Effects of Vehicle Seat Configuration on User Comfort and Sleep Quality for a Lying Occupant

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Content

Resumen

El panorama del sector automovilístico está atravesando actualmente una profunda transformación impulsada por el rápido avance de la tecnología de los vehículos autónomos. Con la progresiva llegada de la conducción totalmente automatizada, nuestra noción tradicional de lo que se entiende como viaje en coche está experimentando una metamorfosis radical. Esto se debe a que los sistemas de conducción autónoma liberan a quienes viajan en dichos vehículos del papel tradicional de la conducción, inaugurando una nueva era de posibilidades para el diseño y la funcionalidad del interior de estos vehículos.

El progreso hacia los vehículos completamente autónomos ha estado marcado por avances tecnológicos significativos y un creciente énfasis en la seguridad, la eficiencia y la comodidad. Los vehículos autónomos son visualizados como un medio para reducir accidentes de tráfico, aliviar atascos y mejorar la eficiencia general de los sistemas de transporte. Prometen redefinir la forma de interactuar con los vehículos, eximiendo a las personas de la responsabilidad de la conducción manual y permitiéndoles centrarse en otras actividades durante el trayecto.

La idea de descansar, relajarse o incluso trabajar mientras el vehículo se mueve de manera autónoma por la carretera promete mejorar significativamente la experiencia de viaje en estos vehículos completamente automatizados. Entre los numerosos usos que son posibles gracias a los vehículos autónomos, uno que ha generado particular interés es la posibilidad de dormir mientras se viaja. Sin embargo, dormir es un proceso fisiológico complejo, susceptible a diversas perturbaciones y que requiere de unas condiciones ambientales específicas. Lograr un sueño reparador en un vehículo en movimiento presenta desafíos únicos que exigen una cuidadosa consideración del diseño interior del vehículo y la ergonomía de los asientos.

Históricamente, los interiores de los vehículos se han diseñado principalmente centrándose en sus ocupantes en una posición sentada y vertical, orientada a la conducción. Este paradigma de diseño está evolucionando a medida que nos adentramos en la era de la conducción autónoma. El cambio se enfoca hacia la creación de un entorno propicio para el descanso y la relajación. Esta transición destaca por la necesidad de explorar diversas configuraciones de asientos que permitan optimizar la comodidad para quienes buscan descansar durante sus viajes. En este contexto, se plantean tres posiciones de asiento distintas: sentado verticalmente, reclinado y totalmente tumbado, como candidatas principales para un examen exhaustivo.

La investigación realizada en este campo representa un esfuerzo pionero destinado a abordar los retos y oportunidades únicos que plantea este nuevo uso del tiempo en vehículos en movimiento. Este trabajo llena una brecha sustancial en nuestra comprensión sobre la comodidad y la idoneidad de diferentes

ángulos de asiento específicamente con el propósito de alcanzar un sueño placentero mientras se viaja en automóvil.

Con la inminente llegada de los vehículos completamente autónomos y su potencial transformador, surge la apremiante necesidad de explorar nuevas aplicaciones y casos de uso para los espacios interiores de dichos vehículos. La industria automotriz está al borde de una revolución, y esta investigación doctoral busca contribuir a esta transformación, proporcionando valiosos conocimientos sobre las condiciones que facilitan el sueño y mejoran su calidad durante el viaje.

En resumen, la motivación detrás de esta tesis está arraigada en el potencial transformador de los vehículos autónomos para servir como entornos propicios para el sueño. Los conocimientos generados por esta investigación desempeñarán un papel fundamental en la orientación del diseño y desarrollo de los vehículos del futuro, asegurando una experiencia de viaje reparadora para sus ocupantes en la era de la automatización.

El propósito general de esta investigación consiste en identificar y definir las características esenciales de los asientos e interiores de los automóviles para que favorezcan un sueño de alta calidad. Esto involucra el análisis de los aspectos ergonómicos de los ajustes de asientos, la evaluación del impacto de distintos materiales y diseños de asientos, y la consideración de la incorporación de tecnologías que apoyen el sueño dentro del habitáculo del vehículo. En última instancia, el propósito es elevar la calidad del sueño de quienes viajan en automóviles completamente autónomos, contribuyendo de esta manera a su bienestar y confort general.

Además, esta tesis busca establecer un marco fundamental y una base de conocimientos empíricos para futuras investigaciones en este campo en crecimiento. Al investigar exhaustivamente el caso de uso del sueño en automóviles completamente autónomos, este trabajo tiene la intención de proporcionar conocimientos útiles y datos que puedan servir como punto de referencia para la investigación en diseño e ingeniería de soluciones innovadoras y mejoras en esta área.

Esta tesis presenta varias contribuciones notables al campo investigado, incluyendo:

- Desarrollo de una metodología novedosa para evaluar sistemas de sueño durante el tránsito.
- Adaptación y recontextualización de técnicas establecidas de evaluación del sueño, como los diarios de sueño y el Índice de Calidad de Sueño de Pittsburgh, para su uso en el contexto del sueño relacionado con los viajes.
- Proporcionar recomendaciones para crear un entorno de sueño ideal dentro de un vehículo.
- Identificación de configuraciones de asientos adecuadas, incluidos ángulos óptimos, para lograr un sueño reparador mientras se viaja.

- Introducción de un diseño innovador de asiento específicamente optimizado para dormir durante el viaje, integrando características de asientos de automóviles con características tradicionales de superficies para dormir.
- Definición de especificaciones de sistemas de seguridad que permiten experiencias de sueño de alta calidad mientras se está en movimiento, además de la aplicación de dichas especificaciones en una propuesta de mecanismos para un sistema de retención plano, móvil y flexible que, en una posición reclinada del asiento, cubre al menos una parte del ocupante. Esta contribución fue objeto de una patente de la doctoranda como inventora, incluida como apéndice de este documento.

Esta tesis por compendio se basa en tres artículos publicados en revistas indexadas, derivadas de estudios relacionados con el sueño en vehículos completamente autónomos. Los artículos son los siguientes:

- Artículo A: "Assessing Car Seat Posture through Comfort and User Experience" publicado en Applied Sciences en marzo de 2022.

- Artículo B: "The effect of seating recline on sleep quality, comfort and pressure distribution in moving autonomous vehicles" publicado en Applied Ergonomics en julio de 2022.

- Artículo C: "Sleep quality and comfort in fully automated vehicles: A comparison of two seat configurations" publicado en Applied Ergonomics en septiembre de 2023.

Estos artículos contienen los resultados de varios estudios con usuarios que evaluaron diferentes configuraciones de asientos y condiciones de sueño en vehículos en movimiento.

El Artículo A consiste en un estudio enfocado a la evaluación de la comodidad de diferentes posiciones de asiento (vertical, reclinada y plana) en vehículos automatizados, específicamente para el escenario en el que se permite dormir mientras se viaja. El objetivo principal fue encontrar la posición más adecuada basándose en un experimento que replica el escenario de uso de un automóvil automatizado durante un tiempo corto. Los participantes en el estudio proporcionaron sus percepciones de comodidad y experiencia de usuario mientras viajaban en un automóvil con un prototipo de asiento de alta fidelidad y en condiciones de prueba cercanas a la realidad. Los resultados apuntaron a que, a corto/mediano plazo, los usuarios prefieren asientos reclinables, mientras que, a largo plazo, la preferencia se inclina hacia los asientos planos. Estos hallazgos tienen implicaciones significativas para el diseño interior de los vehículos del futuro, adaptando las configuraciones de los asientos para optimizar la experiencia de los usuarios en situaciones específicas de conducción automatizada.

El Articulo B contiene los resultados de dos estudios: un estudio del sueño y un estudio de distribución de presión, que se llevaron a cabo para identificar las mejores condiciones que permitan el sueño y mejoren su calidad. Además, los resultados del Articulo A establecieron la preferencia de dos posiciones de asiento principalmente, las cuales fueron objeto de evaluación en estos estudios: reclinada (60° de inclinación del respaldo) y plana (87° de inclinación del respaldo). El primer estudio del sueño, que contó con 40 participantes voluntarios, demostró que ambas posiciones arrojaron resultados similares en términos de comodidad, pero con algunas diferencias marcadas. La somnolencia (Karolinska Sleepiness Scale) aumentó en la posición reclinada, mientras que disminuyó en la posición plana, y el tiempo de vigilia después del inicio del sueño (Wake After Sleep Onset) fue mayor en la posición reclinada. El segundo estudio, en el que se exploró el prototipo del asiento gracias al análisis de distribución de presión, identificó limitaciones en el prototipo, indicando un soporte inadecuado en algunas partes del cuerpo, que fue relacionado con la incomodidad detectada en el estudio del sueño. La conclusión de este artículo cuyo objetivo era comparar las posiciones reclinada y plana, indica que, en vehículos totalmente automatizados en movimiento, la posición plana es la más cómoda y efectiva para dormir.

En el Articulo C se reflejó una investigación basada en un experimento con 12 participantes voluntarios que tuvieron la oportunidad de dormir durante 4 horas en dos configuraciones de asiento: reclinada y plana. El experimento y el prototipo utilizado fueron optimizados siguiendo los resultados de los experimentos previos para poder llevar a cabo una evaluación de sueño exhaustiva de mayor duración. Aunque la cantidad total de sueño fue similar en ambas posiciones, la posición reclinada mostró una leve ventaja en ese parámetro (Total Sleep Time, TST) y en el tiempo despierto después de conciliar el sueño (Wake After Sleep Onset, WASO). También hubo una diferencia en la proporción de tiempo de sueño en la etapa de movimiento ocular no rápido (Non-Rapid Eye Movement stage 3, NREM 3), que tendió a ser mayor en la posición de asiento plano. El tiempo de inicio del sueño también mostró una tendencia hacia una menor latencia (Sleep Onset Latency, SOL) en la posición plana. Además, la mayoría de los participantes expresaron su preferencia por la posición plana sobre la reclinada. Estos resultados sugieren que una posición de asiento plana podría ofrecer ciertas ventajas creando un entorno de sueño más cómodo y satisfactorio para los ocupantes de vehículos autónomos durante trayectos de larga duración.

