten participants in a thirty-minutes power nap. The results indicate a significant increase of sleeping comfort in comparison to sleeping without the design

7.1. Pressure measurement

From literature review, one of the main conclusions extracted for the evaluation of comfort, is the importance of the pressure distribution for ensuring comfort when sitting for longer periods of time. Additionally, different pressure is applied in the head, neck and face. In Chapter 4.1.2, it is already shown the ideal pressure between head and headrest that will provide the lowest discomfort per region.

Because of this, and the use of different soft and harder foam for the prototype (softer in the neck support, harder for the head support), a good method to check if the pressure applied to the product is the appropriate and to test the comfort, is by evaluating the pressure in the different areas of the head support. The main objective of the pressure sensor is:

- Obtain the mean pressure stablished in the head support area, and in the neck support
- Evaluate if there is an increase of pressure over time

7.1.1. Integration of sensors

Four pressure sensors (RP-S40-ST) (Figure 7.1) with a pressure range from 20g to 10 kg have been integrated below the cover of the product. These have been connected to a Raspberry pi that read the information provided by the sensors and translate it to kPa. The sensors are placed under the fabric cover. Figure 7.2. shows where the sensors are placed in the prototype

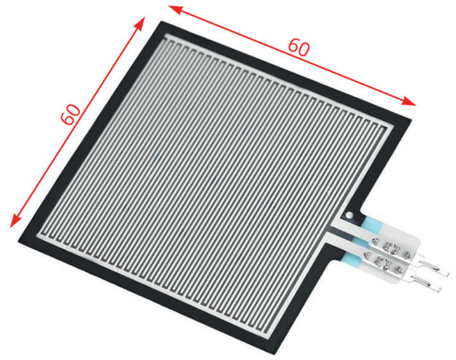


Figure 7.1. Sensor RP-S40-ST

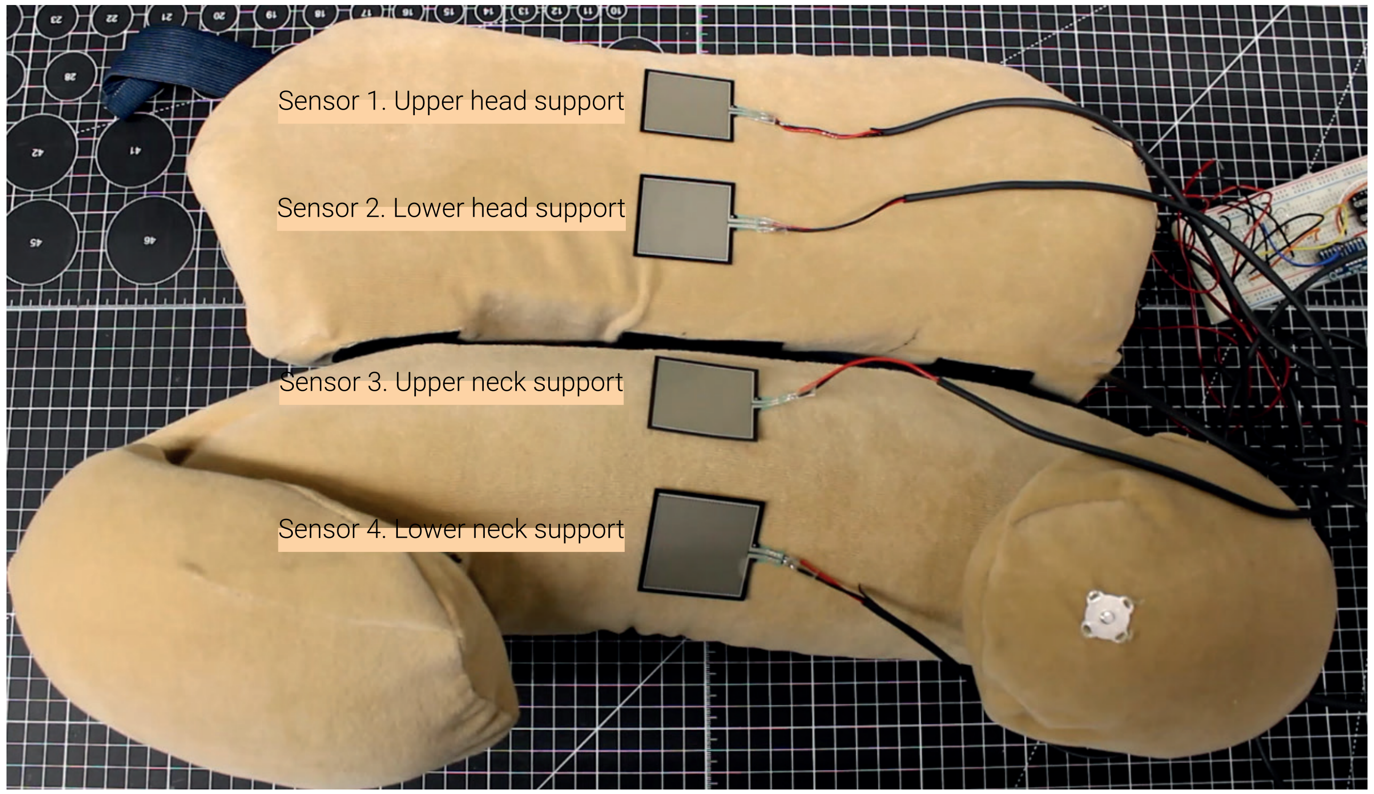


Figure 7.2. Locations of the sensors in the prototype (the sensors were placed under the fabric cover)

