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# The effect of seating recline on sleep quality, comfort and pressure distribution in moving autonomous vehicles

Irene Caballero-Bruno [a,b,*], Thomas Wohllebe [a], Daniel Töpfer [a], Pedro M. Hernández-Castellano [b]

[a] Volkswagen AG, D- 38436, Wolfsburg, Germany
[b] University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain

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ABSTRACT

The revolution of technologically advanced vehicles with a high level of automation involves a profound transformation. The focus of most research in this area has been on the use of travel time for different use cases. Sleeping is one of the most time-consuming activities in everyone's life; therefore, this has been described as one of the most desired use cases for fully automated vehicles. In order to identify the best conditions to allow sleep and improve sleep quality while travelling in such vehicles, two studies were performed: a sleep study and a pressure distribution study, the results of which are included in this document. The focus of both studies was on two seat positions: reclined (60° backrest recline) and flat (87° backrest recline). In the sleep study, forty participants had the opportunity to sleep during a 90-min drive in order to evaluate long-term comfort and subjective sleep quantity and quality. Although both positions resulted in generally similar results in terms of sleep and comfort, some significant differences were identified. Karolinska Sleepiness Scale results showed that sleepiness increased in the reclined position, whereas it decreased in the flat position. Moreover, the self-reported parameter Wake After Sleep Onset was higher in the reclined position. In the pressure distribution study, it was possible to identify specific seat prototype limitations indicating inadequate support, which was related to discomfort detected during the sleep study. As a conclusion, the comparison between the reclined and flat positions showed indications that, in moving fully automated vehicles, the flat seat position is the most comfortable and effective for sleeping.

## 1. Introduction

The development of highly automated driving systems is expected in the near future (Audi, 2022; Daimler, 2022; Moia, 2022; SAE, 2021; Tesla, 2022; Waymo, 2022). One of the main advantages of such systems is the optimization of journey time. It allows the user to focus on side tasks that are not related to driving, also known as non-driving-related tasks. Considering that sleep is fundamental for human beings and that we spend one third of each day sleeping, it can be expected that users of fully automated vehicles would like to sleep while travelling. This same conclusion has led to the recent release of several car concepts from leading automotive manufacturers featuring a sleep/relax environment (Hyundai Motor Group, 2019; Nica, 2020; Volvo Car Corporation, 2015, 2018). Simultaneously, several studies and surveys have focused on the passenger wishes for the new automated setting (Yang et al., 2019). These studies show an increased interest in sleeping or resting while travelling in a fully automated vehicle (Becker et al., 2018; Cyganski et al., 2015; Kyriakidis et al., 2015; Östling and Larsson, 2019). However, limited research has been conducted on sleeping while travelling in vehicles, in particular in a car.

In order to sleep comfortably and safely inside a vehicle, the interior as we know it today should undergo an overall transformation and adapt to an optimum sleep environment. Optimal sleep hygiene parameters are achieved by controlling several factors, including temperature, noise, lightning, humidity and air quality (Caddick et al., 2018). These are all external factors that can be easily modified, in a controlled scenario, with current technology. Other disturbing factors that affect sleep are specific to the vehicle context (Tan et al., 2010). These factors, such as vibration and vehicle movement, can create unnatural, involuntary body movement and have been associated with sleep disruptions (Matsangas et al., 2015) and hence should be minimized as much as possible (Caddick et al., 2017). Meanwhile, other important factors are

* Corresponding author. University of Las Palmas de Gran Canaria, D- 38436 Wolfsburg, Germany.
*E-mail address:* irene.caballero102@alu.ulpgc.es (I. Caballero-Bruno).

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the result of the direct interaction of the person with the sleeping system. Those factors include privacy, safety and comfort.

When the common sleeping space is analyzed, we observe that humans often sleep alone or with their partner. Far from being a social activity, sleep is considered a private matter. The need for personal sleeping space has been defined by NASA as the top priority for sleeping in spacecraft (Harrison et al., 1986).

It has been claimed that fully automated driven vehicles could be safer (Lubbe et al., 2018). However, avoiding all possible collisions cannot be guaranteed. Furthermore, in a scenario where the vehicle seat will not be reclined, shaped, angled or situated in the traditionally forward-facing upright position, the existing 3-point restraining systems are likely not sufficient to provide the same protection as the current standards (Boyle et al., 2019; Rawska et al., 2021; Tang and Liu, 2012; Wiechel and Bolte, 2006). Thus, it is expected that new adapted restraint systems and safety mechanisms will be required. The attitudes towards additional restraint systems were explored in a study by Östling and Larsson (2019), in which most of the participants (63%) were positive about the use of an extra seatbelt in alternative seating positions and that it would be especially needed when resting. In this sense, both factors, comfort and safety, were linked to the restraint systems in a vehicle scenario.

A comfortable bed system that provides sufficient musculoskeletal support is essential to reach good quality sleep (Caddick et al., 2017; Haex, 2004; Verhaert, 2011). In this sense, people tend to sleep on flat and even surfaces that distribute the body load in an optimal way, allowing them to maintain comfortable and supported sleeping positions, such as side, prone and supine. Simultaneously, these surfaces should allow them to shift positions easily during sleep, 2 to 4 times per hour on average (Koninck et al., 1992). Therefore, it is apparent that the sleeping surface is considered to have a great impact on comfort and consequently on the sleep quality.

Existing research in the field of long-haul flights has shown that the seat is the most significant comfort factor when it comes to sleeping (Bouwens et al., 2018; He and Vink, 2020). Moreover, sleeping was found to be not only the most common activity, but also the least comfortable (Bouwens et al., 2017). In this field, seat improvements have been suggested to allow more comfortable sleeping. For example, Roach et al. (2018) investigated the impact of seat back angles on sleep at naptime through polysomnographic data. The results concluded that the quality and quantity of sleep is greater as the seat back angle increases, which is consistent with a previous study (Nicholson and Stone, 1987). However, the study was performed in a static, laboratory scenario, where other specific travelling factors, such as vibration, movement, noise and previous experience and expectations, were not included. These factors might also influence the outcome i.e., sleep quantity and quality.

Another approach when it comes to the evaluation of sleeping surfaces in vehicles is to focus on the biomechanical quality. Stanglmeier et al. (2020) evaluated the interface pressure of different reclined seat back and seat pan angles in a supine body position in order to ultimately define the best seat angle for sleeping. Participants also rated how suitable they considered each seat position for sleeping. However, this did not correspond to the positions with the most favorable pressure properties, which were found for a 155° backrest angle and a 40° seat pan angle from the horizontal. It was argued that this discrepancy could be due to the short sitting duration. However, supine position is not the most common sleeping position and the study did not account for the multiple postural changes during sleep (Koninck et al., 1992). This could have been another reason, since for example, the lateral sleeping posture would have a different pressure distribution.

The main aim of the present study is the evaluation of the comfort of seat angles and in-vehicle sleeping while travelling. The pre-established framework (Caballero-Bruno et al., 2022) allows the user-experience, comfort and safety to be explored through the occupants' physical experience with prototypes. Here, the realistic set up of the conditions, the environment and the study scenario of the user is key to be able to evaluate the sleep support systems. This paper specifically focuses on the comparison of different seat angles, in terms of user comfort and sleep quality through subjective measurements. The objective is ultimately to define the most suitable position of the seat, including the seat pan, backrest and leg rest angles, for sleeping in a moving vehicle environment.

This paper describes two studies conducted on the influence of seat position on comfort and sleep. The first (main) study assessed the comfort and subjective sleep quality of two different seat positions while sleeping in a moving car. The second study evaluates the pressure distribution of the two different seat positions, with the addition of an upright seat position. The main hypothesis of this work was that the quantity and quality of sleep in a seat would increase as the seat recline increases towards horizontal.