Cada uno de los experimentos y estudios científicos incorporados en las publicaciones que integran esta tesis doctoral ha sido meticulosamente concebido, tomando como base el conocimiento bibliográfico actual [1-177].

Las principales contribuciones de esta tesis incluyen la realización de cuatro estudios de usuarios, diseñados para abordar preguntas de investigación relevantes y desarrollos contemporáneos en el campo. Se destaca la participación activa de los usuarios, lo que ha proporcionado una retroalimentación directa, contribuyendo a la comprensión sobre cómo los elementos de diseño afectan al comportamiento humano y la comodidad. Además, la metodología seguida enfatiza la importancia de recopilar datos empíricos para respaldar la toma de decisiones basada en evidencia en el proceso de diseño.

Los hallazgos confirman la viabilidad de lograr un sueño reparador y cómodo en un vehículo, destacando los beneficios de una posición plana para periodos prolongados de sueño. Sin embargo, se reconocen limitaciones iniciales en el diseño del prototipo del asiento, como molestias en la cabeza, cuello, piernas y pies. Estos condicionantes condujeron a una optimización continuada del prototipo del asiento. Otras limitaciones incluyen la muestra de participantes, duración limitada de los estudios y posibles influencias de protocolos de COVID-19.

A lo largo de la investigación se realizaron mejoras continuas en el prototipo, la metodología y la experiencia del usuario después de cada estudio. Las observaciones sobre la distribución de presión, la identificación de áreas de mejora en la comodidad y la ausencia de mediciones objetivas del sueño en los primeros estudios influyeron en el diseño de los últimos estudios. Se concluyó la necesidad de un sistema de restricción adecuado, respaldada por la identificación de molestias relacionadas con los cinturones de seguridad de 7 puntos en el segundo estudio.

Esta tesis no aborda algunos aspectos de investigación, como la optimización de espuma, el análisis del mareo por movimiento o cinetosis, y la evaluación de las vibraciones. Asimismo, excluye el estudio centrado en sistemas de restricción y su seguridad, ya que el enfoque central ha estado dirigido a la evaluación de las experiencias de sueño con énfasis en la mejora de la comodidad. No obstante, dichas cuestiones forman parte de investigaciones en curso o posibles líneas futuras. De hecho, en este documento se presenta la propuesta de un mecanismo para el uso de un sistema de restricción móvil, respaldado por una patente (5.1 Patent), fundamentado en los requisitos de comodidad y experiencia del usuario.

Las principales contribuciones de esta investigación se han publicado en revistas de alta calidad, evaluadas por expertos, lo que confirma la validez y relevancia de los principales resultados de esta tesis, cuyo objetivo principal es contribuir a cerrar brechas de conocimiento en el campo. En este sentido, los hallazgos principales sugieren la viabilidad de lograr un sueño cómodo y de buena calidad durante los viajes futuros. Además, los resultados obtenidos indican que una posición plana del asiento puede facilitar un sueño más profundo y reparador. Así, este estudio establece las bases para futuros avances en el diseño y la tecnología de los asientos de automóviles autónomos, mejorando en última instancia la experiencia general de viaje, promoviendo una calidad óptima de sueño en los trayectos, asegurando la satisfacción de los pasajeros, influyendo, en definitiva, en el futuro del transporte y la movilidad.

Abstract

This doctoral thesis represents an extensive exploration of the role of sleep within the context of fully automated vehicles. Comprising three main studies that complement each other, the research delves into the dynamic requirements and inclinations of users, focusing on the adaptability of new car interiors and seating adjustments. The primary objective was to identify and establish optimal seat angles conducive to an enhanced sleep experience while in transit.

The first study addresses the comfort of different seat angles in the context of sleeping in a moving vehicle, concluding a preference for reclined and flat seats in short-/medium- and long-term use cases, respectively. The second study, focusing on sleep quality and pressure distribution, highlights the advantages of a flat seat position over a reclined position for achieving restful and comfortable sleep during travel. The third study investigates the feasibility of achieving comfortable and restful sleep in reclined and flat seat configurations, inferring the benefits of the flat position for promoting deep and restful sleep.

The research approach involves participant engagement, integrating a wide range of methodologies, questionnaires, and objective measures to assess comfort and sleep quality. The findings confirm the feasibility of achieving a comfortable and meaningful sleep experience in fully automated vehicles. Furthermore, the thesis acknowledges initial limitations in seat prototype design and suggests future directions for research, including the refinement of restraint systems, consideration of gender differences in comfort, and exploration of alternative seat angles and materials to alleviate travel-related discomfort and sickness.

This thesis offers valuable insights into the enhancement of user comfort and sleep quality in fully automated vehicles. The research findings have been disseminated in indexed peer-reviewed journals, underscoring the significance of the contributions and their implications for the future of transportation and mobility. This investigation paves the way for advancements in car seat designs and technology, ensuring an optimal travel experience and passenger satisfaction in the era of automated driving.

1. Introduction

1.1. Background and Motivation

The automotive landscape is currently in the midst of a profound transformation, driven by the rapid advancement of autonomous vehicle technology. With the advent of full automation, our traditional notions of travel are undergoing a fundamental shift. Automated driving systems are liberating passengers from the traditional role of the driver, ushering in a new era of possibilities for vehicle interior design and functionality.

The journey towards fully automated vehicles has been marked by significant strides in technology and a growing emphasis on safety, efficiency, and convenience. Autonomous vehicles are envisioned as a means to reduce traffic accidents, alleviate congestion, and improve the overall efficiency of transportation systems. They promise to redefine the way we interact with our vehicles, freeing us from the responsibilities of manual driving and allowing us to focus on other activities during our journeys.

Among the numerous emerging use cases made possible by autonomous vehicles, one that has gained particular interest and appeal is the prospect of sleeping while traveling in these fully automated cars. The idea of catching up on rest, relaxing, or even working while the vehicle autonomously navigates the road holds the promise of a significantly improved travel experience.

However, the act of sleeping is a complex physiological process that demands specific environmental conditions and is susceptible to various disturbances. Achieving restful sleep in a moving vehicle presents unique challenges that require careful consideration of vehicle interior design and seat ergonomics.

Historically, vehicle interiors have primarily been designed with a focus on occupants in an upright, driving-oriented seating position. This design paradigm is now evolving as we transition into the era of autonomous driving. The shift in emphasis is towards creating an environment conducive to rest and relaxation. This shift underscores the imperative to explore various seat configurations that can optimize comfort for passengers seeking repose during their journeys. Within this context, three distinct seat positions —upright, reclined, and flat— have emerged as prime candidates for comprehensive examination.

The research conducted in this domain represents pioneering efforts aimed at addressing the unique challenges and opportunities posed by sleeping in vehicles. This work bridges a substantial gap in our understanding of the comfort and suitability of different seat angles specifically for the purpose of sleeping in a moving vehicle.

With the imminent arrival of fully automated vehicles and their transformative potential, there is a pressing need to explore novel applications and use cases for the interior spaces of these vehicles. The automotive industry is on the brink of a revolution, and this doctoral research seeks to contribute to this transformation by providing new insights into the conditions that facilitate sleep and improve sleep quality during travel.

In summary, the motivation behind this research is rooted in the transformative potential of autonomous vehicles to serve as conducive environments for sleep. The insights generated by this research will play a pivotal role in guiding the design and development of future vehicles, ensuring a restful travel experience for passengers in the age of automation.

1.2. Objetives

The primary objective of this doctoral thesis is to comprehensively assess the sleep use case within the domain of fully automated cars. This research aims to investigate and understand the evolving needs and preferences of users in the context of new car interiors and seat configurations. The central focus of this study is to examine various seat adjustments and positions, with a specific emphasis on the assessment and determination of suitable seat angles for optimal sleep experiences in the context of fully automated vehicles.

Therefore, the overarching goal is to identify and define the key characteristics of car seats and interiors that facilitate high-quality sleep for passengers. This involves analyzing the ergonomic aspects of seating arrangements, evaluating the impact of various seat materials and designs, and considering the integration of sleep-supportive technologies within the vehicle's interior. Ultimately, the aim is to enhance the sleep quality of passengers during their journeys in fully automated cars, thus contributing to the overall comfort and well-being of passengers.

Additionally, this doctoral thesis seeks to establish a foundational framework and an empirical knowledge base for future research in this burgeoning field. By comprehensively investigating the sleep use case in fully automated cars this work intends to provide valuable insights and empirical data that can serve as a reference point for researchers, designers, and engineers working on innovative solutions and improvements in this area.

In summary, the primary objectives of this PhD manuscript are:

- To assess and understand the sleep use case in the context of fully automated cars.
- To explore new car interiors and seat configurations to determine user needs and preferences.
- To examine various seat adjustments and sleeping positions for passengers.
- To focus on assessing and determining suitable seat angles for sleeping within this framework.
- To identify the characteristics of car seats and interiors conducive to high-quality sleep.

- To serve as a foundational resource for future research in the field of sleep optimization in fully automated vehicles.