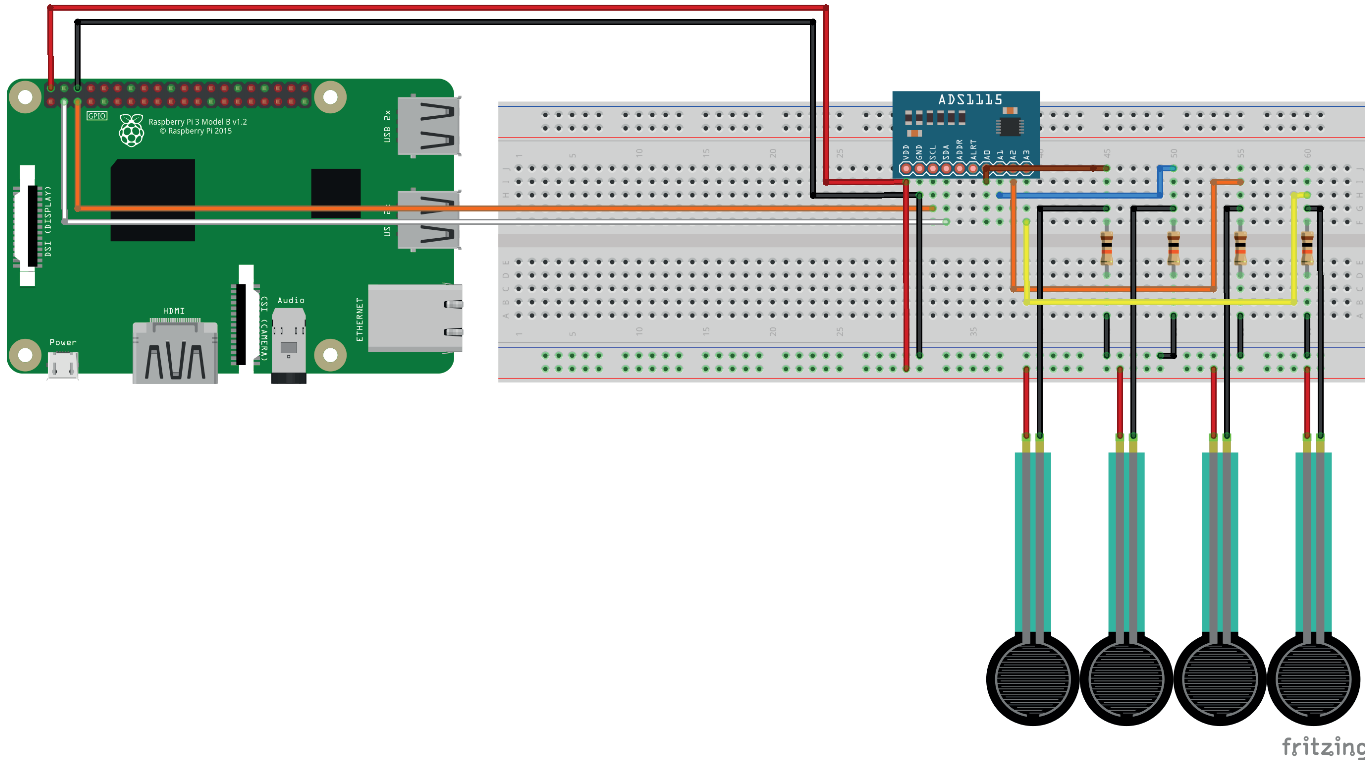


Figure 7.3. Electronic scheme for connecting the sensors to the Raspberry pi

The electronic scheme can be seen in Figure 7.3. The code for reading the sensors and convert them into data can be seen in Appendix H. The code reads the raw data from the sensors once a pressure is applied. Then, taking into account the pressure and the surface of the sensors, this raw data is converted to kPa, the common unit measure used for measure the pressure in this area of the body.

7.1.2. Sensors considerations

While calibrating the sensors and transforming the raw data to the unit measure of Pascals, an inaccuracy of the sensors was noticed.

First, the pressure will vary a lot depending on how the force applied is distributed. Considering the surface of the sensor, the value will change if the force is applied uniformly across all the surface, or if its only applied in one part of the sensor.

This variation in pressure is expected to affect significantly the data obtained by the sensors in the user test. From meetings with electronic experts, the following recommendations were provided:

Integration of more sensors around the whole product, and then compare the results among them and which are the differences. Due to kowledge and time limitations, this had to be discarded.

Place the sensors under a thin layer of fabric or foam. This way, when the force is applied in the surface, it is easier that arrives distributed to where the sensors are. Therefore, the four sensors have been placed under the cover of the prototype and under a thin layer of foam of approximately 1cm.

However, the best method in order to calculate the pressure applied in this occasion would be the use of a pressure mattress, since it will provide direct information in different areas of the product in an accurate way. It was discarded because the main objective of the user test is to evaluate the functionality and comfort of the product.

7.2. Validation test

The main objective of the user test is to check how comfortable the designed product is, and if it improves the sleeping comfort in comparison to the results obtained in the previous sleeping research. By testing the product it will be checked:

- How intuitive the mechanisms are. Is it instinctive to bend the wings to provide support? How intuitive is it to adjust the height of the head and neck support?
- Easy to use. Is the height of the product easy to fix? How easy is it to bend the wings and place them back to its initial position?
- Are the mechanisms resistant enough?
- Does the shape of the design provide comfort when sleeping? Does it improve the sleeping comfort and support the head and neck while sleeping?
- Does the product help to sleep? Is it uncomfortable when not using it? Does it allow change of postures?

Overall, the goal of the user test is to answer the following research question:

Does the design improve the sleeping comfort in comparison with sleeping without any head and neck support?

7.2.1. Procedure

In order to obtain more relevant results about the design, ten participants that had already participated in the previous sleeping research were selected in order to test the design and to compare the sleeping with the previous one they had done some months ago.

For a better comparison between both studies, the participants slept as well during thirty-minutes in the same BMW seat. In this occasion, with the developed head and neck support. Due to the preference of more reclined backrest angle, they tried the concept once in a backrest angle of 140º. The environment was the same as the previous time. providing a silence and half-dark room (Figure 7.4).

First, they were explained some general information about the concept and the test. It was described briefly the functionality of the head support and its features. Then, they were asked to take a seat a seat and place the head support to their preference, being able to modify the height of it and adapt the head and neck support to their body.

Figure 7.4. Set-up of the research

Figure 7.5. shows a participant placing the headsupport to their preference. Once the participant has placed the head support as preferred, the Raspberry pi was connected to read the information about the pressure sensors integrated in the seat. Then, they are asked to sleep (or try to) during thiry-minutes. After the nap, they filled in a short questionnaire about the comfort of the session and the design.

