Novel Car Seat Posture Assessment through Comfort and User Experience

Irene Caballero-Bruno¹², Daniel Töpfer¹, Thomas Wohllebe¹ & Pedro M. Hernández-Castellano²

¹ Volkswagen AG, Germany, ² University of Las Palmas de Gran Canaria, Spain

ABSTRACT

The increasing automation in many industries, including the vehicular market, involves a profound transformation. Since in automated driving systems, driving is no longer the primary task, the driver no longer needs to be the epicenter of the interior design. This research-based design approach explores occupants' physical experience with prototypes, and this becomes an essential part of the design and validation of the future vehicle interior. The current study is the first to examine comfort of different seat angles in order to fulfil the need of sleeping in a vehicle, based on the effect of comfort perception in close-to-real conditions testing. Therefore, user experience and comfort are the main drivers to assess the most suitable seating position, including the seat pan and backrest angles, for sleeping in a vehicle environment. Our findings suggest that users prefer the reclining and the lying seats in, respectively, short/medium and long-term use cases.

KEYWORDS

comfort, user experience, car seat, testing, seat angles

Introduction

In recent years, the trend towards higher automation has increased in many industries, including the vehicular market, where the release of automated driving systems is expected in the imminent future (ERTRAC Working Group, 2019). This new type of transport will involve a deep transformation of mobility to achieve its main general goal, which is to improve quality of life. Within this aim, two specific potential benefits of automated driving are increased transport comfort, safety and more efficient use of time during travelling (Meyer, Blervaque & Haikkola, 2019).

Since in automated driving systems, driving is no longer the main task, the driver no longer needs to be the epicentre of the interior design. Therefore, the purpose of the car interior should be radically changed so that the space can be used to allow alternative activities other than driving. Hence, the shift towards higher automation levels implies a focused search for new use cases that allow optimizing the interior design of automated cars. This search for new vehicle concepts is evident at leading automobile manufacturers, where an intensive and adventurous exploration is taking place in the creation of designs and models in order to define the upcoming future of the car interiors. At the same time, various studies are being carried out with the purpose of finding the most desired or expected uses for the interior of vehicles. As a result of several surveys, when car occupants were asked about more desired activities within automated vehicles, they showed an increased interest in sleeping or resting in this new setting (Cyganski, Fraedrich & Lenz, 2015). However, in order to sleep inside a vehicle, the interior as we know it today would have to be significantly modified.

The current knowledge about car interior, safety, comfort, usability, etc. has been generated for several decades through the optimization and gradually settlement of this technology in society to

establish the current high standards, by learning from user daily use. In the case of the forecasted automated driving revolution, it is now necessary to predict, study and analyse a completely new future scenario in order to be able to develop new viable systems. To date, we have seen both visual and physical replicas of how different conceptual interior environments might look like, including interiors with sleeping as their primary use case. Furthermore, the effort to find technical solutions for the interior arrangement is evident in recent scientific articles and patent publications on the topic. However, most of the knowledge creation on this scope is relying on the setup of theoretical scenarios, where the actual occupant physical experience is none, or very limited. This makes the future scenario difficult to imagine accurately, as most of the information currently is based on simulations, predictions, and assumptions with little or no actual human experience of the proposed systems.

In particular, research on seats for sleeping in cars is quite limited, primarily due to the high level of novelty of the topic. In order to address the issue of sleeping in a new autonomous vehicle environment, multidimensional research becomes necessary to be able to look at the topic from different perspectives, and to find comparable examples in different fields. Thus, when dealing with seats, a predominant topic in the literature has been comfort and discomfort, and, especially, the ergonomics of the seats that are used in different contexts, such as cars, trains, planes, offices, etc. Surveys have been a common method to determine comfort factors affecting user's sleep experience. For example, the work (Rosekind, et al, 2000) studied the factors affecting sleeping comfort on existing aircraft bunks beds versus the experience of sleeping comfort at home, based on the perceptions and opinions of the participants. The main limitation of that study is that it only included crewmembers from three airlines sleeping in bunks of three different aircrafts, limiting the geometries, situations and conditions to those defined by the existing facilities.

The idea of sleeping while travelling has been explored primarily for long-haul transportation industries, such as airplanes. The work (Roach et al, 2018) explored the influence of different seat angles on sleep quality at naptime. The results were consistent with previous studies and concluded that the quantity and quality of sleep increase as the back angle of the seat increases, as they depend mainly on head stability and autonomic activity. However, the study has several limitations, such as dissimilarity to real conditions and characteristics of airplane seats.