## 2. Methods

### 2.1. Sleep study

A user study was conducted in order to explore the sleep experience of two seat conditions in a dynamic set up in the context of autonomous driving. The participants had the chance to experience mainly one of the conditions, a reclined or flat seat position. The objective of this study was to obtain subjective comfort and sleep data that resulted in an evaluation and comparison between the two conditions.

#### 2.1.1. Participants

A representative sample of forty adults, consisting of twenty-five men and fifteen women, volunteered to participate in the between-subject study (Table 1). All participants confirmed that they did not suffer from chronic back pain, recurring motion sickness or illnesses that affect sleep. Due to the prototype seat limitations, the inclusion criteria for participation included: height, not less than 160 cm and not more than 195 cm; and weight, not more than 110 kg. Due to study design boundaries, participants were also recruited according to their chronotype, through a self-assessment questionnaire (Horne and Östberg, 1976; Terman et al., 2001). Definite morning, moderate morning and intermediate chronotypes were favored, as their circadian rhythm would generally allow them to be more prepared for sleeping at an earlier time, compared to those with an evening chronotype. The final distribution of chronotypes of the participants was: definite morning (7.5%), moderate morning (40%), intermediate (50%) and moderate evening (2.5%).

Since each participant mainly only tested one of the positions, participants were divided into two groups: the reclined position group and the flat position group. In order to balance the two groups of participants, criteria were selected and prioritized (Fig. 1). The time of the test varied according to the four test time slots starting at 18:00, 20:00, 22:00 or 00:00. As a priority, each individual time slot was balanced to have the same number of participants who tested the reclined and the flat conditions. Furthermore, participants' chronotypes, genders and heights were also considered when dividing participants into the two groups.

Due to the COVID-19 pandemic, a special hygiene protocol had to be followed. This included several procedures and measures during the test. Firstly, the participants were required to sign a declaration of no COVID-19 symptoms before the test. After each participant, all contact surfaces

**Table 1**
Anthropometric measurements of the participants.

| Participants [n = 40] | Mean | SD |
|---|---|---|
| Age (years) | 41 | 12 |
| Height (cm) | 174.5 | 8.2 |
| Body weight (Kg) | 78 | 11 |

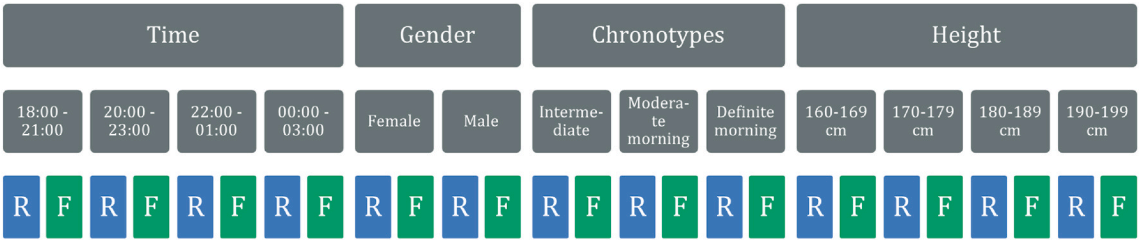



**Fig. 1.** Diagram of balancing criteria for the 2 groups of participants: Reclined position group (R) and Flat position (F) group.

were cleaned and disinfected and the vehicle was aired. A maximum of two people were allowed inside the vehicle, the test director/driver and one participant. The test director was asked to wear a FFP2 mask during the whole test, as well as to disinfect their hands and writing material regularly. Each participant was provided with an unused individual blanket and pillowcase, and, if needed, a medical mask. The participant was required to wear the medical mask throughout the trial, including while sleeping.

Participants were advised to wake up as early as possible and to not take naps during the day of the study. In order to find potential correlations, demographic and sleep habits were inquired. Participants sleep habits were self-assessed using the Pittsburgh Sleep Quality Index (Buysse et al., 1989). Before the experiment, the participants were informed about the content and procedure of the study and provided their informed consent.

### 2.1.2. *Test conditions*

The study was carried out by using a prototype seat located inside the back part of a Volkswagen T6.1 Multivan (Fig. 2). The interior of the car was modified to reproduce a comfortable, private environment comparable to a luxury class airline. The seat prototype consisted of a backrest (899 mm × 643 mm), a seat pan (482 mm × 665 mm) and a leg rest (348 mm × 436 mm). When flat, the total lying surface was contained in an area of 1.91 m by 0.66 m.

The two conditions that were tested consisted of two seat positions, a reclined and a flat position (Fig. 3). The back angles of the seat to the vertical were: 60° in the reclined condition, which is similar to the reclined positions mentioned by Smulders et al. (2016) and Stanglmeier et al. (2020); and 87° in the lying position, very close to the flat angle of a bed. Respectively, the seat pan and leg support angles were selected by researchers during pilot testing according to what was most comfortable for each of the backrest angles. The seat pan was positioned at 20° and 0° (with respect to the horizontal) and the leg support was set at 65° and 90° (with respect to the vertical).

Since the study was dynamic, and in order to have a similar experience to a real car, the seat prototype included minimal side bolsters (Fig. 4). The surface consisted of a foam layer of 8–13 kPa hardness and a cotton cover. In order to support the spine and minimize stress, the foam stiffness in the back and buttocks area was lower than the rest of the seat. The seat could be electronically actuated into the flat and the reclined position from a normal upright position.

Moreover, the seat included a 7-point seatbelt, composed by a traditional 3-point seatbelt and a 4-point seatbelt crossed over on the opposite side (Fig. 5). Apart from both sides of the hip, a buckle point was between the upper legs.

**Fig. 2.** Prototype seat and environment in the reclined (left) and flat (right) seat positions.

### 2.1.3. *Sleep environment*

General sleep environment recommendations suggest a cool, dark, and quiet environment (Caddick et al., 2018). However, the specific sleep setting characteristics and thresholds are very individual (McGuire et al., 2016; Pan et al., 2012; Tsang et al., 2021). Therefore, the test environment inside the vehicle was controlled, but could be partially modified according to individual needs. The controlled sleep environment factors comprised noise, light, temperature and ventilation.

In terms of noise levels, the vehicle with the original diesel motor was driven at a low and constant speed (30 km/h). Although there is no definite conclusion in the literature (Caddick et al., 2018), constant noise is generally perceived as less disruptive than intermittent/short noise events. During the test, any other external noises were minimized, i.e., a no-talk environment, with music and radio turned off, closed windows and low air conditioner setting. However, some other noise events could not be avoided. For example, there were rare intermittent noises from the prototype seat from the construction load, as well as rain.

The passenger could select the ambient temperature through the vehicle's air conditioning system (mean ± SD: temperature 20.6 °C ± 1.5). A blanket was supplied as a tool to self-regulate the bedding microclimate at the optimal temperature range (17 °C and 28 °C) (Caddick et al., 2018), and create a suitable sleep environment.

Light appears to be one of the most influential external factors on sleep, as it resets the circadian pacemaker (Caddick et al., 2018; Czeisler and Dijk, 1995; LeGates et al., 2014; Zeitzer et al., 2000). For sleeping, total darkness is the most common optimal option (Cho et al., 2016; Ohayon and Milesi, 2016). Therefore, windows at the rear part of the vehicle were covered, and front and rear were divided with a dense fabric, blocking out most of the external light and making the environment dark (under 5 lx, luminous intensity) and suitable for sleeping. One participant requested to have a dim warm light on during the trip. Additionally, a pillow was provided to support the head and replicate a common bed environment.

### 2.1.4. *Experimental procedure*

The study consisted of a moderated between-subject design with two conditions. The test consisted of a questionnaire before the trial, a 90-min trial drive in the first position, a questionnaire after the trial drive, a 5-min trial drive in the second position, and a final questionnaire. Therefore, each participant had the opportunity to test one condition primarily.