1.3. Main Contributions

This thesis makes several notable contributions to the body of knowledge, including:

- Development of a novel methodology for assessing sleep systems during transit.
- Adaptation and recontextualization of established sleep evaluation techniques, such as sleep diaries and the Pittsburgh Sleep Quality Index, for use in the context of travel-related sleep.
- Provision of recommendations for creating an ideal sleep environment within a vehicle.
- Identification of suitable seat configurations, including optimal seat angles, for achieving restful sleep while traveling.
- Introduction of an innovative seat design specifically optimized for sleeping during travel, integrating automotive seat features with traditional sleep surface characteristics.
- Proposal of mechanisms for a movable, flexible planar restraint element which, in a reclined and flat seat position, covers at least a portion of a partial area of the vehicle occupant and does not cover the vehicle occupant in an upright seat position.

1.4. Out of the Scope

The following topics are not covered by this thesis:

- User studies on restraint systems, only handling the mechanism proposal and definition of the characteristics of the safety system that allows good quality sleep.
- Safety evaluation and analysis of the restraint system for sleeping in a lying posture. However, concerns regarding the lying position and crash safety are included in this document as part of the discussion.
- Specific seat optimizations and in-depth research regarding foam or seat contour.
- Motion sickness analysis.
- Analysis of driving comfort and vibrations.
- Specific evaluation of sleep environment conditions such as temperature, light, air quality, etc. These parameters have been controlled during the experiments, but only for user study purposes.

1.5. List of Publications

The exploration and evaluation of sleeping while driving in the context of fully automated vehicles has been the main purpose of this work. Particularly, the research for this thesis has focused on the assessment and determination of a suitable seat configuration for sleeping in a moving vehicle. Performing user studies in a suitable and realistic environment has been one of the main advantages of this research. Moreover, the continuous improvement and optimization of the car seat and interior based on feedback from participants has been of great importance in this research. The user studies were designed considering the previous studies experience and outcomes. This resulted in a set of user studies that rigorously researched the topic from different points of view. The main characteristics and conditions of the four studies carried out are summarized in Table 1:

Table 1 Characteristics and conditions of user studies on sleeping while driving in fully automated vehicles.

	Study A	Study B	Study B.1	Study C
Evaluation objective	Short-term seat comfort	Medium-term sleep comfort and seat comfort	Seat pressure distribution	Long-term sleep quality and comfort
Tested seat configurations (Angles: backrest from the vertical, seat pan from the horizontal, leg rest from the horizontal)	Upright (20°, 10°, 10°), Reclined (40°, 20°, 65°), Flat (87°, 0°, 90°)	Reclined (60°, 20°, 65°), Flat (87°, 0°, 90°)	Upright (20°, 10°, 10°), Reclined (60°, 20°, 65°), Flat (87°, 0°, 90°)	Reclined (60°, 20°, 65°), Flat (87°, 0°, 90°)
Number of participants	10 (2 women, 8 men)	40 (15 women, 25 men)	8 (4 women, 4 men)	12 (7 women, 5 men)
Experimental study design	Within subject	Between subject	Within subject	Within subject
Testing length per seat condition	15 minutes	90 minutes	5 min	240 minutes
Starting testing time	-	18:00, 20:00, 22:00 or 00:00	-	19:30
Driving scenario	Constant 30 km/h	Constant 30 km/h	Static	Static
Subjective measurements	Comfort/ discomfort	Comfort/ discomfort, KSS, sleep quality, wake/sleep timeline	Comfort/ discomfort	Comfort/ discomfort, KSS, sleep quality, wake/sleep timeline
Objective measurements	-	-	Pressure mat	PSG (EEG, EMG, EOG), heart rate, temperature, accelerometer
Seatbelt wearing	7-point seatbelt	7-point seatbelt	None	None
Article that includes the results	Article A	Article B	Article B	Article C

This thesis builds upon the research presented in three articles published in indexed journals, which are referenced in the text using alphabetical letters:

Article A	Caballero-Bruno, I., Töpfer, D., Wohllebe, T., Hernández-Castellano, P.M., 2022. Assessing Car Seat Posture through Comfort and User Experience. *Applied Sciences* 12 (7), 3376. https://doi.org/10.3390/app12073376

Article B	Caballero-Bruno, I., Wohllebe, T., Töpfer, D., Hernández-Castellano, P.M., 2022. The effect of seating recline on sleep quality, comfort and pressure distribution in moving autonomous vehicles. *Applied Ergonomics* 105, 103844. Elsevier. https://doi.org/10.1016/j.apergo.2022.103844
Article C	Caballero-Bruno, I., Lingelbach, K., Wohllebe, T., Weng, M., Piechnik, D., Tagalidou, N., Vukelić, M., Hernández-Castellano, P.M. (2024). Sleep quality and comfort in fully automated vehicles: A comparison of two seat configurations. *Applied Ergonomics*, 114, 104137. Elsevier. https://doi.org/10.1016/j.apergo.2023.104137

Article A, derived from the outcomes of Study A, represents a pioneering experiment conducted in real-world driving conditions, incorporating systematic subjective evaluations. This context provided an ideal setting to examine how user preferences evolve in the short term. The study's findings indicated a preference for a flat seating arrangement for long-term sleep and a reclined seat position for short to medium-term sleep. These insights laid the foundation for subsequent investigations into sleep-related comfort.

Article B, building upon the findings of Study B and Study B.1, delves into the concept of sleeping while traveling in a moving vehicle using an interactive approach, along with an evaluation of seat pressure distribution. The primary objectives were to enhance comfort and assess the feasibility of sleeping in such circumstances. Participants were afforded a 90-minute opportunity to sleep while the car was in motion. Although self-reported sleep duration and quality were generally similar between the two studied seat positions, notable differences emerged. Analysis of the Karolinska Sleepiness Scale revealed increased sleepiness in the reclined seat (with a 60˚ backrest recline) and decreased sleepiness in the flat seat (with an 87˚ backrest recline). Furthermore, the relevant parameter known as WASO, short for Wake After Sleep Onset, was higher in the reclined seat. Thus, the experimental results suggest that a fully reclined seat position appears more conducive to sleeping compared to a partially reclined one.

Article C, grounded in the findings of Study C, provides an extensive examination of reclined and flat sleeping positions. Unlike previous studies, it uses polysomnographic data as the primary research methodology. Both seat positions demonstrated mostly good sleep quality, with two noteworthy conclusions. Firstly, the Slow-Wave Sleep (SWS), often also referred to as NREM3 or deep sleep, constituted a significantly higher proportion of total sleep duration in the flat position, with an earlier onset observed in this configuration. Additionally, a majority of participants favoured the flat position for sleeping during car travel.

Each of the scientific studies included in the publications that constitute this doctoral thesis has been meticulously designed, drawing upon the current bibliographic knowledge [1-177].

In Table 2, the main bibliographic characteristics of the three articles are presented, including impact factors, publication date and number of cites:

Table 2 Bibliographic characteristics of published articles.

	Article A	Article B	Article C
JCR Quartile	Q2	Q2	Q2
JCR Categories	Chemistry, multidisciplinary; Engineering, multidisciplinary; Materials science, multidisciplinary; Physics, applied	Engineering, industrial; Ergonomics; Psychology, applied	Engineering, industrial; Ergonomics; Psychology, applied
Impact Factor	2.7	3.2	3.2
SCImago Quartile	Q2	Q1	Q1
SJR	0.492	0.922	0.922
Number of Cites	6	10	-
Publication Date	March 2022	July 2022	September 2023

The three articles shown in Table 2 were prepared in collaboration with the co-authors. The main work of planning the experiments, analyzing the data and writing the papers was performed by the author of this thesis.

1.6. Thesis Structure

This document begins with a comprehensive summary in Spanish, encapsulating all the key aspects of the original text (Resumen). It furnishes a thorough overview of the research within the specific context of this doctoral thesis, adhering to the guidelines set forth by the University in its Regulation for Doctoral Studies at ULPGC and national regulations, as outlined in RD 576/2023. Following this, the document transitions into the doctoral thesis abstract, offering a concise yet informative glimpse into the essence of the research presented in the document (Abstract).

The context and objectives of this thesis are introduced in the first chapter of this document (1. Introduction). The main content is formed by the three publications drawn from the four user studies (2. Articles). The four different experiments that shaped the three publications are here titled Study A, Study B, Study B.1 and Study C.

The Study A served as the basis for the establishment of the subjective assessment methods, as well as for the determination of the objectives and specific testing parameters. This study resulted in a short-term comfort evaluation. The publication (2.1 Article A), presenting the results from the first experiment, is the paper published in the Comfort Congress Special Issue, part of the Applied Sciences Journal. This article was an extension of the initial article published in the proceedings of the 2021 edition of the renowned International Comfort Congress [32].

The Study B evaluated medium-term comfort and sleep in a moving vehicle and Study B.1 was an ergonomic assessment of the seat. The second paper (2.2 Article B) was based on the results of these studies and was published in the Elsevier Applied Ergonomics Journal.

The last study, Study C, was a long-term comfort and in-depth sleep assessment. The third and last planned publication (2.3 Article C), has been accepted and is already available online, although its official publication date is in 2024.

The next chapter includes the main conclusions of the research along with some open lines (3. Conclusions and Future Works). This document ends with the compilation of all the references used in the three published articles, which offers a detailed overview of the scholarly foundation supporting this doctoral thesis (4. References). These carefully chosen references showcase the breadth of literature influencing this research.

Finally, an appendix has been included with a related published patent published by the author, which contains several proposals for mechanisms for a movable, flexible planar restraint element transition, used in a reclined or flat seat position (5.1 Restraint system mechanism patent).