Another approach to defining the characteristics of the best ideal seat for sleeping in a vehicle is to focus on biomechanical quality. The study (Stanglmeier et al, 2020) evaluated the biomechanically quality using the interface pressure score, according to the effect of the different seat pan angles and three different backrest angles. These evaluations were complemented by the subjective evaluation carried that the participants made when they were asked how adequate the position is for sleeping. Some seat angles were defined as the most suitable because they provide the most favourable pressure properties, but this does not correlate with the highest rating in suitability for sleeping. Some limitations of that study include the short duration of the test session, a static scenario, and only male participants. Analysing a scenario closer to reality, i.e., more dynamic and with a wider range of participants and a longer test time, would be beneficial to obtain a more reliable result. Moreover, subjective ratings need to be further explored, as purely pressure data can overlook the actual user needs.

The main aim of the present study is to develop a replicable framework where user experience, comfort and safety are the main drivers for the design and validation of future vehicle systems, and where the occupants' physical experience with prototypes becomes an essential part of the development process. This paper specifically focuses on explorations of the seat towards the definition of the most suitable position of the seat, including the seat pan and backrest angles, for sleeping in a vehicle environment.

Method

In the study carried out for this paper, subjective comfort and user experience were analysed to discuss possible answers to the following questions:

- How is the perceived comfort of the seat position affected by driving dynamics of realworld conditions?
- Do seat angles affect perceived comfort in real-world conditions?
- Do discomfort of different human body areas and restraint systems affect general comfort ratings?
- How does time affect comfort and discomfort ratings?
- How do first impressions of different seatback angles reflect on their suitability for sleeping?

To answer these questions, an experimental evaluation was carried out consisting of a trial drive in a vehicle equipped with a prototype seat configured based on a close-to-real scenario. In particular, the used vehicle was a Volkswagen T6.1 Bus equipped with a mounted prototype seat at the back part of the vehicle. The vehicle environment was representing the environment of a driverless vehicle, and the space for the participant was a free, clean area, with darkened windows, in order for the user to concentrate on the seat, comfort and experience. The seat used for all the conditions and all the participants was designed to be suitable for three positions as well as for the transition between them in a suitable manner. The seat had a minimal geometry, similar to car seat designs, and did not include any armrest.

A study of several parameters on perceived comfort was carried out and the influence of different seat angles in the same condition was evaluated. To determine which driving scenario would be more suitable for investigating the questions discussed here, a number of possible cases involving different tracks, times, speeds and manoeuvres were screened, and higher speeds and accelerations were excluded to avoid unclear and unsafe conditions. The selected scenario involved a 15 minute-drive per position at a constant speed of 30 km/h through a dynamic track that included a series of different curves. Moreover, the accelerations were controlled (ay $\leq 0,2g$) during the drive. Furthermore, in order to maintain maximal safety levels, the seat included a 7-point seat belt, result of the combination of a typical 3-point seat belt and a 4-point seatbelt in the opposite direction with an extra buckle point between the users' upper legs. The trial drives were conducted in the dynamic track of Ehra-Lessien Proving Ground in Germany for two days.

The definition of the conditions involved the selections of the suitable seat pan, seat back and leg support angles. The choice of angles was done with the selection of use cases in mind to cover a broad range. The three seat positions were: upright, reclined and lying (see Figure 1). The back angles of the seat to the vertical were: 20° in the upright condition, which is comparable to the one in typical car; 40° in the reclined condition, which is the back angle of some car seats under development for future cars (Nica, 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 in order to support the body in a natural way for each of the use cases. The seat pan was positioned at 10°, 20° and 0° (with respect to the horizontal) and the leg support was set at 10°, 65° and 90° (with respect to the vertical). The seat was adjusted always from the upright position to the designed position (e.g., reclined) before each trial drive in a smooth pre-programmed transition with the user already correctly sitting. Each round was 1.25 km approximately and involved a series of different curves. The goal of the trial drive was to represent a drive with an autonomous car, which would have a smooth drive



Figure 1: Configuration of seats for the upright, reclined, and lying conditions.

Ten healthy adults (8 men and 2 women) volunteered for a subjective experimental testing of a reclining seat. The participants had some previous knowledge on the topic, but no previous experience in using the seat under the defined conditions. The participants had a mean age (\pm SD) of 42.9 \pm 12.0 years, a mean height of 182.8 \pm 9.6 cm, a mean weight of 80.9 \pm 13.1 kg, and a body mass index mean of 24.1 \pm 2.7 kg/m2.