For the product validation, the data collected is:

- A short post-nap questionnaire, regarding subjective data about sleeping and product functionalities and comfort.
- Recording of the sleeping session, in order to analyse movements in the head and neck, shift of postures and sleeping factors
- Pressure applied towards the design in kPa

Figure 7.5. Participant testing the design features

7.2.2. Comfort measurement

Due to our main interest of analyzing the comfort/discomfort experienced in the head / neck / shoulders area, the perceived discomfort is rated on a visual discomfort scale (Figure 7.6) used by Franz et al., (2012) and Bouwens et al (2016).

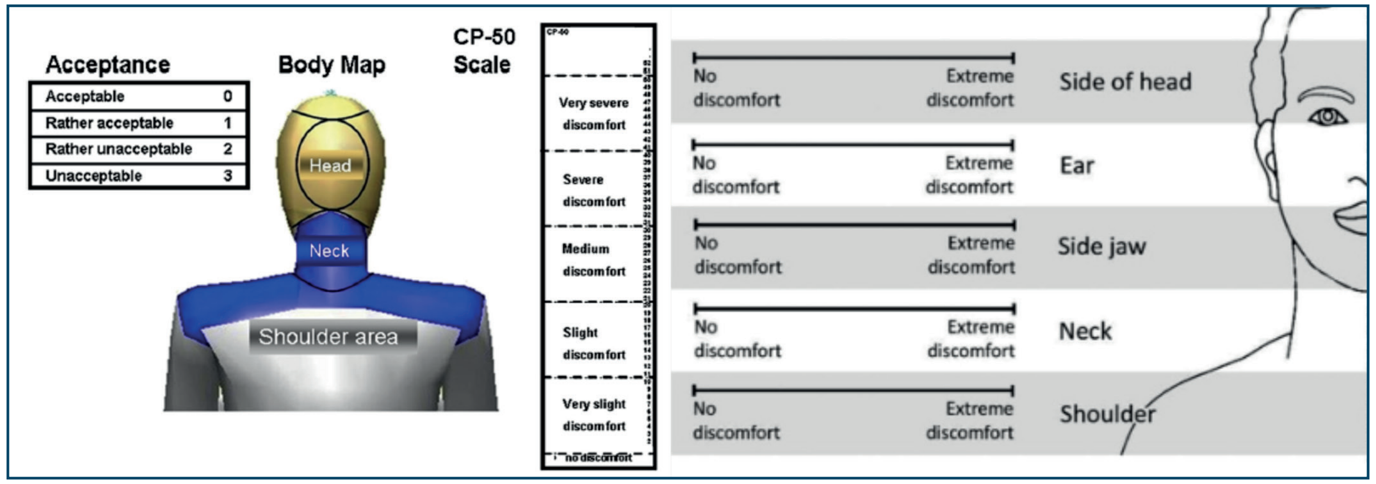


Figure 7.6. Visual discomfort scale upper area of the body, by Franz et al., (2012) (right) and Bouwens et al., (2016) (left)

7.2.3. Hypotheses

From the design development, some hypotheses are elaborated to pay more attention to these areas while analysing the results. Figure 7.7 shows an overall of them, marked in red the negative ones, in green the positive, and in orange the ones that not influence that much the functionality of the design.

Due to design requirements such as the need of obtain a seamlessly integration in the seat, the size of the head support had to be reduced. Because of this, it is expected that it will not provide the desired support to the head and cheeks, and therefore the head might still move while sleeping.