1.7. Justification

This PhD thesis aligns with the thematic topic of the Chemical, Mechanical, and Manufacturing Doctoral Program due to several key reasons:

- Mechanical and Ergonomic Aspects: The research investigates the effects of vehicle seat configuration on user comfort, which is inherently related to mechanical and ergonomic considerations. Understanding how different seat configurations impact the comfort of occupants involves analyzing the mechanical properties of seats, their design, and how they interact with the human body.
- Human Factors: Examining how seat configurations affect sleep quality touches upon human factors and ergonomics, a crucial component of the program's thematic area. It involves understanding how humans interact with mechanical systems (seats in this case) and how these interactions impact their well-being.
- Interdisciplinary Approach: This research integrates mechanical engineering principles with considerations of human comfort and sleep quality, which requires an interdisciplinary approach. Thus, that interdisciplinary intersection includes multiple fields, such as mechanical engineering and human factors.

- Real-world Application: The findings from this research can have practical implications for the automotive industry, leading to the development of more comfortable and ergonomically designed vehicle seats. This aligns with the program's focus on research with real-world applications.

In summary, this PhD thesis on the effects of vehicle seat configuration on user comfort and sleep quality is well within the thematic scope of the Chemical, Mechanical, and Manufacturing Doctoral Program at the University of Las Palmas de Gran Canaria due to its integration of mechanical, ergonomic, and human factors aspects with practical applications in the automotive field.

2. Publications

2.1. Article A. Assessing Car Seat Posture through Comfort and User Experience

applied sciences

MDPI

Article

Assessing Car Seat Posture through Comfort and User Experience

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Abstract: The vehicular market is undergoing a profound transformation that includes a trend toward fully automated driving. When travelling in automated systems, the main task is no longer driving. Therefore, the interior design of automated vehicles requires a renovation to adapt to new use cases. With this motivation, the use case of sleeping while travelling was chosen for this user study, in which different seat configuration conditions were evaluated. The three preselected seat positions for this research included the upright, reclined and flat seat positions. To the best of our knowledge, this study is the first to examine the comfort of different seat angles in meeting the need to sleep in a moving vehicle. Since the physical experience of the occupants with a high-fidelity seat prototype is essential to evaluate the new interior concept of the vehicle of the future, in this study, the experimental participants were asked about their perception of comfort and overall user experience while travelling by car under close-to-real test conditions. Therefore, the primary objective of this evaluation was to explore different seat configurations and find the most suitable seat position for the use case of sleeping in a car while moving. Our findings suggest that users prefer reclining and flat seats in short-/medium- and long-term use cases, respectively.

Keywords: comfort; user experience; car seat; testing; seat angles

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1. Introduction

The expectation of the release of fully automated vehicles has increased in parallel with the trend of higher automation in the industry. In the near future, as such systems emerge in the general market, a profound evolution of mobility and the transport segment will be needed [1]. Many potential benefits of this new type of vehicle are anticipated, such as increased transport comfort and safety [2]. However, the optimization of mobility through the more efficient use of travel time has given rise to the search for new use cases, which must be analyzed.

In automated driven systems, driving is no longer a core task [3], and travelling can have new side purposes. Currently, the interior design of the car is focused on the driver and the driving tasks, spaces and instruments. This same space can be used for activities other than driving. The search for new vehicle concepts, led by automobile manufacturers, is an intensive and adventurous exploration which involves the creation of designs and models to define the future car interior. Simultaneously, various studies and questionnaires have been carried out to determine the desired uses for the interior of vehicles. One of the most desired activities while travelling is to rest or sleep [4]. To allow sleep activity inside the vehicle, the interior as we know it must undergo a significant transformation.

The process of designing and configuring the current car safety, ergonomic and usability systems has been a long and gradual process where the knowledge develops at the same time as the needs of society and advances in technology. The high criteria when evaluating cars has been created through an ongoing adaptation process and a slow establishment of ever-higher standards. To create systems that adapt to new use cases of high

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automation in the vehicular field, it is important to study, predict and forecast the new future situation. Thus, in the analysis of this upcoming scenario, it is necessary to imagine and test new interior environments, creating prototypes in a various ways, both visual and physical. The development of technical solutions for such concepts is also required. The literature includes both patents and scientific papers that explore different technical solutions. However, the real, or close-to-real, physical experience of occupants is often not used due to the complexity of building such high-fidelity prototypes. Therefore, until now, the establishment of knowledge in this field has primarily consisted of very limited user experiences and the creation of imaginary scenarios. In addition, participants in user studies and tests in the field of autonomous cars have pre-conceived, inaccurate ideas about what the future will look and feel like based on current cars and expectations [5]. In conclusion, to develop new technological advances, it is important that users are directly involved and have realistic close-to-real experiences [6,7].

In particular, the research that can be found in the literature on seats for sleeping inside 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 is necessary to look at the topic from different perspectives, and to find comparable examples in different fields [8]. Thus, when dealing with seats, a predominant topic in the literature has been comfort and discomfort, especially, the ergonomics of the seats used in different contexts, such as cars, trains, planes, offices, etc.

Surveys have been a common method of determining comfort factors that affect the user’s sleep experience. The authors of [9] focused on non-driving-related tasks and provided a list of requirements for future automated vehicle interior based on an online survey and a small-scale experiment. Regarding the seat, the study determined two related preliminary requirements: the seat should support a flat position facing the driving direction, and the seat should be wider without side supports.

An alternative method of research is to administer a questionnaire of a regular event. For example, the authors of [10] analyzed the factors affecting sleeping comfort for flight crew members. The study aimed to evaluate existing aircraft bunks beds, comparing these experiences with sleeping comfort at home, based on the participants’ perceptions and opinions. The main limitation of that study is that it only included crewmembers from three airlines sleeping in bunks on 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 authors of [11] 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 mainly depend on head stability and autonomic activity. However, the study has several limitations, such as the dissimilarity with the real conditions and characteristics of airplane seats.

Another approach to define the characteristics of the best ideal seat for sleeping in a vehicle is to focus on biomechanical quality. The authors of [12] evaluated biomechanical quality using the interface pressure score based on the effect of different seat pan and backrest angles. These assessments were complemented by subjective evaluations made by the participants when they were asked how adequate the positions were for sleeping. One of the seat configurations was defined as the most suitable because it provided the most favorable pressure properties. However, the pressure evaluation did not correlate with the higher subjective rating in suitability for sleeping. Some limitations of the study included the short duration of the test session, the static scenario and the inclusion of only male participants. Analyzing a scenario closer to reality, i.e., more dynamic, and with a wider range of participants and longer test length, would be beneficial to obtain a more reliable result. Moreover, subjective ratings need to be further explored, as pure pressure data can overlook actual user needs.

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

2. Materials and Methods

In this study, different seat configurations were evaluated for the purpose of sleeping. An experimental procedure and method were designed to conduct a user study on the subject's comfort and user experience. Three different seat configurations were applied under a dynamic moving vehicle condition. Subjective questionnaires of the topic were given during a ride using the experimental setup.

2.1. Participants

Ten healthy adults with some previous knowledge on the topic were recruited. Eight men and two women, with a varied range of heights and weights, volunteered for subjective experimental testing. The participants had an average age (±SD) of 42.9 ± 12.0 years, and an average height and weight of 80.9 ± 13.1 kg and 1.83 ± 0.1 m, respectively. According to the authors of [13], the target market for self-driving cars is consumers who are 18 years or older and hold a driver's license. Thus, the sample age, height and weight are representative of a normal population that would use such autonomous vehicle. Participants had no previous experience with the defined seat configuration and test conditions. All participants confirmed that they did not suffer from any conditions that could affect the test results, such as musculoskeletal injuries or other related diseases. Before the experiment, they were informed in detail about the content and procedure of the study, and provided their informed consent.

2.2. Test Conditions

The study was carried out using a tailored prototype seat inside a vehicle. In particular, the seat prototype was mounted in the rear of a Volkswagen T6.1 Multivan. The same seat prototype was used for every condition. The seat was designed to adapt to a wide range of configurations and be suitable for each of the seat configurations tested. In addition to the seat positions, the automatic seat transition was carefully configured for the purpose of the study.

To be representative of a car environment and suitable for every seat configuration, the seat was similar in design to current car seats with minimal geometry or contours and no armrests (Figure 1). The dimensions of the seat included a 900 mm by 645 mm backrest, a 480 mm by 665 mm seat pan, and a 350 mm by 435 mm leg rest. The total flat surface was contained in an area of 1.90 m and 0.66 m. The seat top layer consisted of a layer of 8 to 13 kPa harness foam and a cotton cover over it. The rear of the vehicle, surrounding the prototype seat and the participant, was a free, clean area. The windows in the rear were darkened to help participants focus on the seat, comfort, user experience and sleep use case.

The definition of the conditions included the selection of different seat pan, seat back and leg support angles. The choice of seat angles was made to have three wide-ranging seat configurations and cover a broad range of use cases. The final chosen seat configuration conditions consisted of an upright, reclined and flat position (Figure 2). The back angles of the seat with respect to the vertical were 20° in the upright condition, which is a usual configuration in current cars; 40° in the reclined condition, which is the angle of some car seats under development for future cars [14]; and 87° in the flat position, which is very close to the flat angle of a bed. The seat pan and leg support angles were selected correspondingly to support the body in a natural way for each of seat configurations. 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.