The participants were welcomed and the instructions were explained. In particular, before the experiment, the participants were informed in detail about the content and procedure of the study and given their informed consent. Besides, all participants confirmed that they did not have any musculoskeletal injury or disease that affected sleep. Afterwards, they had the chance to drive in the car and answer a comfort questionnaire. Throughout the experimental testing, the subjects were object of a survey with 15 questions of varied format, including multiple-choice, short written responses, and fill-in-the-blank answers. The survey was divided into four sections: "Questions Before Trial Drive" (basic demographic - 5 questions), "Comfort during the trial drive" (questions while the participant is using the seat for each condition - 4 questions), "Pause Questions- After each Seat Position" (questions after the trial drive for each condition - 4 questions) and "Comfort after the complete trial drive" for each condition, the participant answer questions starting at minute 0 and again at minute 10 of the drive. The study had repeated measures, counter-balanced and randomized design with the three conditions.

Measurements of comfort and discomfort were obtained using a modified scale of the Borg (1990) CR-10 scale and the Corlett and Bishop (1976) discomfort scale, which assesses the degree of discomfort/comfort with respect to the seat. Participants rated one item on a seven-point Likert scale as to how comfortable they felt (-3 = strong discomfort, +3 = strong comfort) and four items on a four-point numerical rating scale as to how uncomfortable they felt (-3 = strong discomfort, 0 = neutral/no discomfort). Participants were asked to rate these items three times, at 0 minutes of the test drive, and just after the test drive. These ratings help identify areas of discomfort and track the perception of comfort in a brief experience. The hypothesis of the study was that increasing the back angle would to contribute to occupant comfort and be perceived as a more adequate for sleep in a driving scenario.

Initial findings

The 1.2.5042 version of RStudio (RStudio Team, 2020) was used for all statistical analyses. The data was tested for normality using the Kolmogorov-Smirnov test, and tested for association between paired samples using one of Pearson's product moment correlation coefficient, Kendall's tau or Spearman's rho, in order to describe the effect of different back and seat angles on the result variables. No significant conclusion was found in an initial analysis, probably because this first test was of a short duration and included a low number of participants. However, an analysis through

observation yielded more successful results drawn from the study. Table 1 details a summary of mean values, standard deviations, and test statistics for the analysed data. A difference can be perceived in the ratings of the different positions throughout the three different recording times (0 min, 10 min, 15 min). In the case of the upright position, the comfort ratings worsen with the time. Meanwhile, the reclined maintained the ratings mostly stable for the duration of the study. Finally, the lying position rating improved over time, from minute 0 at 1.2 to the end of the drive at minute 15 at 1.9. This phenomenon can be explained by many comfort perception models, such as the model proposed in (Naddeo, Cappetti & D'Oria, 2015), where comfort is the result of several factors, such as environment, psycho social, and cognitive factors, rather than strictly physical qualities. In several similar models, one of the inherited parts of comfort perception is the expectation or previous experience. Thus, it could be assumed that the participants had experience with normal car seats and their angle, and that they had no experience with lying position in similar circumstances (i.e., inside a car in a dynamic scenario).

Table 1: Measures for the comfort and discomfort perceptions for the upright, reclined and lying condition

Variables			Upright (20°)	Reclined (40°)	Lying (87°)
	Time	Body part	M (±SD)	M (±SD)	M (±SD)
Overall comfort	0′		2.0 (±0.9)	1.6 (±1.1)	1.2 (±1.4)
(-3 = strong discomfort, +3 =	10′		1.6 (±1.0)	1.8 (±0.7)	2.0 (±0.4)
strong comfort)	15´		1.2 (±1.5)	1.7 (±0.8)	1.9 (±1.4)
Discomfort	0′	Head/Neck	0.0 (±0.0)	-0.4 (±0.9)	-0.6 (±0.7)
(-3 = strong discomfort, 0 =		Back	-0.4 (±0.5)	-1.1 (±1.0)	-0.7 (±0.6)
no discomfort)		Buttocks	-0.1 (±0.3)	-0.4 (±0.7)	-0.2 (±0.4)
		Legs/Feet	-0.7 (±0.8)	-0.9 (±0.8)	-0.4 (±0.5)
	10′	Head/Neck	-0.2 (±0.4)	-0.4 (±0.7)	-0.7 (±1.0)
		Back	-0.6 (±0.7)	-0.8 (±0.7)	-0.8 (±0.9)
		Buttocks	-0.1 (±0.5)	-0.4 (±0.7)	-0.3 (±0.6)
		Legs/Feet	-0.8 (±0.7)	-1.0 (±0.8)	-0.2 (±0.4)
	15´	Head/Neck	-0.2 (±0.4)	-0.4 (±0.5)	-0.8 (±0.7)
		Back	-0.4 (±0.5)	-0.7 (±0.6)	-0.7 (±0.8)
		Buttocks	-0.4 (±0.7)	-0.4 (±0.7)	-0.3 (±0.6)
		Legs/Feet	-0.8 (±0.7)	-0.9 (±0.7)	-0.3 (±0.6)
Any discomfort by the seatbelt?		No (80%),	No (100%),	No (50%),	
			Yes(20%)	Yes(0%)	Yes(50%)