Participants arrived at the test facilities at Volkswagen Proving Ground at either 18:00, 20:00, 22:00 or 00:00, where they received explanations on the procedure, and completed general questionnaires regarding anthropometrics. Right after that, each participant was welcomed to sit inside the vehicle on the prototype seat and the position was set up to the corresponding condition, either reclined or flat. Participants were then asked about their comfort and sleepiness state by means of a 7-point Likert scale and 10-point Karolinska Sleepiness Scale

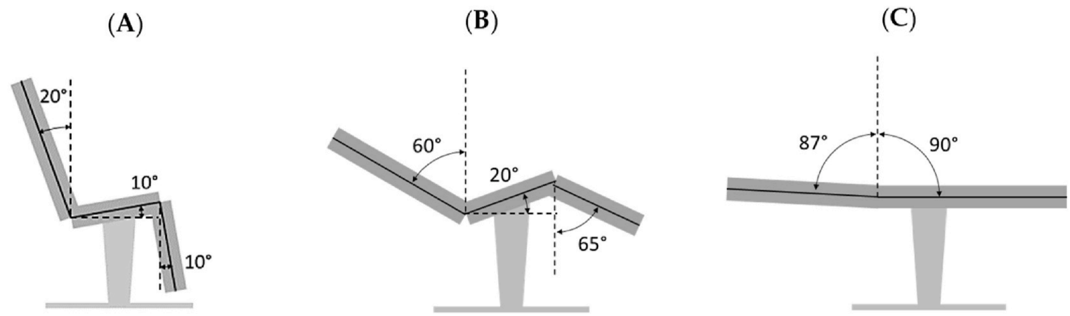



**Fig. 3.** Seat configurations for upright, reclined and flat seat conditions. (A) Upright. (B) Reclined. (C) Flat.

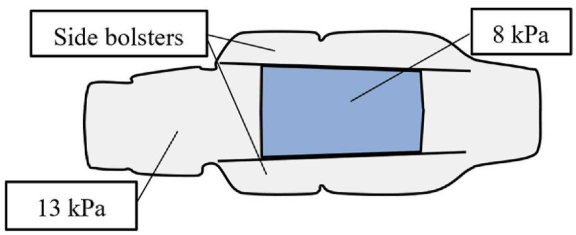



**Fig. 4.** Top view diagram of seat prototype in flat condition. Blue areas represent 8 kPa and grey areas 13 kPa hardness. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

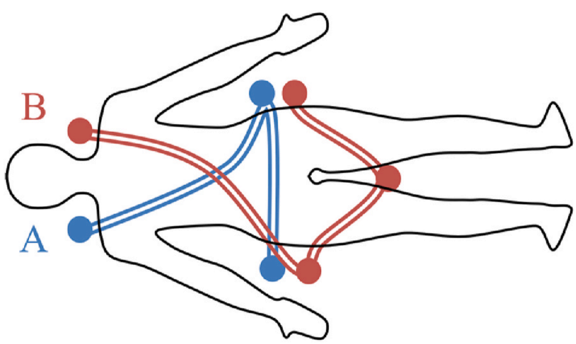



**Fig. 5.** Diagram of the 7-point seatbelt setup, consisting of a traditional 3-point seatbelt (A) and a 4-point seatbelt (B). In the upright position, only the 3-point seatbelt (A) was used, where for the reclined and flat conditions the full 7-point seatbelt was used (A + B).

(KSS). Participants were advised to relax and try to sleep in order to complete the 90-min trial drive. Participants were free to move within the seat and the restraint system during the drive. The restraint system limited the range of positions and, consequently, a prone position was not possible. However, supine and side positions were allowed and possible during the drive. During the ride on the 2.5-km test track, at a constant speed of 30 km/h, the participant had the chance to sleep and experience system. A trial drive time duration of 90 min was chosen, because this is the usual length of one complete sleep cycle (Carskadon and Dement, 2005). Once the trial drive was over, the participant was asked about their comfort and sleepiness, as well as their sleep experience, opinion and preferences. These ratings help identify areas of discomfort and track the perception of comfort after the sleep experience.

### 2.1.5. Sleep quality and comfort rating

The objective of the study was to obtain the perception and opinions of the users in terms of comfort, sleep and suitability for sleeping. To obtain overall ratings of comfort and discomfort, we have chosen to use a visual body mapping analogue scale for the whole body (Fig. 6). The scale and mapping were modelled after the modification by Kyung et al. (2008) of the Borg (1990) CR-10 scale and of the Corlett and Bishop (1976) discomfort scale, which assesses the degree of discomfort/comfort with respect to the seat. Participants rated five items on a 7-point Likert scale as to how comfortable they felt (−3 = strong discomfort, +3 = strong comfort). Participants rated seat comfort initially at minute 0 and again after the trial drive at minute 90. These ratings help identify problem areas that produce discomfort, as well as the perception of comfort over time.

Regarding sleep assessment, although polysomnography is considered the gold standard and is often the preferred method, it was not suitable for this specific user test. This is due to its complexity, limitations of time and space, and COVID-19 restrictions. Actigraphy is another popular alternative method for assessing sleep objectively (van de Water et al., 2011). Nevertheless, there were two main difficulties in using it: detection of short sleep or naps is unclear as it is limited to lengths of at least 1 h (Zambotti et al., 2019); and its use in a moving vehicle is not referenced in the literature.

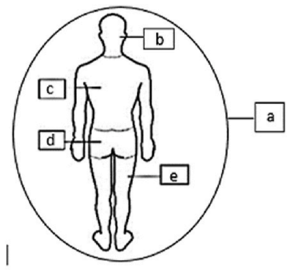
Therefore, sleep was evaluated through subjective means. The Pittsburgh Sleep Quality Index (PSQI), which is the most widely used questionnaire for subjective sleep quality, was used for evaluating participants sleep quality at home before the test drive. Relevant questions of the PSQI were used to evaluate the sleep during the test. Due to the lack of an established method for subjective sleep evaluation of a specific sleep episode, a self-reported sleep timeline outline (Fig. 7) was also filled in retrospect. This was done to get an approximate perceived sleep quantity, latency, and sleep disturbances during the 90-min drive. Reported sleep disturbances were translated into Wake After Sleep Onset (WASO), which is the total amount of time participants spent awake after initially falling asleep and before the end of the experiment.

In order to further define sleep quality, preferences and opinions related to sleep, the following questions were incorporated: Karolinska Sleepiness Scale (Akerstedt and Gillberg, 1990; Kaida et al., 2006), a promoting-interfering 5-point Likert scale (Rosekind et al., 2000) and a Multidimensional Mood Questionnaire (MDMQ) (Steyer et al., 1994).

### 2.1.6. Statistical analysis

RStudio version 1.2.5042 (RStudio Team, 2020) was used for all statistical analyses. Before the significance tests were performed, corresponding data assumptions were checked. The additional preliminary tests that were performed in order to do this were: the Shapiro-Wilk normality test and the Levene's test for equality of variances. Moreover, significant outliers were identified in advance and the corresponding data was excluded when data were missing.