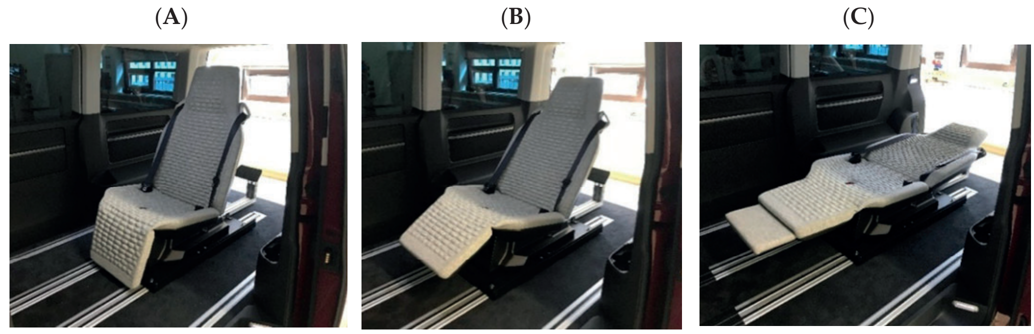


Figure 1. Prototype seat and environment in the upright, reclined and flat seat positions. (**A**) Upright. (**B**) Reclined. (**C**) Flat.

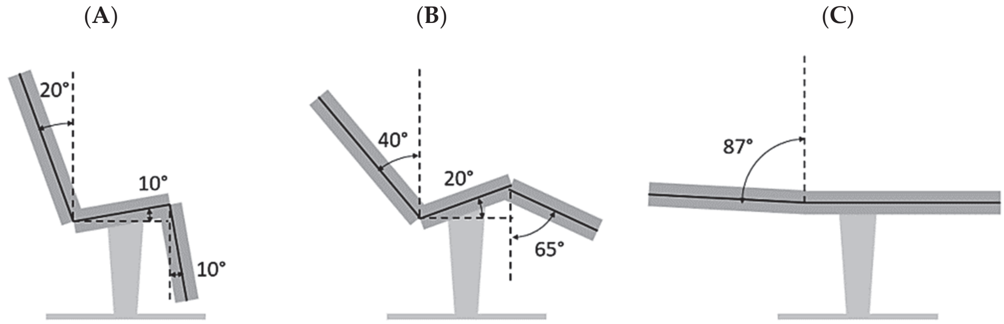


Figure 2. Configuration of seats for the upright, reclined and flat conditions. (**A**) Upright. (**B**) Reclined. (**C**) Flat.

Before each trial drive, the seat was adjusted from the upright position to the designed position (e.g., reclined) in a smooth pre-programmed transition while the participant was sitting correctly. In addition, to maintain safety levels in the reclined and flat positions, the seat included a seven-point seatbelt, which was the result of the combination of a conventional three-point seatbelt and a four-point seatbelt in the opposite direction, with an extra buckle point between the users' upper legs (Figure 3).

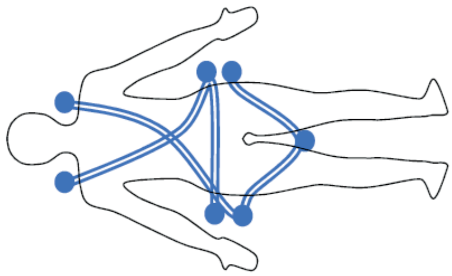


Figure 3. Diagram of the 7-point seatbelt setup on a human body.

2.3. Experimental Procedure

A dynamic user study was conducted to investigate seating comfort under a wide range of seat configurations with the purpose of sleeping while driving. The main hypothesis of the study was that a more reclined back angle would contribute to occupant comfort and be perceived as a preferred configuration for the sleeping use case in a driving scenario. Subjective comfort and user experience were analyzed to answer the following research questions:

- Do seat angles affect perceived comfort in real-world conditions?
- Does the 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 their suitability for sleeping?

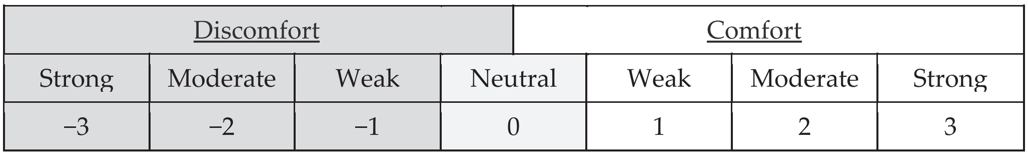
These questions were answered through an experimental evaluation. The study was a moderated in-between designed study with three conditions. The study had repeated measures, and a counter-balanced and randomized design. Participants were welcomed and the instructions were explained. The questionnaire contained 15 questions of varied formats, including multiple-choice, short written responses and fill-in-the-blank answers. The survey was divided into four sections: "Questions before trial drive," which included basic demographic questions; and "Comfort during the trial drive," "Comfort after each seat position," and "Comfort after the complete trial drive," which included comfort questions during and after sitting in the seat, respectively, as well as preference questions. Comfort and discomfort ratings tend to change over time [15]. Therefore, for each condition, the participant rated comfort starting at minute 0, again at minute 10 of the drive and after the drive at minute 15. During the drive, participants were instructed to relax and imagine sleeping during a long-term drive in an autonomous car. Moreover, they were instructed to focus on the seat comfort and their experience. During the drive, questions were orally asked by a moderator, and participants rated the comfort verbally. The moderator transcribed the answers from the subjects. Participants experienced all the three conditions in a randomized order. They had a few minutes between conditions to stand up and take a break before the new condition.

The trial drive was conducted in the dynamic track of Volkswagen Proving Ground in Germany over 2 days. The controlled trial drive was designed to be safe and represent close-to-real dynamic conditions. The purpose of the designated drive condition was to represent a constant smooth drive with an autonomous car on a highway. The driving scenario was selected to offer the closest conditions to the use case while maintaining safety standards. The resulting scenario provided a real feeling of driving, including low speed and accelerations, which are suitable for evaluating comfort and trust [16]. Previous studies [17] have evaluated comfort after 15 min of driving motion, as this has been designated as sufficient time for passengers to settle in a moving car [18]. Therefore, the driving scenario involved a 15 min drive per condition at a constant speed of 30 km/h through a dynamic track that included a series of different curves. As safety was a priority, higher speeds and accelerations were excluded due to concerns in the unusual seating position. Moreover, the accelerations were controlled ($a_y \leq 0.2$ g) during the drive. Each round was approximately 1.25 km and took 5 min.

Due to the COVID-19 pandemic, after a robust risk assessment, a special hygiene protocol was established. This procedure, which included measures before and during the test [19], was followed. Before each participant entered the vehicle, the surfaces were disinfected, and the vehicle was aired. During the study, the participants had to wear a special full-body protective suit while travelling inside the vehicle. This was a requirement to minimize the contact with surfaces. Moreover, a medical mask was worn by all passengers, including the participant. These additional measures were necessary at the time of the experiment and could not have been avoided by alternative procedures.

2.4. Sleep Quality and Comfort Rating

The evaluation of comfort was executed through subjective methods. The scale was the result of the modification of two well-known comfort scales: the Borg (1990) [20] CR-10 scale, and the Corlett and Bishop (1976) [21] discomfort scale. These scales assess the degree of discomfort and comfort of the participant with respect to the seat. The resulting general scale (Figure 4) is a seven-point Likert scale that measures the level of general comfort, from −3 (strong discomfort) to +3 (strong comfort). Similar modifications have been performed previously in the literature [22]. An additional four-point Likert scale was used to identified body specific discomfort, from -3 (strong discomfort) to 0 (neutral/no discomfort). Using these scales helped to identify areas of discomfort and track the perception of comfort in the brief sitting experience. The comfort and discomfort scales, as well as the questionnaire, were explained to the participants beforehand. The participants were encouraged to ask for clarification during the test when needed.



Discomfort				Comfort		
Strong	Moderate	Weak	Neutral	Weak	Moderate	Strong
−3	−2	−1	0	1	2	3

Figure 4. General comfort scale.

2.5. Statistical Analysis

The 1.2.5042 version of RStudio [23] and Microsoft Excel were used for the statistically analyzes. Additional tests, namely the Shapiro-Wilk test for normality and Levene's test for the equality of variances, were performed to check the data assumptions: Moreover, other preliminary tests included the identification of outliers.

To describe the effect of the different back and seat angles and the time on the comfort variables, two-way repeated measures ANOVAs were performed. Two within-subject factors were included: time and seat angle. Each factor had three levels. The time factor included minute 0, minute 10 and minute 15; and the seat angle factor included upright, reclined and flat. Furthermore, two-tailed paired t-tests were calculated to identify any effects among pairs of factors.

Due to the small number of participants in this study, effect sizes were calculated using Cohen's d formula for paired comparisons. This provided an indication of the size of the difference in each dependable variable, even if the effect was not statistically significant. 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 $d \geq 1.2$ [24,25]. Lastly, to answer some of the research questions, Spearman's correlation was performed to compare the means pairs of variables, such as body part discomfort and general comfort.

3. Results

3.1. Seat Comfort

An initial analysis through observation yielded notable results. The general comfort ratings obtained during the dynamic experiment were mostly positive in all conditions and times of measuring. Table 1 details a summary of the mean values and standard deviations from the analyzed data. The means for general comfort, for any seat position during any time (0 min, 10 min, 15 min) of measuring, were between 1.2, slightly over a "weak" comfort, and 2.0, a "moderate" comfort. This outcome shows that there were no major points of short-term discomfort during the driving and sitting experience. However, discomfort-specific ratings showed that some parts of the seat produced more intense discomfort in certain conditions. For example, the legs and feet area was rated more negatively in the upright and reclined positions, whereas the head region was the most negatively evaluated by participants in the flat condition.

The first remarkable observation that can be detected when graphically plotting the results is the different behavior of the comfort ratings of the conditions with time (Figure 5). Throughout the three measuring times, 0 min, 10 min and 15 min, the comfort ratings changed differently depending on the conditions. In the case of the flat position, the mean ratings improved over time, from minute 0 at 1.2 to the end of the drive (minute 15) at 1.9. Meanwhile, while in the reclined condition, the means remained mostly stable for the duration of the study. Lastly, in the upright position condition, the general comfort mean declined with time.