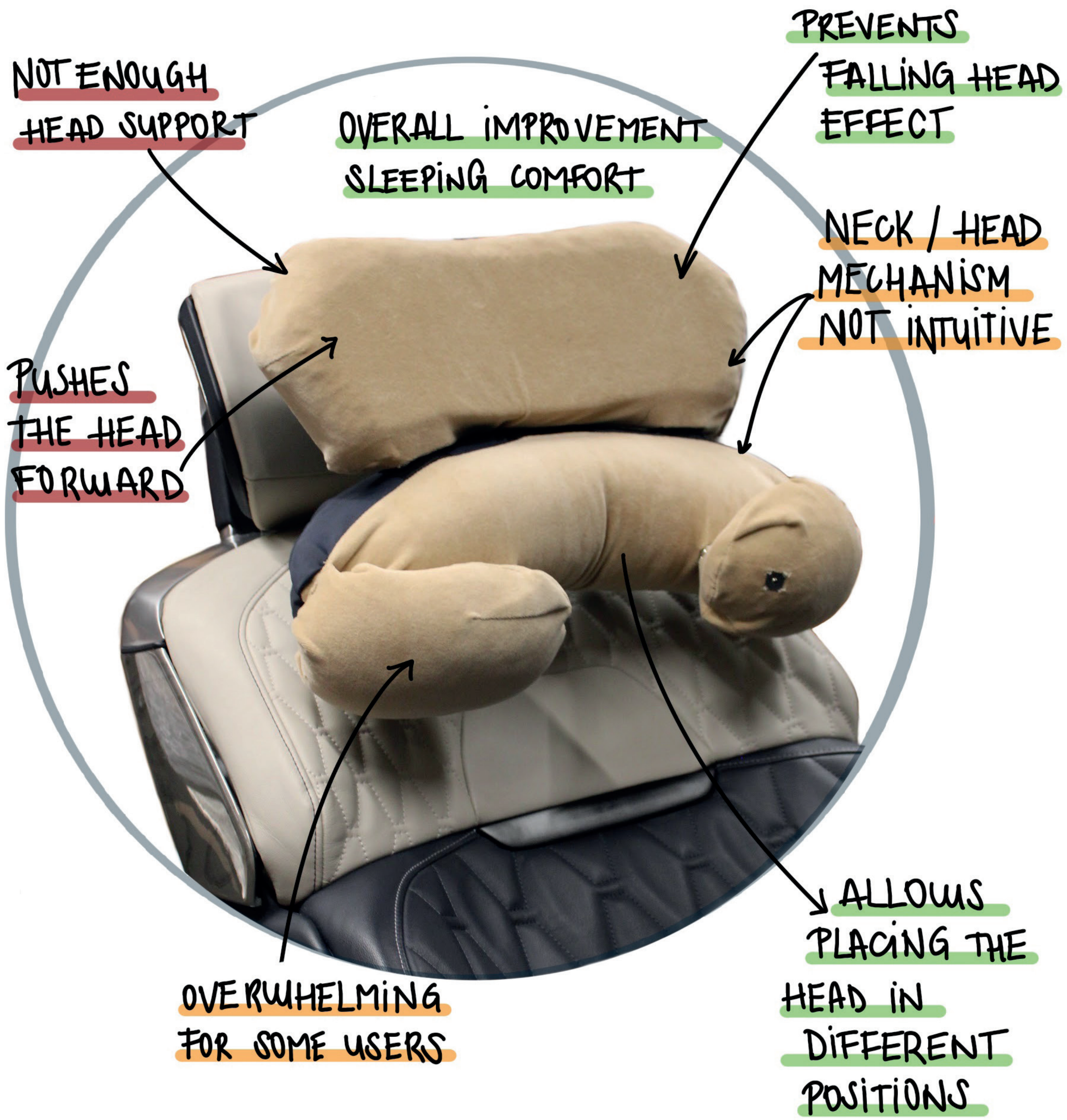


Figure 7.7. Hypotheses of the prototype

7.3. Results

7.3.1. Pressure sensors

Considering the two initial goals of integrating sensors in the head and neck support:

- Obtain the applied pressure in both areas of the design and compare it with the results of Franz et al. (2012)
- Observe the pressure distribution and its variation the time of thirty minutes

Due to the mentioned inaccuracies of these type of sensors for these applications, the first goal was initially discarded. The pressure sensors had very different results depending on where the force was being applied, if at the whole surface or only to some part, even though the amount of force was the same.

The data recorded by the sensors was analysed by creating four different charts for each participant: one chart per sensor. However, not all the charts provided relevant information. Due to the limited number of sensors integrated in the design, some participants did not applied pressure to the area on where the sensor was