Two-way mixed ANOVAs were performed to determine the effects of seat angle on dependent variables related to comfort and sleepiness (KSS) over time. For each ANOVA, the between-subject factor, i.e., the seat angle, had two levels: reclined and flat; and the within-subject factor, i.e., the time, had 2 levels: before (at 0 min), and after the drive (at 90 min). Effect sizes were calculated using Cohen's D formula




| | | Strong Discomfort | Moderate Discomfort | Weak Discomfort | Neutral | Weak Comfort | Moderate Comfort | Strong Comfort |
|---|---|---|---|---|---|---|---|---|
| | | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| a | Whole body | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) |
| b | Head / Neck | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) |
| c | Back | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) |
| d | Buttocks | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) |
| e | Legs / Feet | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) | ( ) |
| | | Any Comment? | | | | | | |

**Fig. 6.** Comfort scale and body diagram.

Example:

| *0′* | | *10′* | | *20′* | | *30′* | | *40′* | | *50′* | | *60′* | | *70′* | | *80′* | | *90′* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sleeping* | | | *x* | *x* | *x* | *x* | *x* | *x* | | *x* | *x* | *x* | *x* | *x* | | | *x* | *x* |
| *Awake* | *x* | *x* | | | | | | | *x* | | | | | | *x* | *x* | | |
| *Reason to be awake* | *Time to fall asleep* | | | | | | | | *Noise* | | | | | | *Discomfort due to the seat* | | | |

**Fig. 7.** Sample question about sleep timeline given to participants.

for paired comparisons. This shows an indication of the size of the difference in each dependent variable between conditions. The effect sizes were interpreted as very small, if $d < 0.2$; small, if $d \geq 0.20$; moderate, if $d \geq 0.40$; large, if $d \geq 0.80$; and very large, if $d \geq 1.2$ (Cohen, 1988; Sawilowsky, 2009).

On the other hand, two-tailed unpaired t-tests were used to determine the effects on the dependent variables relates to sleep amount and latency. Meanwhile, a two-sided unpaired Wilcoxon test was performed to determine the effects on the variables sleep quality and WASO.

### 2.2. *Pressure distribution study*

A smaller study was performed in order to obtain the pressure distribution of the seat in upright, reclined and flat positions. The objective of this study was to compare the subjective comfort results with objective pressure data, to confirm the discomfort areas identified in the sleep study, and to identify any other comfort problem that might be apparent from an evaluation based on the contact pressure. Moreover, pressure distribution analysis could not be included in the main sleep study due to organization complexity and time limitations.

#### 2.2.1. *Participants*

In order to have results that are related to the values of the sleep study, participants that match the minimum, mean and maximum height values for each gender of the sleep study participants were recruited (Table 2). In total, eight adults, 4 women and 4 men, volunteered to participate in the study representing a wide range of heights and weights (Table 2).

Prior to the study, subjects received instructions not to wear clothing with solid components (e.g., buttons, buckles and zippers) or very rigid fabric (e.g., jeans), on the day of the study on their legs, buttocks and back to prevent influencing measured pressure.

#### 2.2.2. *Test conditions*

The pressure distribution test was carried out using the two thin (0.09 cm) capacitive pressure measure systems from XSensor, X3 LX100,

**Table 2**
Measurements of minimum, mean and maximum height of participants of the sleep study and corresponding height of participants of the pressure distribution study.

| Participants [n = 8] | | Sleep study | Pressure distribution study |
|---|---|---|---|
| Stature (cm) | Minimum | 160 | 164 |
| | Mean (±SD) | 174 (±8.15) | 174 (±7.84) |
| | Maximum | 192 | 191 |
| Weight (kg) | Minimum | 57 | 48 |
| | Mean (±SD) | 78 (±11.01) | 73 (±14.72) |
| | Maximum | 102 | 98 |

(XSensor Technology Corporation, Calgary, Canada). The two pressure mats were used to measure the backrest, seat pan and leg rest. The largest pressure mat consisted of 2560 (40 x 64) sensing points and covered an area of 50.8 cm × 81.2 cm and was used to measure the backrest. Meanwhile, the smallest pressure system was used to measure both the seat pan and leg rest by changing its position. It was comprised 2304 (48 x 48) sensing points and covered an area of 60.9 cm × 60.9 cm. Each mat had a sensor pitch of 12.7 mm and a measurement range of 0.07–2.7 N/cm2 (accuracy: +- 5% full scale). Pressures were recorded individually for each seat part using the software XSENSOR PRO V8 (XSensor Technology Corporation, Calgary, Canada). For each measurement, the pressure mats were laid over the seat and fixed by Velcro to the seat edges, always in the same position in each of the seat parts. During the test, the participant was instructed to sit carefully to avoid creating wrinkles in the mats. Otherwise, the final results might not be representative and the mats might get damaged. Pressure distribution data such as mean pressure, peak pressure and contact area of the human-seat interface was analyzed.

#### 2.2.3. *Experimental procedure*

Each participant experienced the upright, reclined and flat seat position. The angles of the upright position consisted of: 20° backrest with respect to the vertical, 10° seat pan with respect to the horizontal and 10° leg support with respect to the vertical (Fig. 3 A). The participants were instructed to assume and maintain a relaxed supine position, with arms resting naturally next to the torso and parallel straight legs position. Due to technical problems, pressure had to be recorded separately for each seat part (i.e., leg rest, seat pan and backrest). Moreover, the two pressure mats used did not cover the whole seat surface. Therefore, when needed, the participant had to stand up momentarily after a measurement, so that the pressure mats could be moved and adjusted to the next seat part (Fig. 8). Participant's body position with respect to the seat was carefully monitored. Participants were instructed to be in the middle along the width of the seat, as well as to keep the buttocks on the seat pan.

Each seat part measurement lasted approximately 5 min, including 2 min to get comfortable and check the position of the mat and body, 2 min to record pressure, and about 1 min to verify and save the data. Therefore, in total, participants experienced each sitting position condition for at least 10 min. After each complete pressure measurement, a short questionnaire on comfort and discomfort of the respective position was completed. Finally, after the whole trial, overall seat position preference for the sleeping use-case was asked.

#### 2.2.4. *Data analysis*

Pressure distribution recordings were taken by the software XSensor Pro V8 (XSENSOR Technology Corporation, Calgary, Canada). For each participant and pressure mat measurement, 3 min was recorded at 1 frame per second. Since the participants did not move and it was a short time only one frame was taken for further analysis. For each of the readings, the 50th frame was checked against the rest of frames, and it was selected for the analysis when it did not differ from the majority visually. This was done in order to simplify and discard initial and final frames to avoid misrepresentative readings. The body was divided into 10 different zones (Fig. 9) in order to evaluate each one considering their sensitivity and specific characteristics (Binderup et al., 2010; Vink and Lips, 2017). The largest pressure mat used for the backrest was divided into 4 areas. The smallest pressure mat used for the seat pan and the leg rest was divided into 3 areas respectively. Values not belonging to the specified body zones, such as arms, were removed. In order to perform the pressure distribution analysis, the total contact area, peak pressure, average pressure and load were calculated for the total body as well as for each of the predefined body zones. Moreover, the pressure heat map of each of the participants for each of the seat positions was visually assessed and compared to the pressure maps of a seating and a lying position.

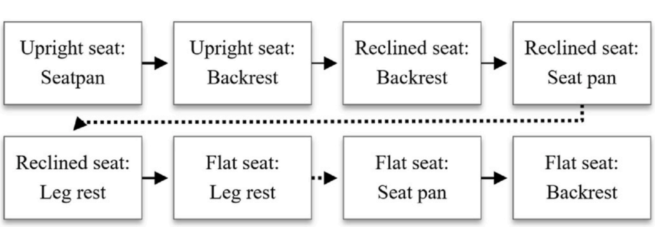



**Fig. 8.** Pressure evaluation procedure. Dotted line represents the pressure mat change of position.

## 3. Results

### 3.1. *Sleep study*

#### 3.1.1. *Comfort*

Discomfort and comfort ratings were plotted to perform the first visual graphical evaluation and interpretation (Fig. 10). Whole body comfort and body parts discomfort were generally evaluated positively. Nevertheless, a couple of discomfort points can be identified in the graph and through the ANOVA results (Fig. 10). The two areas with the most discomfort after the 90-min drive are: head/neck and legs/feet areas. Moreover, it can be observed that the discomfort gets worse over time, especially in the reclined seat position condition case.

In the case of the head/neck area, 40% of participants found the head/neck area uncomfortable (i.e., from −1 to −3), with the rating being more negative in the case of the flat position. Moreover, open-ended questions revealed that the position of the headrest was perceived as "too forward" for some participants.