With regard to discomfort in different body parts, there was only a clear effect on overall comfort ratings in the case of the legs/feet and back areas. The discomfort ratings in the head and the buttocks areas showed no correlation with the overall comfort ratings, which could be seen as a somewhat surprising result. Besides, the presence of seatbelt discomfort shows no direct relationship with overall comfort ratings. Thus, the restraint system impact on user experience and comfort should be further explored in future research.

When the participants were asked about preferred position for sleeping the results varied according to the use case. The lying position was the favoured position by most of the subjects (90%) for sleeping in long-term travelling. In contrast, the reclined position was selected by 60% in both the short and medium term travelling.

The current study is the first to examine comfort of different seat angles in order to fulfil the need of sleeping in a vehicle, based on the effect of comfort perception in a close-to-real conditions.

Preliminary findings suggest that both the seat base and the back angles affect the comfort perception and that users are drawn to choosing a flatter position than the current one in series production cars, for the sleeping use case.

Conclusions

The present study proposes a combination of tests in real conditions with methodical subjective ratings to provide the most favourable conditions to understand how user opinions can change in the short term. The results suggest that users prefer the reclining and the lying seat in different use cases (long versus short and medium term). This work provides the basis for further investigations on long-term comfort, safety and vehicle movement effects on comfort related to sleep. On the other hand, to overcome the inherent limitation that the data collected is subjective, in future works the pressure record or other objective measurements will be included to complement subjective data. Besides, a longer-term study in which different types of car occupants can have the chance to sleep in close-to-real conditions would be ideal for a profound and reliable conclusion.

References

- Borg, G. (1990). Psychophysical scaling with applications in physical work and the perception of exertion. Scandinavian journal of work, environment & health, 55-58.
- Corlett, E. N., & Bishop, R. P. (1976). A technique for assessing postural discomfort. Ergonomics, 19(2), 175-182.
- Cyganski, R., Fraedrich, E., & Lenz, B. (2015). Travel-time valuation for automated driving: A usecase-driven study. Proceedings of the 94th Annual Meeting of the TRB.
- ERTRAC Working Group. (2019). Connected Automated Driving Roadmap, https://www.ertrac.org [Accessed 15 January 2021].
- Meyer, G., Blervaque, V., & Haikkola, P. (2019) STRIA Roadmap on Connected and Automated Transport: Road, Rail and Waterborne. European Commission. https://ec.europa.eu/research/transport [Accessed 15 January 2021].
- Naddeo, A., Cappetti, N. & D'Oria, C. (2015). Proposal of a new quantitative method for postural comfort evaluation. International Journal of Industrial Ergonomics, 48, 25-35.
- Nica, Gabriel. (2020): BMW X7 ZeroG Lounger features next-level seats. https://www.bmwblog.com/2020/01/07/bmw-x7-zerog-lounger-features-next-level-seats/ [Accessed 15 January 2021].
- Roach, G. D., Matthews, R., Naweed, A., Kontou, T. G., & Sargent, C. (2018). Flat-out napping. The quantity and quality of sleep obtained in a seat during the daytime increase as the angle of recline of the seat increases, Chronobiology International 35 (6), S. 872–883. https://doi.org/10.1080/07420528.2018.1466801.
- Rosekind, M. R., Gregory, K. B., Co, E. L., Miller, D. L., & Dinges, D. F. (2000). Crew factors in flight operations XII: A survey of sleep quantity and quality in on-board crew rest facilities. NASA technical memorandum 2000–209611, NASA Ames Research Center.
- RStudio Team. (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.
- Stanglmeier, M. J., Paternoster, F. K., Paternoster, S., Bichler, R. J., Wagner, P. O., & Schwirtz, A. (2020). Automated driving: a biomechanical approach for sleeping positions, Applied ergonomics, 86, 103103. https://doi.org/10.1016/j.apergo.2020.103103.