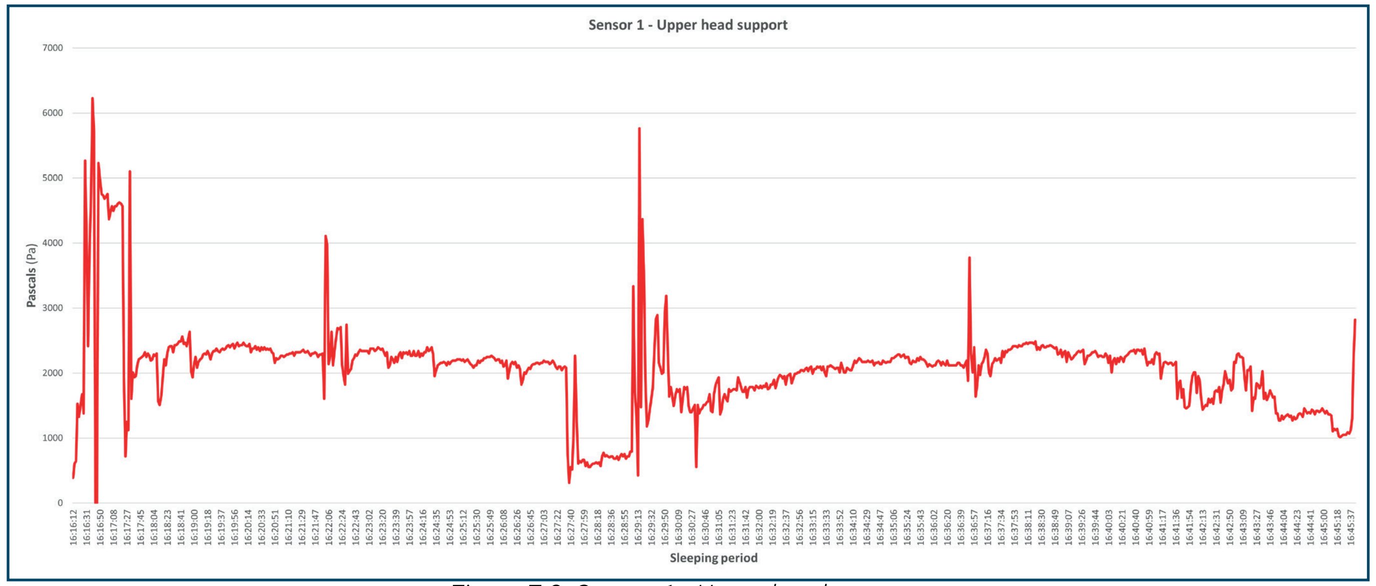


Figure 7.8. Sensor 1 - Upper head support

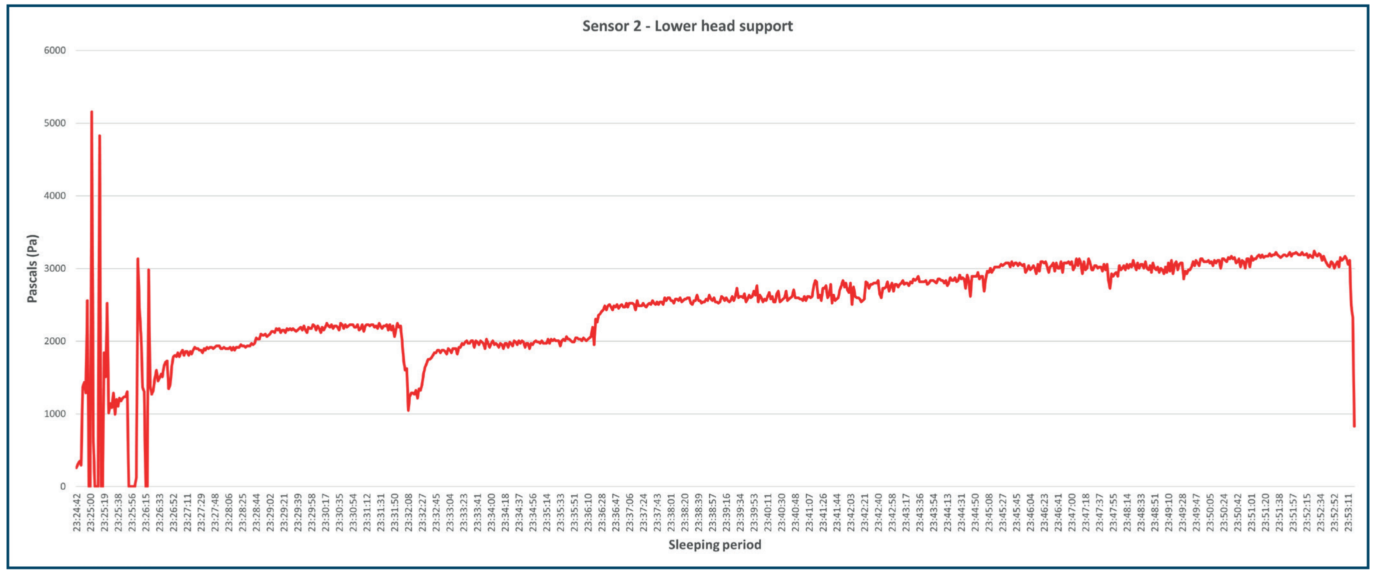


Figure 7.9. Sensor 2 - Lower head support

Table 7.1. Estimated pressure per body area and appropiate material (Franz et al., 2012)

Body region	Condition	Maximum pressure	Material
Head	lower pressure = bigger discomfort	1,8 kPa - 3,7 kPa	firm foam for the back side of the head
Neck	increasing pressure = bigger discomfort	< 1 kPa	soft foam
Shoulder	average pressure = lower discomfort	2 kPa - 7,6 kPa	firm to extra firm

integrated or the head did not make contact with the support. Additionally, the accuracy of the sensors needs to be considered for the results. Therefore, it has been mainly analysed the ones that provided more relevant information.

From evaluating the charts, it can be seen the difference between the pressure applied to the head support (Figure 7.8 and 7.9) and the pressure applied to the neck support (Figure 7.10 and figure 7.11). Comparing them from the results obtained by Franz et al. (2012) (Table 7.1), the design provides the desired pressures for ensuring comfort, obtaining from 1,8 to 3 kPa for the head support and less than 1 kPA (between 0,2 to 0,5) for the neck support.

From the Figures it can be seen a slow increase in pressure over time. As mentioned in Chapter 2, pressure will always increase over time. However, the test was only performed for thirty minutes. It should be analysed if this increase in pressure causes too much discomfort in a longer sleeping (90 minutes full sleeping cycle), and how much the pressure increases.

The different peaks observed in the figures can mean a change in posture of the head. This explains the starting of each chart, in which the participant is placing the upper area of the body to a comfortable position and trying to sleep.