Table 1. Measures for the comfort and discomfort perceptions for the upright, reclined and flat conditions.

Variables			**Upright (20°)**	**Reclined (40°)**	**Flat (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,	10′		1.6 (±1.0)	1.8 (±0.7)	2.0 (±0.4)
+3 = 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)
		Back	−0.4 (±0.5)	−1.1 (±1.0)	−0.7 (±0.6)
(−3 = strong discomfort,		Buttocks	−0.1 (±0.3)	−0.4 (±0.7)	−0.2 (±0.4)
0 = no discomfort)		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)

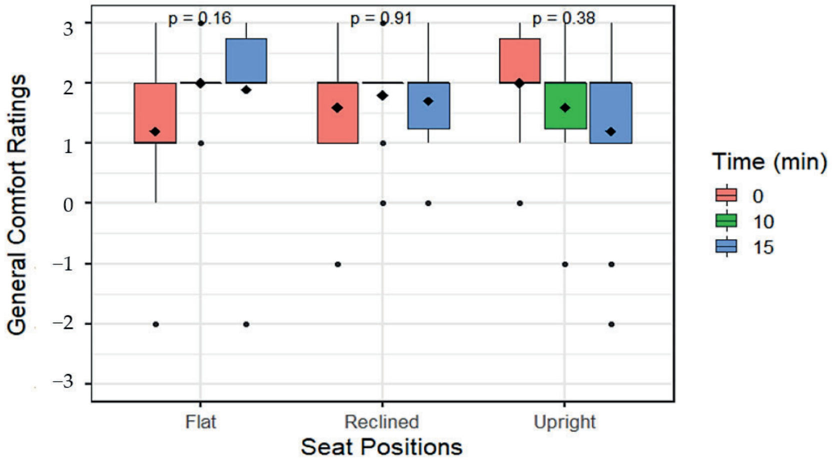


Figure 5. Boxplot with general comfort ratings for the flat, reclined and upright seat conditions over time. The diamond shapes indicate the mean and circles indicate outliers.

When visually observing the discomfort of different body areas (Figure 6), it can be detected that of the region of highest discomfort was the back area for all the seat positions. Moreover, another discomfort area was the lower part of the body in the reclined position. On the other hand, as the seat position grew more reclined, the discomfort seemed to be located higher on the body. Regarding the time of the rating, we could not find a correlation visually.

ANOVA significant tests also support the previous claim that general comfort ratings were significantly different depending on the condition and time of the comfort rating. This differing behavior was revealed by the indication of a significant effect on the interaction (Table 2). Moreover, ANOVAs did not indicate any other significant differences except in the legs and feet area, where the seat position was shown to affect leg discomfort ratings.

Further analyses, for example, paired comparison, showed additional significant results. For instance, between the upright and reclined positions, there was a significant difference in terms of back discomfort, where discomfort was consistently greater in the reclined condition. Paired comparisons between upright and flat conditions revealed that discomfort was significantly higher for the variables head and legs/feet in the flat and upright position, respectively. Finally, the paired comparison between the reclined and flat positions found no significant effect, except in the leg factor, and the reclined position received consistently higher discomfort ratings. The results concerning Cohen's d effect sizes, indicating large or very large sizes of effect, were according to the significant test results.

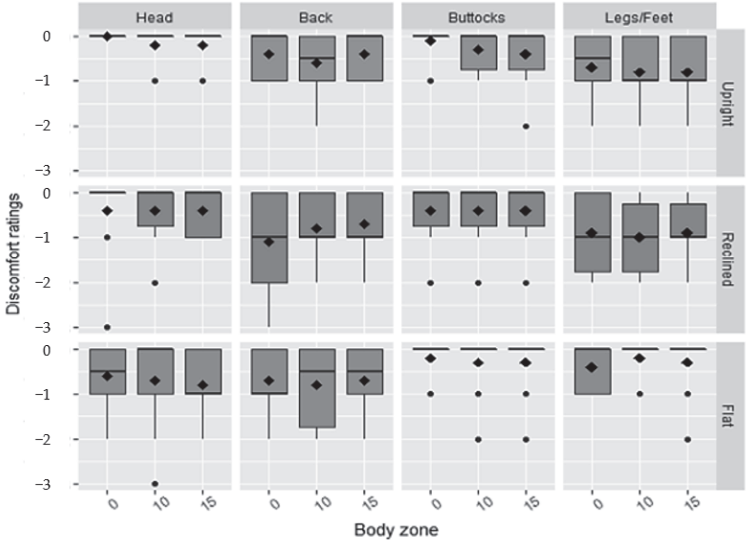


Figure 6. Boxplot with different body part comfort ratings for the upright, reclined and flat seat conditions over time. The diamond shapes indicate the mean and circles indicate outliers.

Table 2. ANOVA and *t*-test paired comparison for dependent variables related to comfort and relax level in the seat for the upright (Up), reclined (Rc) and flat (Fl) conditions. * Symbol indicates a significant effect ($p < 0.05$).

Dependent Variables		**Main Effect of Condition**						**Paired Comparisons (Seat Position Factor)**		
		Two Way Repeated Measures ANOVA						***t*-Test**		
		Seat Position		**Time**		**Interaction**		**Up vs. Rc**	**Up vs. Fl**	**Rc vs. Fl**
		F	***p***	**F**	***p***	**F**	***p***		***p***	
COMFORT	General	0.04	0.961	0.94	0.377	3.11	0.045 *	0.721	0.754	1
	Head	4.51	0.050	0.42	0.662	0.26	0.899	0.738	0.001 *	0.143
	Back	2.20	0.140	0.38	0.686	1.99	0.170	0.038 *	0.138	0.533
	Buttocks	0.72	0.502	0.42	0.662	0.88	0.483	0.213	0.651	0.416
	Legs	3.91	0.039 *	<0.01	1	0.39	0.813	0.411	0.008 *	<0.001 *

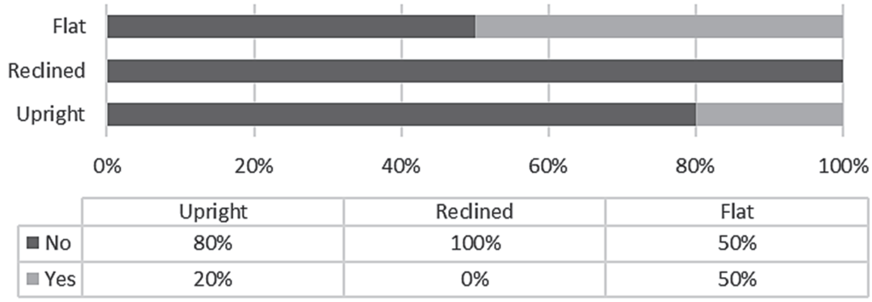
Regarding the discomfort in different body parts and correlation with general comfort ratings, there was only a clear effect in the case of the legs/feet and back areas. The discomfort ratings in the head and the buttocks areas showed no correlation with the overall comfort ratings.

3.2. Seatbelt Discomfort

The participants were asked to evaluate seatbelt discomfort (Figure 7). The restraint system created discomfort mostly in the flat position. The presence of seatbelt discomfort showed no direct relationship with the overall comfort ratings. Thus, the restraint system impact on user experience and comfort should be further explored in future research.

3.3. Relax Levels

Additional results include the relax levels after each condition. The question "How relaxed did you feel while experiencing the seat?" was rated on a seven-point Likert scale (Figure 8). The position with highest relax level was the flat condition, followed by the reclined position and the upright position. When further analyzed, we found significant differences between the upright position and both the reclined and flat conditions.



	Upright	Reclined	Flat
■ No	80%	100%	50%
■ Yes	20%	0%	50%

Figure 7. Seatbelt discomfort, answer to the question "Did you perceive discomfort caused by the seatbelt?"

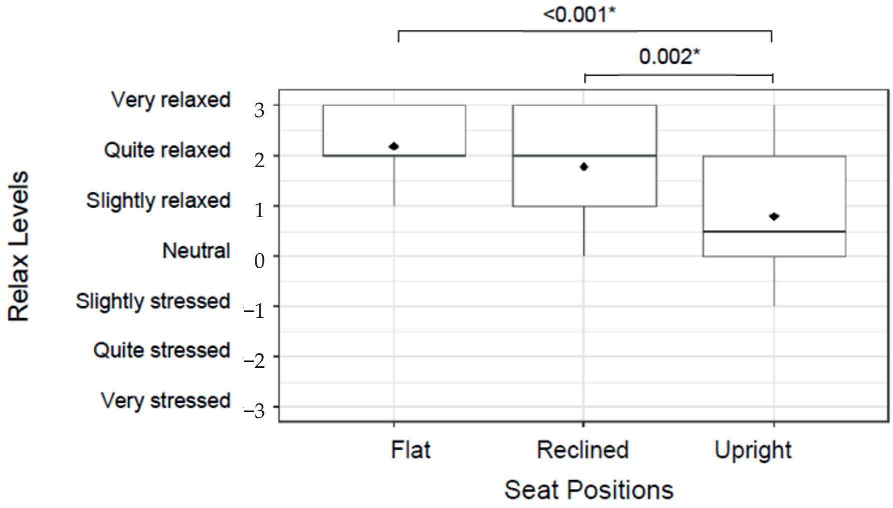
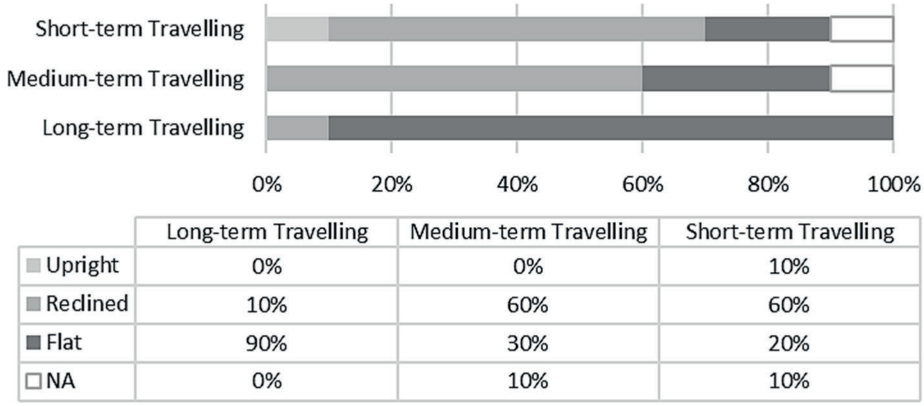


Figure 8. Relax levels from the question "How relaxed did you feel while experiencing the seat?" * symbol indicates a significant effect ($p < 0.05$). The diamond shapes indicate the mean.