The legs/feet area was also somewhat problematic, with 40% of the participants feeling discomfort in this area in the reclined position and 25% of the participants in the flat position. Some participants revealed through open questions that the discomfort in these areas was due to a numbness sensation in the feet after some time sitting/lying, caused by high pressure at the calves. Moreover, open-ended questions show that the seat pan foam was sometimes too hard for the reclined position.

Regarding the restraint system, around 40% of the participants expressed some discomfort due to the seatbelt. Comments on this issue were mainly due to the tightness and restraint of the belt, specifically around the hip and legs, as well as the position of the shoulder belts too close to the neck.

#### 3.1.2. *Sleep*

Participants' perception regarding sleep duration, awakening times, sleep latency, sleep quality, and sleep comfort and discomfort was evaluated. Due to the subjective nature of the self-reported data, high accuracy is not expected (Matthews et al., 2018); rather, participants' perception and opinion concerning sleep in a vehicle while travelling is.

Firstly, we asked the participants if they had got any sleep during the 90-min drive. Most of the participants (75%) answered "yes", while 17.5% "maybe" and 7.5% "no". At the time of self-reporting the sleep on a timeline (Fig. 7), only 3 participants (7.5%) indicated that they did not sleep during the drive, all of them in the flat position condition. The 3 participants that did not sleep were excluded from the sleep quantity analysis.

Table 3 shows the different sleep data that was collected through the self-reported sleep timeline. Regarding the sleep quantity, it is evident that mean values are quite similar, being close to 55% of the total driving time of 90 min. However, standard deviations, and minimum and maximum values of each position for sleep quantity differ considerably (Fig. 11); being the minimum lower and the maximum higher for the flat position. However, this difference was not significant. Regarding sleep latency, it can be observed that people reported a higher sleep latency in the flat seat position. In contrast, the WASO is higher in the

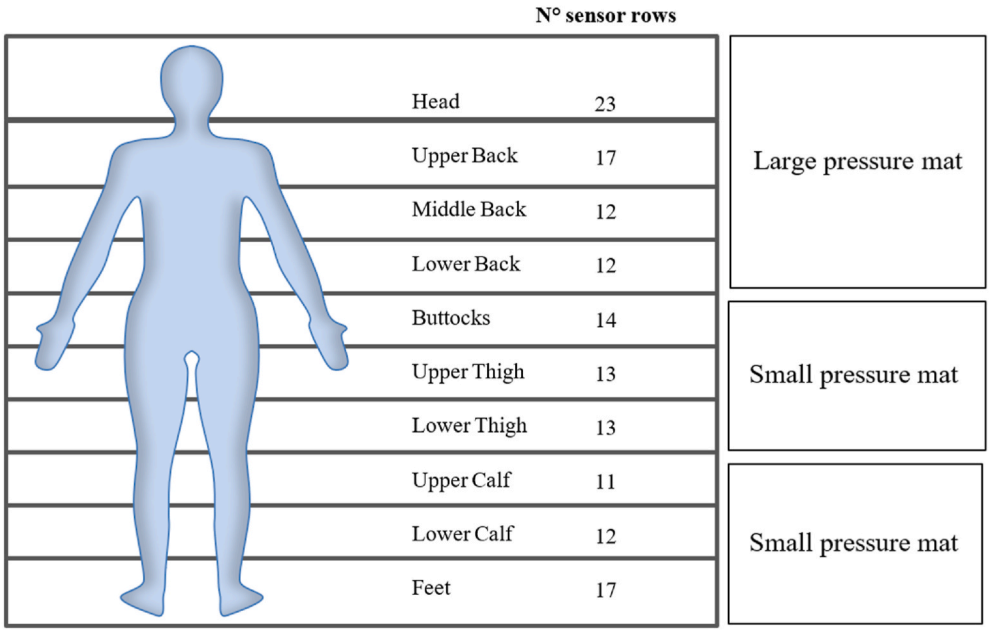



**Fig. 9.** Predefined body zones and number of sensor rows per zone.

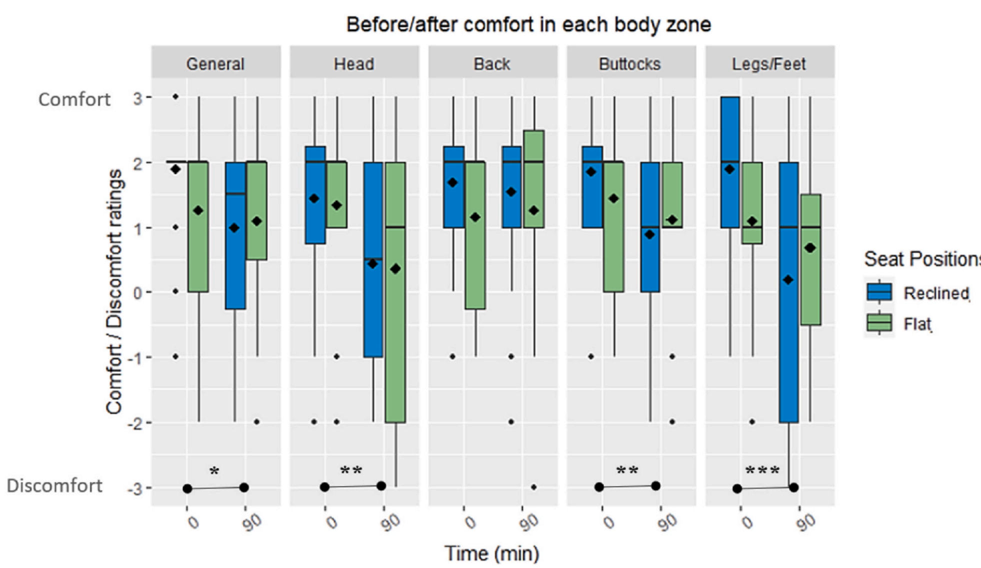



**Fig. 10.** Boxplot with different body part comfort ratings for flat and reclined seat conditions over time (N = 40, ◆ mean, ● outliers). Differences between factors through ANOVA (*<0.05, **≤0.01, ***≤0.001).

**Table 3**
Descriptive statistics for self-reported sleep. (N = 37, 3 participants were excluded from the Flat seat position due to reporting no sleep).

| Variables | Reclined seat position (60°) | | | | | Flat seat position (87°) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | mean | SD | min | max | N | mean | SD | min | max |
| Sleep Quantity **(min)**<br>***higher sleep quantity is better*** | 20 | 48.8 | 17.5 | 20 | 70 | 17 | 52.6 | 19.7 | 15 | 85 |
| Sleep Quality **(3-very good sleep, 0-very bad sleep)**<br>***higher sleep quality is better*** | 20 | 2.0 | 0.6 | 2 | 4 | 17 | 2.1 | 0.5 | 2 | 4 |
| Sleep Latency **(min)**<br>***lower sleep latency is better*** | 20 | 19.5 | 9 | 5 | 35 | 17 | 26.2 | 18.1 | 5 | 70 |
| WASO **(min)**<br>***lower sleep WASO is better*** | 20 | 21.8 | 18.5 | 0 | 60 | 17 | 11.8 | 10.9 | 0 | 35 |