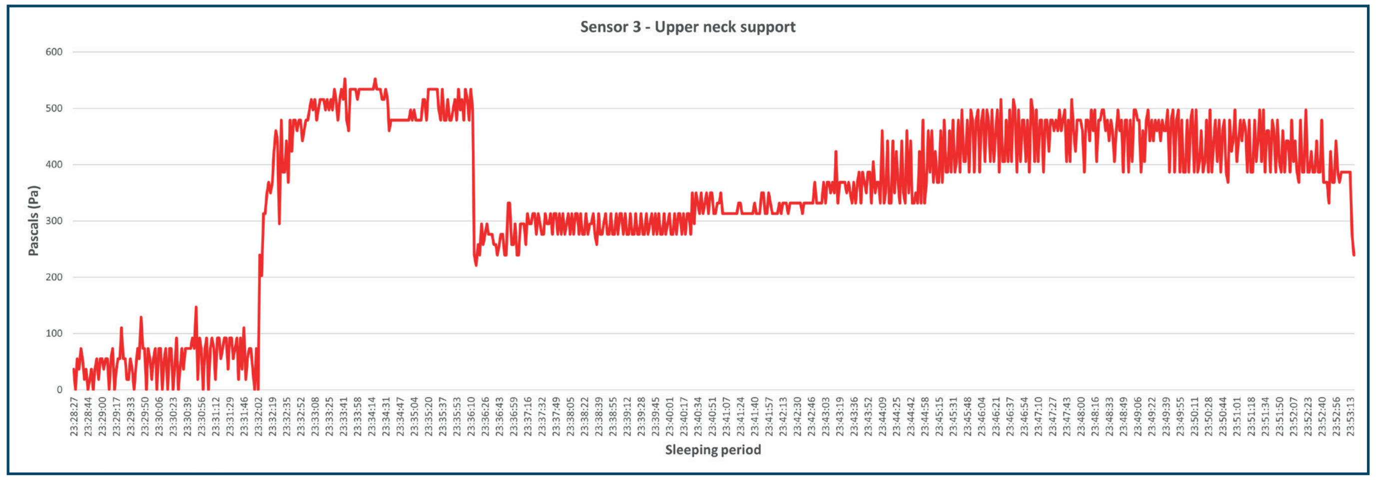


Figure 7.10. Sensor 3 - Upper neck support

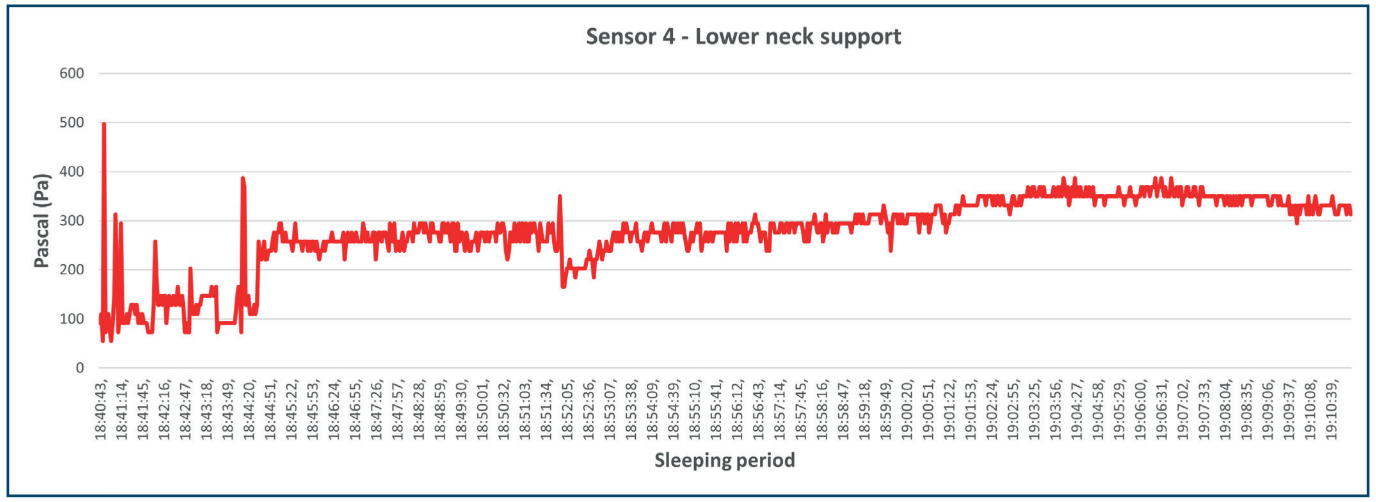


Figure 7.11. Sensor 4 - Lower neck support

7.3.2. Comfort of the product

Comparing the overall comfort with the comfort obtained in the previous sleeping test after napping in 140º backrest angle, the design significantly improves the comfort for 1 point. (Mean overall comfort with comfy neck: 8,5. SD: 0,699) (Figure 7.12)

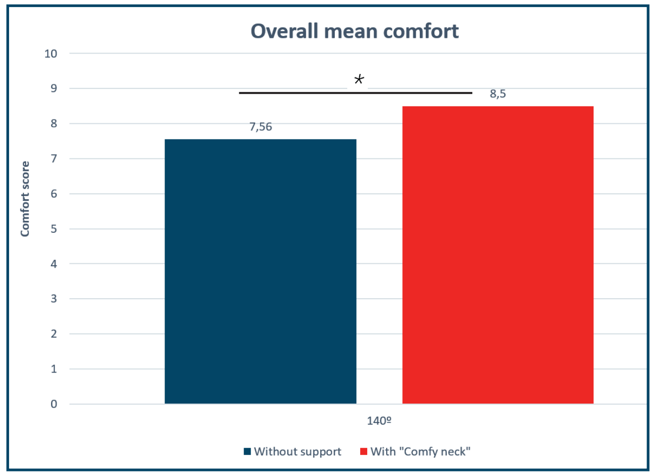


Figure 7.12. Overall mean comfort
** sign. p<0.05, Wilcoxon signed rank test*

Comparing the overall comfort of the head/ neck support before and after the nap, the score is the same with a mean of 8 and a SD of 1,15 before nap and an SD of 1.03 after nap. Regarding how intuitive was to adjust the head and neck support to their preferences, it is evaluated with a mean of 7 (being 10 vey easy to adjust). Majority of participants mentioned that once they knew that the head and neck support could be adjusted it was easy to modify, but initially it is not very clear which areas of the product are adaptable.

Due to the hypotheses, it was asked to evaluate the head support regarding the tilting it has towards the laterals and if they would prefer to have it fixed. Most of them compared the head support to the ones integrated in the seat aircrafts. Although 4/10 prefer the head support fixed, 6/10 likes the freedom of movement that the tilting allows, mentioning that the support in aircrafts tends to be "too hard".

However, from analysing the recordings, 3 out of 10 participants suffered from falling head effect, as seen in Figure 7.13). The reason for it can be due to two factors:

Figure 7.13. Participant sleeping reclining the head over time

Participant	Amount of sleep	Change of head position	Attachment of neck support	Falling head effect	Change of posture
1	15 min	2 times	No	No	No
2	20 min	3 times	Yes	No	No
3	20 min	2 times	No	No	No
4	20 min	No	No	No	No
5	15 min	2 times	Yes	No	No
6	20 min	2 times	Yes	Yes	No
7	10 min	2 times	Yes	No	No
8	10 min	No	No	No	No
9	15 min	No	Yes	Yes	No
10	25 min	No	Yes	Yes	No

Table 7.2.Obtained results from recordings

- Not enough head support
- Too much tilting of the head support

The recordings were analysed and a series of relevant factors were evaluated. Table 7.2 shows the results.

Regarding the body local discomfort map, all the body areas were evaluated with no discomfort. The most affected was the neck, obtaining overall a very slight discomfort.

The most relevant feedback from the open-ended questions can be seen in Figure 7.14.

Figure 7.14. Feedback from the questionnaire

7.4. Discussion

From the results, all the participants were comfortable during the thirty-minutes power nap. The amount of sleeping obtained, extracted from video recording and questionnaires indicate an increase in sleeping time in comparison with the previous sleeping research. With the head support, they slept a mean of 17 minutes, in comparison to 13 minutes in the previous research.

In order to answer the main research question "Does the design improve the sleeping comfort", it can be concluded that it does. Not only increases the sleeping time, but also the overall comfort after nap. Additionally, the local body areas did not suffer any extreme discomfort, apart from slight discomfort in the area of the neck.

Considering the feedback and the recordings, the head support helps with maintaining the head without undesired movements to some participants. However, it still created an undesired tilting towards the laterals when sleeping. Although this movement is not sudden and it is notorious over time, it can become more uncomfortable when sleeping during longer periods.

Other of the features of the head support was the ability to move the headrest in the laterals creating a tilting. It is important to consider that this freedom of movement was evaluated positively by six participants, while four participants considered this uncomfortable. It needs to be tested if this freedom of movement increases for longer periods of sleeping (mainly in the neck).

From the participant's feedback, it can be extracted how much varies the preferences regarding the head and neck support. For instance, some participants prefer a harder head support in terms of foam, while others suggested a softer head support. Also, while some participants found overwhelming the neck support, others would have preferred a bigger neck support.

Initially, the head and neck support it is not intuitive. Participants mentioned that before the explanation regarding the features, it is not clear what areas can be adapted and which ones not. The same occurs with the height adjustment. However, once it is explained the different adjustments of the design, it was easy for all of them to adapt it to the desired position.