3.4. Preferred Position for Sleeping

When participants were asked about preferred position for sleeping (Figure 9), results varied according to the use case. The flat position was the was favored by most subjects (90%) for sleeping during long-term travel. In contrast, the reclined position was selected by 60% of subjects for both short- and medium-term travel.



	Long-term Travelling	Medium-term Travelling	Short-term Travelling
■ Upright	0%	0%	10%
■ Reclined	10%	60%	60%
■ Flat	90%	30%	20%
□ NA	0%	10%	10%

Figure 9. Preference of seat configuration for sleeping during long-, medium- and short-term travel.

4. Discussion

The study methodology, with a close-to-real dynamic condition, resulted in some significant outcomes, indicating that both seat base and backrest angles affect comfort perception. For the sleeping use case, it was also concluded that users are drawn to choosing a flatter position than the current one in series production cars. This outcome agrees with findings of some previous studies [11,26,27].

On the other hand, the results of the general comfort rating obtained in the study showed an unexpected behavior. Comfort ratings were expected to worsen with time [28], and this was the case for the upright position. However, the flat position had an opposite effect on comfort. This phenomenon can be explained by many comfort perception models, such as the Cappetti and Naddeo comfort/discomfort perception model [29]. In the mentioned model, the resulting comfort is the result of several factors, such as environment, and psychosocial and cognitive factors, rather than strictly physical qualities. In previous similar models, one of the inherited components of comfort perception is expectation or previous experience [30]. One hypothesis could be that the participants had experience with normal car seats and their angles. In contrast, it is expected that participants did not have similar experiences travelling in a lying position inside a car in a dynamic scenario. Therefore, the initial more negative comfort rating of the flat condition could have been caused by the difference in seat expectations in a moving vehicle. Once the participants experienced the seat in the moving car for 5 min, the expectation was readjusted to a more positive opinion.

The analysis of discomfort in different body areas indicates that some of the discomfort originated from seat comfort limitations, whereas other discomfort was inherently specific to seat position. The seat design was based on the design of an automotive seat. Although the intention was to acclimate to the specific scenario and use case, in some cases, the seat prototype was insufficient to truly represent a comfortable futuristic reclined seat. Consequently, this resulted in some localized discomfort in the reclined and flat positions, for example, in the legs/feet and head areas.

Other study limitations were the low number of participants and short duration of the experiment. The constant low speed and accelerations due to safety standards also limited the evaluation of specific driving-related discomforts. These aspects explain the relatively low number of significant results. Another major limitation was the low number of female participants. Gender-based differences in comfort and higher pressure sensitivity have been reported [31,32] and thus must be taken into account when performing comfort user studies. Furthermore, an additional special COVID-19 protocol, which included full bodysuits, protective facemasks and reduced control of the in-vehicle environment temperatures due to constant airing, may have affected the comfort ratings [33,34] and, ultimately, the results.

5. Conclusions

To the best of our knowledge, the present study is the first to examine the comfort of different seat angles in meeting the desire to sleep in automated vehicles, based on the effect of comfort perception in close-to-real conditions. It includes a combination of tests in real conditions with methodical subjective ratings to provide the most favorable conditions and understand how user opinions can change in the short term.

The primary objective of this study was to explore different seat configurations suitable in the use case of sleeping inside a moving car. The close-to-real dynamic scenario was of particular importance in this paper to fill the corresponding gap of knowledge of comparable research in the literature [11,12,22]. The present study suggests that users prefer flat and reclining seat configurations for long- and short/medium-term use, respectively.

This work provides the basis for further studies on long-term comfort, safety and vehicle movement effects on comfort related to sleep. Future research should focus on overcoming the limitations of the present study and exploring the matter more deeply. On the one hand, future works should include pressure distribution, EEG or other objective measurements to complement subjective data. Seat prototype comfort limitations should be identified and improved, with special consideration given to the reclined and flat positions. On the other hand, a longer-term study in which different types of car occupants can sleep in close-to-real conditions would be ideal for a deep and reliable conclusion.

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Conflicts of Interest: 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 I.C.-B., at the University of Las Palmas de Gran Canaria, Spain, under the supervision of P.M.H.-C., I.C.-B., D.T. and T.W., who are employees of Volkswagen AG, Wolfsburg. The results, opinions and conclusions expressed in this paper are not necessarily those of Volkswagen Aktiengesellschaft. All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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2.2. Article B. The effect of seating recline on sleep quality, comfort and pressure distribution in moving autonomous vehicles

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

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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

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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

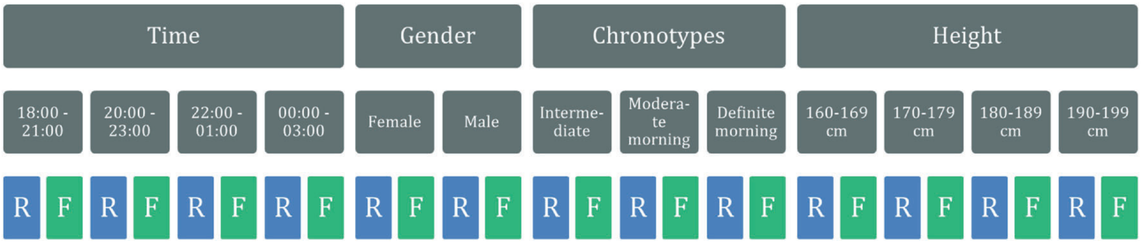


Fig. 1. Diagram of balancing criteria for the 2 groups of participants: Reclined position group (R) and Flat position (F) group.

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

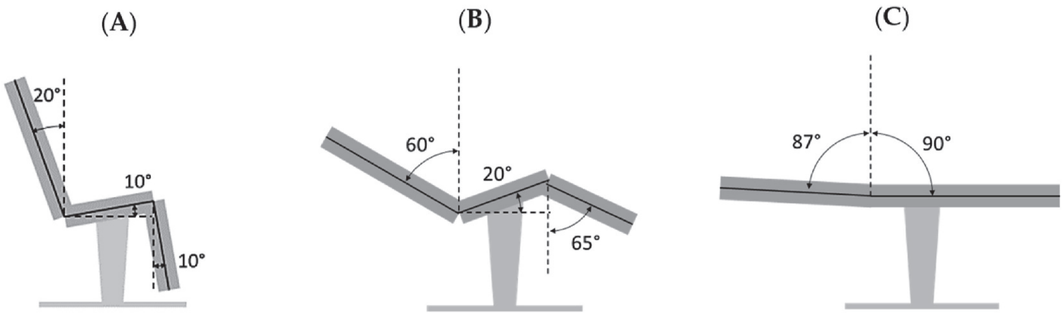


Fig. 3. Seat configurations for upright, reclined and flat seat conditions. (A) Upright. (B) Reclined. (C) Flat.

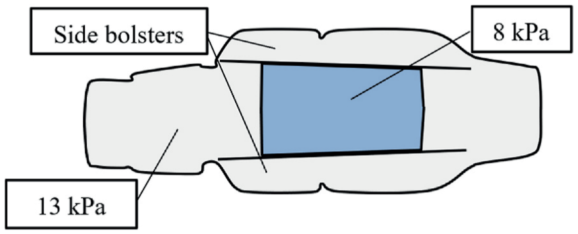


Fig. 4. Top view diagram of seat prototype in flat condition. Blue areas represent 8 kPa and grey areas 13 kPa hardness. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

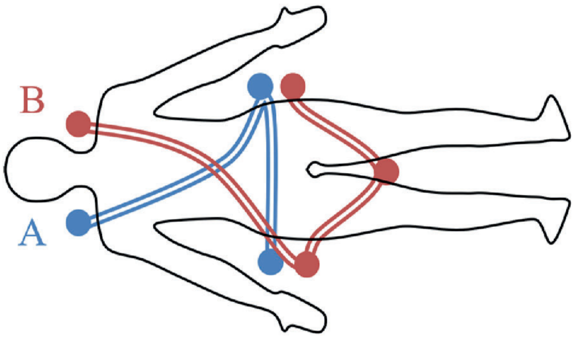


Fig. 5. Diagram of the 7-point seatbelt setup, consisting of a traditional 3-point seatbelt (A) and a 4-point seatbelt (B). In the upright position, only the 3-point seatbelt (A) was used, where for the reclined and flat conditions the full 7-point seatbelt was used (A + B).

(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.