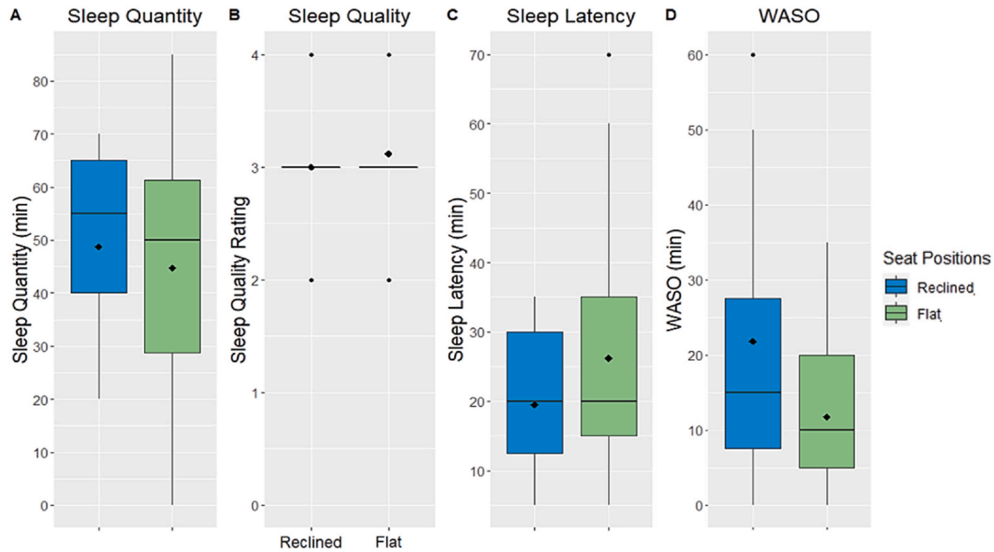



**Fig. 11.** Sleep Quantity boxplot for the reclined and flat seat conditions. (N = 40, ◆ mean).

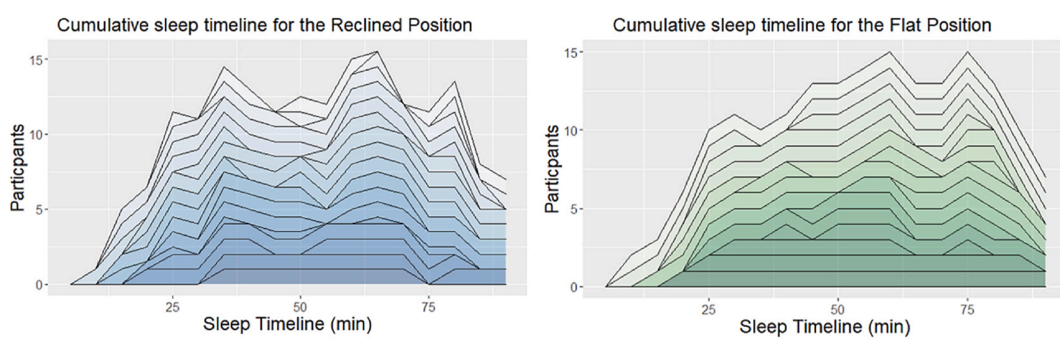



**Fig. 12.** Self-reported cumulative timelines for reclined (left) and flat (right) seat conditions. Three participants reported that they did not sleep in the flat seat condition.

reclined position.

When plotting a cumulative image of all the individual sleep timelines, the reclined seat position produced a more fluctuating sleep timeline (Fig. 12), with more awakening episodes and a less uniform sleep appearance. This behavior is ultimately the representation of the differing WASO.

Another difference between the two seat positions was the difference in sleepiness measured through the KSS (Table 4). The sleepiness assessment before the ride was performed when the participant was already in the designated position (reclined or flat) at minute 0, whereas the post-drive assessment was performed once the participant finished the trip at minute 90 in an upright seating position. Sleepiness differed in two main ways: first, before the ride, the participants were on average sleepier in the flat position and more awake in the reclined position; secondly, the participants were on average more awake after the ride in the flat positions and sleepier in the reclined position.

### 3.1.3. Significance

In Table 5 the results of the two-way ANOVA tests are shown. They were performed in order to find the significance effects on comfort/discomfort and sleepiness dependent variables. The two independent variables are seat position and time, and their interaction with each other was also tested for significance. ANOVA tests revealed that time has a significant effect on four comfort/discomfort variables: general, head/neck, buttocks and legs/feet. Moreover, the legs discomfort showed a significant interaction effect, which shows that the effect of the seat position on discomfort depended on the value of time. However, when performing paired comparisons, significance is only found in the reclined position condition for the variables general comfort, and buttocks and legs/feet discomforts. This indicates that time had a more substantial effect on the reclined seat condition. Another remarkable result is the significant interaction effect found in the KSS ratings. The interaction effect means that the KSS score depended on both the time of the measuring and the seat position.

Regarding sleep, two-sided unpaired t-tests were performed to determine the effects on the dependent variables related to sleep quantity and latency (Table 6). Furthermore, two-sided unpaired Wilcox tests were used for the variables sleep quality and WASO. Regarding

**Table 4**
Descriptive statistics for sleepiness.

| Variables | | Reclined seat position (60°) | | | | | Flat seat position (87°) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | mean | SD | min | max | N | mean | SD | min | max |
| (1-very alert, 9-very sleepy) | KSS at 0 min | 20 | 4.7 | 1.7 | 3 | 8 | 20 | 5.6 | 1.6 | 3 | 8 |
| | KSS at 90 min | 20 | 5.2 | 1.9 | 1 | 8 | 20 | 4.7 | 1.9 | 2 | 9 |

**Table 5**
Effects of the seat angle and time on the dependent variables related to comfort and sleepiness (KSS).

| Dependent Variables | | Main effect of condition | | | | | | Paired comparison | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mixed two-way ANOVA | | | | | | *t*-test | | | |
| | | Seat Position | | Time | | Interaction | | Before | After | Reclined | Flat |
| | | F | p | F | p | F | p | p | | | |
| Comfort/Discomfort | **General** | 0.85 | 0.363 | 4.39 | **0.043*** | 2.08 | 0.158 | 0.138 | 0.839 | **0.040*** | 0.762 |
| | **Head** | 0.05 | 0.821 | 10.77 | **0.002*** | 0.01 | 0.930 | 0.834 | 0.896 | 0.059 | 0.104 |
| | **Back** | 1.20 | 0.281 | <0.01 | 0.988 | 0.34 | 0.561 | 0.204 | 0.587 | 0.711 | 0.836 |
| | **Buttocks** | 0.07 | 0.796 | 8.39 | **0.006*** | 1.94 | 0.173 | 0.255 | 0.672 | **0.027*** | 0.442 |
| | **Legs** | 0.13 | 0.717 | 13.42 | **<0.001*** | 4.88 | **0.033*** | 0.054 | 0.424 | **0.004*** | 0.377 |
| Sleepiness | **KSS** | 0.23 | 0.631 | 0.30 | 0.589 | 5.10 | **0.030*** | 0.076 | 0.414 | 0.337 | 0.119 |

* Significant effect ($p < .05$).

**Table 6**
Effects of seat angle and time on dependent variables related to sleep.

| Dependent variables | Significance | | Effect Size | |
|---|---|---|---|---|
| | Two-sided unpaired *t*-test | | Cohen's | 95% Confidence Interval |
| | t | p | d | [lower, upper] |
| ***Sleep Quantity*** | −0.5639 | 0.5761 | −0.1783 | [-0.82, 0.53] |
| ***Sleep Latency*** | 1.4333 | 0.1609 | **0.4699*** | [-0.45, 0.87] |
| | Two-sided, unpaired Wilcox test | | Cohen's | 95% Confidence Interval |
| | p | | d | [lower, upper] |
| ***Sleep Quality*** | 0.5675 | | 0.2054 | [-0.16, 1.07] |
| ***WASO*** | 0.0564 | | **−0.7367*** | [-1.36, 0.19] |

* Effect size is moderate (d∼0.40), large (d∼0.80) or very large (d∼1.2).

these tests, a significant effect was not found in any of the variables, therefore effect sizes were calculated through Cohen's D test. A moderate effect was detected ($d \geq 0.40$) for the variables sleep latency (Mean; Reclined 19.5, Flat 26.2) and WASO (Mean; Reclined 21.8, Flat 11.8).