Lastly, two participants mentioned that the head support pushed the head too much forward. It is important to consider due to the already existent head restraint of the seat. It should be considered if the existent head support can be leaning back, or by reducing the thickness of the designed head support, this problem would disappear. Figure 7.15 shows visually possible redesign opportunities

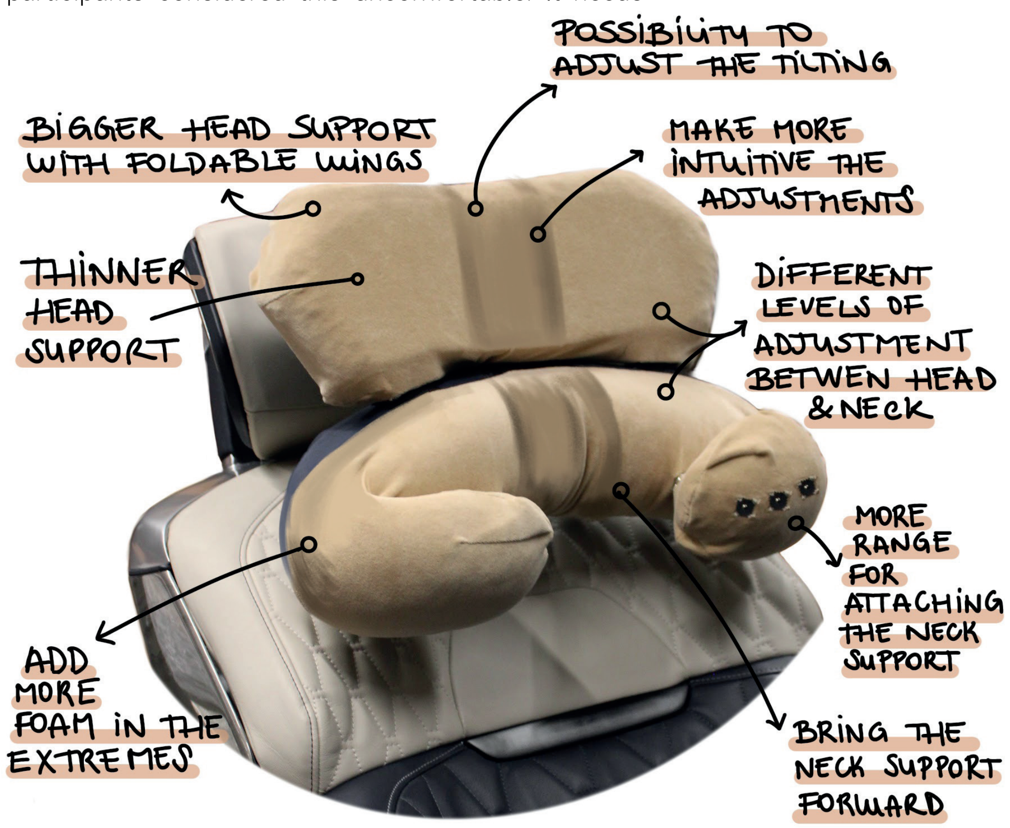


Figure 7.15. Possible redesign opportunities

7.5. Conclusion

After testing the design, it can be conclude that the design meets with most of the requirements, while others still need to be tested, as seen in Table 7.3.

As already mentioned, the design undeniably enhances sleeping comfort, altough remain areas are yet for refinement. However, it needs to be taken into account that providing sleeping comfort is subjective and subject to individual preferences. While the product fulfills the main objective, adressing the problem definition in Chapter 5, accommodating every user's comfort preferences presents a formidable challenge

Requirements	**Design meets the requirement (Hypotheses)**	**Accomplished**	**Feedback / Inisghts**	**Redesign opportunity**	**Further testing**
The design is easily integrated in the current seat	Yes	Not tested		Adaptability for different types of seats	Evaluate how easy it is to entegrate with the proposed solution
Neck and head support can be adjustable to different anthropometrics	Yes	Yes	Easy to adjust and adapt	Place it closer to the neck, more levels for attaching	
The design improves overall comfort and sleeping comfort on the seat	Yes	Yes	Participants fell asleep after few minutes		
The design has an aesthetic appearance similar to the seat	More development needed	Not tested			Test different materials, ways of attach both parts
Mechanisms can be integrated easily in the concept	Yes	Not tested			Evaluate proposed mechanisms: smaller and compact
The design adapts to the shape of the seat and does not take more than the necessary space	Yes	Yes	The design does not provide discomfort in other areas		
The shape of the headrest is not overwhelming when folded and different postures are allowed	Yes	Yes	Different preferences depending on the participant	Adaptability between fixed or tilting headrest	
The design avoids falling effect while sleeping	More development needed	Depending on the user	Some participants suffered reclination of head while sleeping	Fixing the head suppport while making it bigger	
The mechanisms integrated are safe, easy and intuitive to use	Yes	Not tested	Intuitive after explanation		
The design enables easy repairability and cleaning of the product	Yes	Not tested		Test with fabrics that are easier to clean, covers easier to remove	
The design supports the head and neck equally and provides comfortable placement of them	Yes	No	supports the neck but not always the head		

Table 7.3. Requirements checklist

8 Discussion & Conclusion

The last chapter of this project provides a summary of what has been achieved with this thesis, and provides a list of recommendations and future implementations.

8.1. Conclusions

The project has successfully researched and delivered a new design for head and neck support that can be integrated in the current seat, considering the scenario of relaxing and napping.

First, this thesis shows how discomfort in the neck and head is one of the most important factors regarding sleeping in constrained spaces. Not only vehicle seats, but also in trains or aircrafts. Additionally, it has been proved that through the design of a head and neck support following the literature research recommendations, the overall and sleeping comfort significantly increases. There are a lot of studies regarding ergonomic and design considerations for comfort in constrained spaces. However, when evaluating the current market, most of these considerations are not applied yet.

BMW did an exceptional job with the design of the seat, as verified by the sixteen users that tested it for napping during thirty minutes. Proof of this is how enthusiastic they were for joining the second session of the research. The fact that more than half of the participants managed to sleep in less than thirty minutes in a constrained space also indicates it. However, one of the most critical points when trying to sleep in such spaces has always been the upper part of the body, and from here, the second goal of the project started.