### *3.1.4. Other findings*

Other remarkable findings from the study include a gender difference. Gender appears to influence the selection of the preferred seat position. Women preferred the reclined position more often, 10 out of 15 participants (67%), while men preferred the flat position more often, 18 out of 25 participants (72%). Open questions did not reveal any potential reasons. However, gender did not show a significant effect on preferred seat position preference.

## *3.2. Pressure distribution study*

### *3.2.1. Evaluation of pressure characteristics*

When assessing comfort through pressure, generally ideal features and characteristics include: larger contact area and reduced interface pressure, both peak and mean (Stanglmeier et al., 2020). Moreover, the body needs to distribute load in a correct way, for example, by reducing unwanted load in sensitive areas (e.g., upper back), minimizing spine stress and intervertebral pressure (Wilke et al., 1999), and allowing a correct spine position; i.e., slightly smoothen lumbar lordosis (Haex, 2004). From the pressure evaluation study, the necessary values have been drawn in order to assess comfort.

The mean pressure ($P_m$), peak pressure ($P_{MAX}$), contact area ($A_c$) and load (L) for each of the three seat position conditions are shown in Table 7. From this table, these values behave as expected, causing the load and contact area to increase in the upper body as the seat recline increases. The values for the upright position are those expected and within the normal comfortable load ranges for each body zone according to its sensitivity (Naddeo et al., 2018). On the other hand, for the reclined and flat position, the surface appears to be too firm, compared to the normal pressure values of a mattress (Haex, 2004; Hu et al., 2020). A few areas where the peak pressure might be too high for the sensitivity of the body region were identified. For instance, although the sensitivity of all the different body parts could not be found in the literature, values above 1 N/cm$^2$ have been perceived as too high for more sensitive areas (Hu et al., 2020; Naddeo et al., 2018). Above this threshold, the head area in the reclined and flat conditions and the lower calf area in the flat condition have been identified. Particularly, higher peak pressures were observed, confirming the discomfort identified by the subjective discomfort ratings in the lower calf region.

### *3.2.2. Pressure heat map*

Pressure heat maps were visually analyzed and compared to a pressure map taken from lying person on a flat comfortable mattress (Hu et al., 2020). The most remarkable findings from this visual analysis are

**Table 7**
Values for the three conditions, upright, reclined and flat.

| | Upright | | | | Reclined | | | | Flat | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P_m$ N/cm$^2$ | $P_{MAX}$ N/cm$^2$ | $A_c$ cm$^2$ | L % | $P_m$ N/cm$^2$ | $P_{MAX}$ N/cm$^2$ | $A_c$ cm$^2$ | L % | $P_m$ N/cm$^2$ | $P_{MAX}$ N/cm$^2$ | $A_c$ cm$^2$ | L % |
| Head | 0.16 | 0.29 | 12 | 0% | 0.36 | 1.39 | 44 | 2% | 0.38 | 1.41 | 59 | 3% |
| Upper Back | 0.21 | 0.62 | 151 | 5% | 0.21 | 0.76 | 220 | 7% | 0.20 | 0.69 | 265 | 7% |
| Middle Back | 0.22 | 0.63 | 159 | 5% | 0.22 | 0.72 | 242 | 7% | 0.24 | 0.74 | 271 | 9% |
| Lower Back | 0.14 | 0.33 | 91 | 2% | 0.13 | 0.38 | 109 | 2% | 0.19 | 0.62 | 179 | 5% |
| Buttocks | 0.42 | 1.15 | 452 | 27% | 0.34 | 0.95 | 439 | 21% | 0.28 | 1.01 | 472 | 19% |
| Upper Thigh | 0.34 | 1.00 | 527 | 26% | 0.22 | 0.63 | 385 | 12% | 0.14 | 0.37 | 187 | 4% |
| Lower Thigh | 0.24 | 0.67 | 255 | 9% | 0.16 | 0.38 | 161 | 4% | 0.13 | 0.28 | 62 | 1% |
| Upper Calf | No contact | | | | 0.30 | 0.87 | 181 | 8% | 0.27 | 0.68 | 138 | 6% |
| Lower Calf | | | | | 0.26 | 0.79 | 145 | 6% | 0.31 | 1.08 | 180 | 7% |
| Feet | | | | | 0.05 | 0.10 | 1 | 0% | 0.20 | 0.46 | 12 | 0% |
| TOTAL | 0.32 | 1.16 | 1648 | 75% | 0.26 | 1.39 | 1927 | 70% | 0.24 | 1.59 | 1825 | 63% |

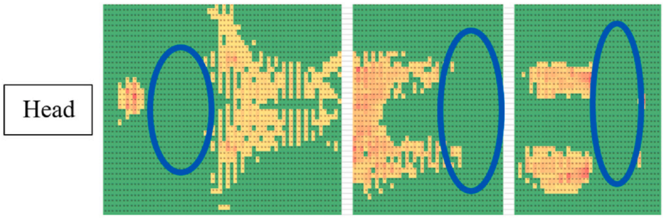



**Fig. 13.** Pressure heat map example with non-contact areas highlighted.

the areas of non-contact, such as the lower head, neck, thighs and ankles (Fig. 13).

## 4. Discussion

### 4.1. Comfort

The present study proposed a method to assess the comfort and user experience of a sleeping episode of a travelling passenger. An optimal system for sleeping while travelling in a vehicle must be able to support the body adequately, allowing the activity of sleep in the context. During the conducted study, participants had the chance to experience the seat for 90 min for its intended use, sleeping. This resulted in the identification of discomfort points of the seat through a numeric rating and open-ended questions.

Generally, the discomfort increased over time. This is consistent with previous studies and theories (El Falou et al., 2003; Lantoine et al., 2022; Vink et al., 2017). Additionally, particular discomforts points were drawn from this study.

Even though a head pillow was provided for both the reclined and full-flat position, the support seemed not to be adequate for the head and neck region. The combination of the seat geometry and foam, closer to a car seat, and the inclusion of an additional head pillow, may not create a very suitable surface for sleeping. The source of the discomfort is believed to be the involuntary movement and instability of the head during the drive due to vehicle movements and vibration. Ultimately the discomfort might have been caused by the muscle activity required to maintain a stable head position, consequently resulting in stretching and fatigue of the neck muscles (Smulders et al., 2019; Zhang et al., 2021). Moreover, discomfort might have also been related to motion sickness. Although motion sickness was not the focus of this study, discomfort and motion sickness has been linked in the literature (Winkel et al., 2022). A possible solution could be an adjustable foldable/pneumatic headrest or shaped pillow like the in the work of Zhang et al. (2021).

Another problematic region in terms of discomfort was the legs and feet area. This was due to a limitation of the seat design. The foot support is formed by an extendable platform that comes out of the end of the upper leg support. The edge of approximately 5 cm between the two surfaces, created a hanging effect of the feet for some participants (Fig. 14). This, generated a feeling of numbness at the feet after a certain time, due to high local loads at the lower calves (Bennett et al., 1980; Goossens and Snijders, 1995).

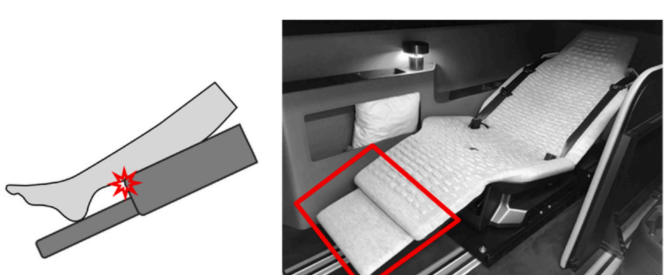


**Fig. 14.** Diagram of hanging feet effect by the seat prototype. The red start shape indicated the location of the increased pressure by the edge of the leg support. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Discomfort due to the restraint system tightness and the shoulder belts being proximate to the neck was also identified. This occurrence has been similarly observed in upright seat positions (Osvalder et al., 2019). A new design for the restraint system is needed because of the safety concerns of the new reclined positions (Boyle et al., 2019; Rawska et al., 2021; Tang and Liu, 2012; Wiechel and Bolte, 2006). Discomfort is a main influencing factor when using current restraint systems (Spado et al., 2019), and so it affects the discomfort perception of current cars. Consequently, restraint systems might have an impact on sleep quality while travelling. Hence, the relationship of the restraint system with the sleep quality while travelling should be further explored. Furthermore, restraint systems for such new vehicles should be designed with sleep quality specifications, e.g., allowing movement and postural changes.

When performing paired comparisons, significant discomfort differences over time were identified, particularly in the reclined position. A possible interpretation of the results is that the reclined position is not as suitable as the flat position for sleeping in a moving vehicle. In the reclined condition, time had an impact on the evaluation of comfort in a more substantial way than in the flat condition. This might be because the flat condition allows more common sleep positions and, over time, the comfort levels did not decrease as drastically.

Another remarkable point is the fact that the flat position initially had slightly more negative comfort ratings, although it was not considered a significant difference. This can be explained to some extent by the difference in expectations (Naddeo et al., 2015). In this case, the expectation in the context of a car is to have an upright seat position, and a flat seat position is the furthest from this. While the preliminary experience of the flat position is similar to that of a mattress. This discrepancy between previous experiences and the expectation (Vink and Hallbeck, 2012) of a car seat and mattress, respectively, could have created this marginally more negative initial opinion.

The comfort and discomfort being in the same scale has also been identified as a limitation of this study setup, as the two concepts are often defined as independent variables by the literature (Looze et al., 2003; Vink and Hallbeck, 2012; Zhang et al., 1996). The use of two distinguished scales, one for comfort and one for discomfort, might have led to more significant and accurate results and, therefore, should be considered for future research.

### 4.2. Sleep

It is worth mentioning that, even if the used method was a retrospective self-report, the results are expected to be modestly associated with the actual sleep that would be measured by polysomnography (PSG) (Matthews et al., 2018).

Regarding the difference in sleepiness levels, in the reclined seat condition KSS scores increased, while in the flat seat condition it decreased. The initial higher sleepiness of the flat position could be explained again by the role of expectation on experienced comfort (Naddeo et al., 2015). The increasing level of sleepiness in the reclined position behavior could be explained, to some extent, by a difference in the quality of sleep and rest. It appears that the flat condition allows the participant to rest better during sleep, whereas the reclined position causes tiredness in the participants. Alternatively, this could also be a sign of sleep inertia created by an unnatural awakening in the middle of a sleep cycle (Tassi and Muzet, 2000).

The limited sleeping time duration of 90 min was possibly too short to evaluate the sleep quality and observe substantial differences, although previous experiments show that an increase in seat recline has a positive effect on sleep quality (Roach et al., 2018). Besides this, the sleep data collected through the experiment was exclusively subjective. The low accuracy of the sleep data due to its subjective nature was possibly the reason for very similar sleep results between the two conditions. Actual accurate sleep recordings measured by polysomnography might produce different results. The work by Lee and Park (2006) compared “comfortable” and “uncomfortable” mattress, and found a small but significant difference in sleep efficiency, and larger differences on WASO and deep sleep, showing a clear variance in sleep quality in favor of the “comfortable” mattress. Therefore, to overcome these limitations in future work, an objective sleep recording (e.g., EEG, polysomnography, heart rate variation) could be included to complement the subjective data.

The tendency of participants choosing more reclined seat positions for sleeping while travelling has been evident in several studies (Bohrmann and Bengler, 2020; Östling and Larsson, 2019; Roach et al., 2018; Smulders et al., 2016; Stanglmeier et al., 2020; Yang et al., 2019). In the present study, due to the between-subject nature, participants could not knowledgably state a preference for a seat position, having experienced mainly only one of the two seat positions. Therefore, although there is no definitive confirmation of this preference, there are several indications, like the difference in WASO, KSS and comfort significance, to support this claim. In future research within-subject design should be favored in order to obtain the participant preference.

### 4.3. Other findings

The link of gender with the preference in position for sleeping while travelling in an automated vehicle was not anticipated. Vink and Lips (2017a) reported significant differences between males and females in sensitivity to pressure in the seat pan and backrest, and this might have been one of the reasons of the difference in preferences. Other reasons like anthropometric differences (Beach et al., 2008), such as pelvis size and flexibility, might have also been of influence. Although significant differences were not identified, this factor was revealed as a possible influence in the preference and design of the seat angles for sleeping while travelling in an automated vehicle. Thus, it should be further studied and explored in future research.

### 4.4. Pressure distribution

Data obtained from the subjective comfort evaluation was consistent with the results of the subsequent pressure evaluation. The pressure evaluation helped confirm, further identify and differentiate discomfort points by analyzing pressure values and heat maps. These points of discomfort were identified either by high peak pressures, meaning high pressure concentration; or missing contact, meaning missing support. Some of the identified discomfort points, found by subjective ratings as well as the pressure evaluation, were shared between all the seat positions. The specific discomforts generated by the seat prototype itself, and not its position, might have limited the detection of significant differences. Therefore, the seat should be optimized in order to pinpoint the position-specific differences in comfort.

## 5. Conclusion

The current study is pioneering in exploring sleep while travelling in a moving car, with the objective to improve comfort. The objective of finding the most comfortable sleeping position was explored through an interactive approach, close to a real scenario. Results of experiments conducted with participants who slept while riding in a vehicle suggest that a lying seat position appears to be more favorable for sleeping compared to a reclined seat.

According to the results of the present study, self-reported sleep quantity and quality were generally similar between the two seat positions. However, two key findings can be highlighted: the KSS and the WASO. KSS results show that sleepiness increased in the reclined seat (60° backrest recline), whereas sleepiness decreased in the flat seat (87° backrest recline). Moreover, the WASO was higher in the reclined seat. Based on PSG in a static setting, Roach et al. (2018) came to a similar conclusion. Although in this study PSG was not performed, based on the differences obtained in KSS and WASO, it is arguable that sleeping in a moving vehicle in a full-flat seat is more favorable, showing indications of better sleep quality.

Self-reported comfort data differentiating between the reclined and the flat seat positions did not produce significant variances, possibly due to their subjective nature or limited duration of the experiment. Pressure mapping revealed some limitations, indicating inadequate support by the seat prototype, resulting in discomfort. The seat prototype should be further improved in order to obtain the needed whole-body support for comfortable sleeping by solving identified discomfort points. The identified discomfort points include concentrated pressure at the calves and the missing support at the neck, lower back and legs.

Therefore, this work is a promising basis for research on sleeping while travelling. Further research should incorporate more objective measurements, such as PSG, and longer sleep events. This would make it possible to evaluate sleep efficiency in different seat positions. Additionally, further improvements to the seat prototype for sleeping are needed, as seating and sleeping require different support (Smulders, 2018). A dedicated investigation on restraint systems for highly reclined seats that allow comfortable and effective sleep should also be conducted. Finally, more research on comfort is needed to understand the influencing factors and how to optimize systems in terms of comfort (Vink and Hallbeck, 2012).

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: This manuscript is part of the PhD research of ICB, who is enrolled at the University of Las Palmas de Gran Canaria, Spain: ICB is initiator of the study. She designed and conducted the user study and is responsible for the conceptualization, study design and data analysis. ICB and TW were in charge of the conceptualization, methodology and formal analysis. PMHC and DT were involved to guide the scientific approach. All Authors were engaged in the writing, reviewing and editing process of the manuscript. The scientific quality had the highest priority. ICB, DT and TW are employed by Volkswagen AG, Wolfsburg. The objective of this paper was to define the best seat configuration for sleeping during a car journey. The results, opinions and conclusions expressed in this article are not necessarily those of Volkswagen Aktiengesellschaft.

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