Improving the neck and head support of the seat was not easy. Lots of development and innovation in the market regarding travel pillows, car seat pillows or similar already try it. However, the main challenge here was to develop a support that can adapt to different anthropometrics in terms of head and neck adjustment, while offering different height ranges.

The design process involved many ideation steps, sketches, iterations on the prototype, and difficult choices in order to develop the product on time. The choice of developing a headrest as an accessory, instead of trying to modify the current backrest of the seat, was a hard one. Although it is not clear if this is the best solution for the problem, it has been useful in order to check that, either with the integration of this personalized support, or by redesigning the backrest and integrating a new support of similar characteristics, the sleeping comfort will significantly increase.

From there, countless sketches and quick prototypes with paper were done in order to come up with a functional shape that can adapt nicely to the current seat. Two low fidelity prototypes were done and quickly tested in order to check that adding a support to that part of the seat will improve the comfort. From there, iterations with two more prototypes varying the shape were useful to assess the feasibility regarding sizes, materials and mechanisms. This resulted in a final design with modifications in all of these three aspects: smaller, with softer materials and lighter mechanisms. These variations and iterations have allowed developing a final design that is easy to integrate in the seat and aesthetically pleasant.

For delivering a personalised headrest to the needs of the user, multiple mechanisms and designs were evaluated. Coming up with mechanisms that can fulfill all the requirements proposed resulted in different challenges, such as integrating visible mechanisms while making sure these are easy to use and intuitive for the user

The final prototype has been validated with ten possible future users while sleeping for thirty minutes. The fact that they had already participated in the initial sleeping research helped to discover the strong points and limitations of the design. This was done through observations, interviews, and data from pressure sensors.

Integrating pressure sensors helped to validate the project and compare it with the scientific results that are currently published about comfort on head and neck support. Although these sensors are not the best way to test the pressure distribution and how much pressure is applied to different areas of the design, the results obtained do provide an estimation of these. The data obtained matches with the expected and shows how the product should increase the levels of comfort.

This data is supported by the feedback from the participants, who evaluated the design positively and all managed to sleep in a thirty minute nap. Validating the design has given a better visualization of the product, and has been useful to discover redesign opportunities for improving further the sleep, such as trying to increase the size of the head support or placing the neck support forward for better contact. However, the contradiction on design opportunities provided by users shows how subjective the comfort is in terms of sleeping. One feature can be really comfortable for a group of users while being quite uncomfortable for others.

8.2. Limitations and future opportunities

Design recommendations

From the design recommendations extracted by the participants feedback and the observations, a new prototype should incorporate following recommendations: The new design should undergo further validation in the context of sleeping, but also when not sleeping, in order to check if it is disruptive.

Although there are formulated multiple design improvements, it is recommended to mainly analyze and avoid the falling head effect over time during napping. While it has not provided notorious discomfort for a short nap, this discomfort would increase when trying to sleep for longer periods.

An important recommendation is to keep the tilting while offering the opportunity to keep the headrest fixed if desired. Most of the participants valuated positively the opportunity to move the head towards the laterals while having a support that prevents the head from falling, comparing it by being better than the ones in seat aircrafts. A bigger head support that can reach the cheeks would prevent an undesired falling head effect. However, this should be tested and check if it is feasible for a seamless integration with the aesthetics of the seat.

Further ideation and testing should be done regarding the integration of the product to the seat. However, the possibility of offering a removable head support provides the passenger/driver the opportunity to use it when desired, such as resting in a long trip or when it is needed to take a nap at a certain moment while charging. This way, it is not uncomfortable or overwhelming when not using it.

Design iterations and further research on fabric and foam can increase the comfort of the product and the durability. Although it is already integrated with a harder foam in the head support and a softer for the neck area, it might be interesting to check if memory foam would improve comfort in some of these areas. Regarding the fabric, the final prototype is done with natural cotton, while the first iterations, a cover of artificial leather was developed. Although this is more durable and easier to clean, it was too hard for bending and not comfortable with the contact of the upper area of the body.

Further testing of the design

To ensure an accurate pressure distribution of the user towards the support, another user test should be performed with the integration of a pressure mattress. This would allow us to analyze the points on where most pressure is created over time and how comfortable it is in order to change movements to relieve pressure.

Integration of the support VS removable support

Further evaluation should be done in order to check if it is better to integrate the product as a part of the seat or provide it as an accessory. It should be considered the need of adapting it for shorter people. The current backrest fits only a person from a bigger percentile than P50, in order to reach the current head support.

8.3. Personal reflection

Looking back to my thesis briefing, it is fulfilling to see how all the personal ambitions and learning goals have been accomplished along the project.

While there are many things that I would have done differently in this project (such as focus less on prototyping the mechanisms, try to integrate the product in the seat earlier, or having the report up to date), I am surprise on how I have been able to handle each step of this project on time according to my timeline. Undoubtedly, out of my six years as a university student, this project has been the most enjoyable to develop and has taught me the most. Working with such an inspirational and passionate team has helped me to give my best and encouraged me in every step.

The challenges have not been few, but from them I have learnt the most. From carrying out research on my own with sixteen participants, analyzing the data and providing relevant results to BMW, to come up with a product that I have been able to validate. These are few of many more goals accomplished that have enriched me with new knowledge that I certainly did not have five months ago.

The goal was not simple. The market is full of travel pillows and neck supports designed for traveling in aircrafts or for attaching to the car seat. However, I felt that something unique could come up by focusing on the BMW seat and the needs mentioned by the participants, focusing mainly on what is necessary for fully sleeping comfortably.

The literature research regarding measure comfort, and the sensors that BMW had integrated in the seat sparked my curiosity towards the possibility of integrating my own sensors in my design. Integrating a few sensors that basically read information might look easy, but considering that I had never worked with electronics of this type, it has been a challenge from which I have learnt and at the same time enjoyed when the code was giving me errors. Honestly, discovering that the proposal of integrating was not accurate enough to calculate the overall pressure, was, to say the least, demotivating. However, it was really curious to analyze the results of each participant. Although some charts did not record enough data due to the pressure applied by the participants, it was encouraging to see how most of the charts accomplished the data observed in literature research.

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