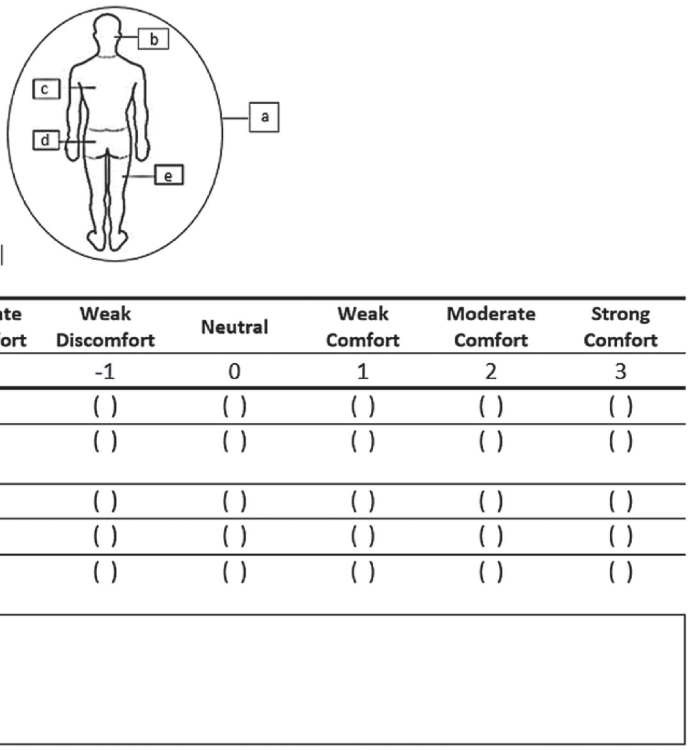
Therefore, sleep was evaluated through subjective means. The Pittsburgh Sleep Quality Index (PSQI), which is the most widely used questionnaire for subjective sleep quality, was used for evaluating participants sleep quality at home before the test drive. Relevant questions of the PSQI were used to evaluate 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.

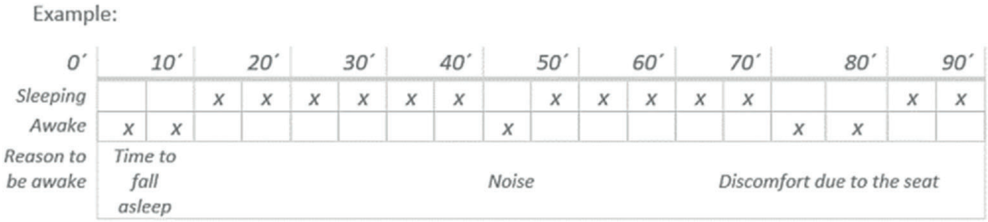
Two-way mixed ANOVAs were performed to determine the effects of seat angle on dependent variables related to comfort and sleepiness (KSS) over time. For each ANOVA, the between-subject factor, i.e., the seat angle, had two levels: reclined and flat; and the within-subject factor, i.e., the time, had 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.

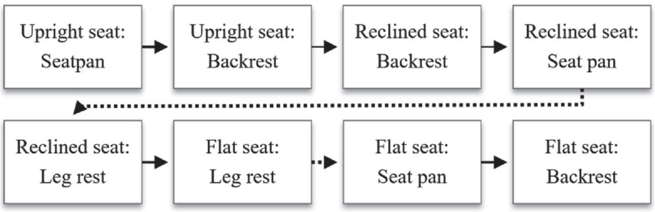


Fig. 8. Pressure evaluation procedure. Dotted line represents the pressure mat change of position.

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

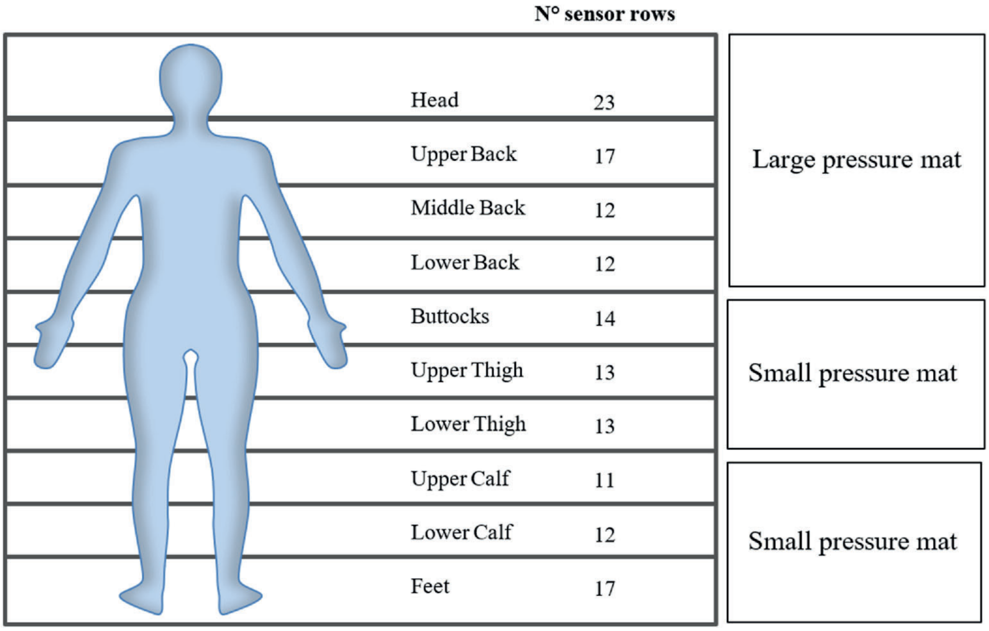


Fig. 9. Predefined body zones and number of sensor rows per zone.

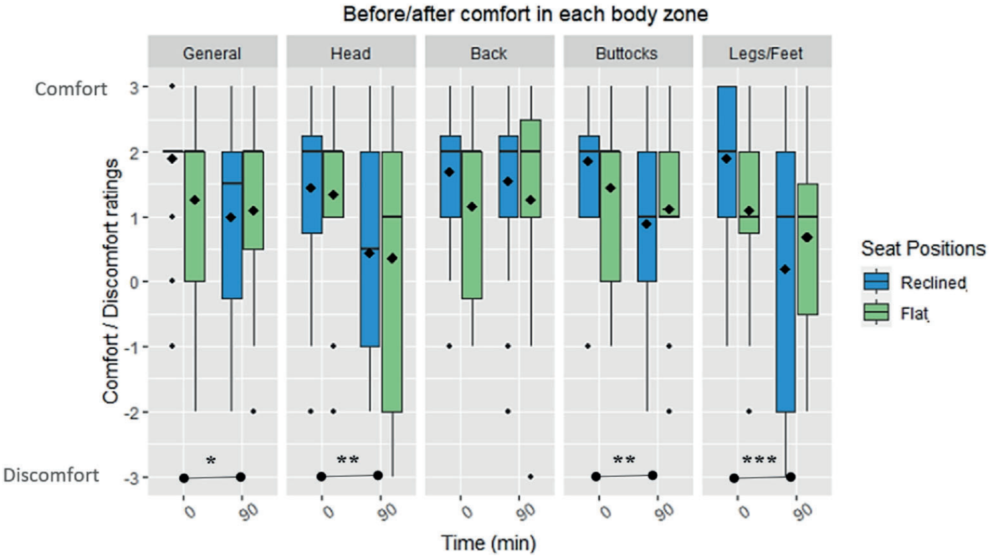


Fig. 10. Boxplot with different body part comfort ratings for flat and reclined seat conditions over time (N = 40, ◆ mean, ● outliers). Differences between factors through ANOVA (*<0.05, **≤0.01, ***≤0.001).

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)** ***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)** ***higher sleep quality is better***	20	2.0	0.6	2	4	17	2.1	0.5	2	4
Sleep Latency **(min)** ***lower sleep latency is better***	20	19.5	9	5	35	17	26.2	18.1	5	70
WASO **(min)** ***lower sleep WASO is better***	20	21.8	18.5	0	60	17	11.8	10.9	0	35

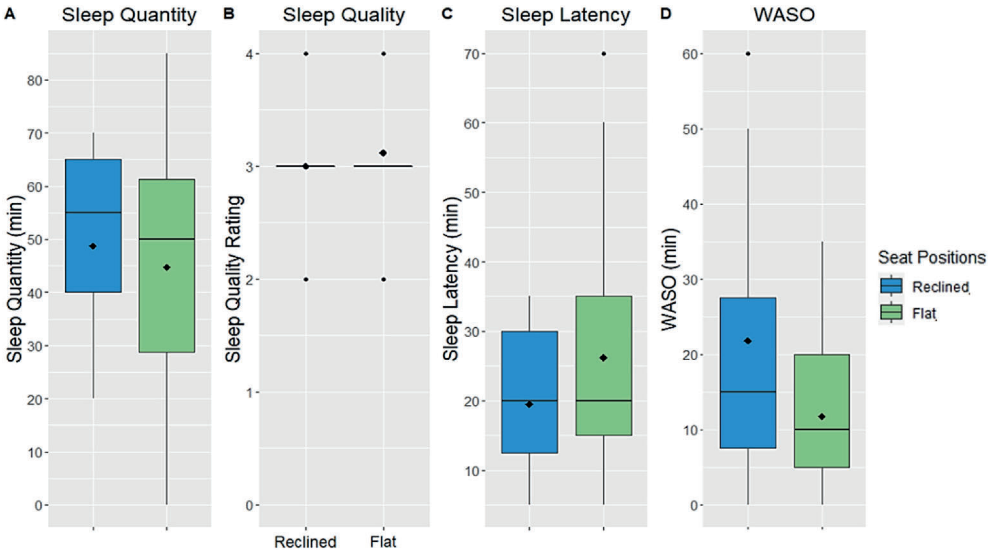


Fig. 11. Sleep Quantity boxplot for the reclined and flat seat conditions. (N = 40, ◆ mean).

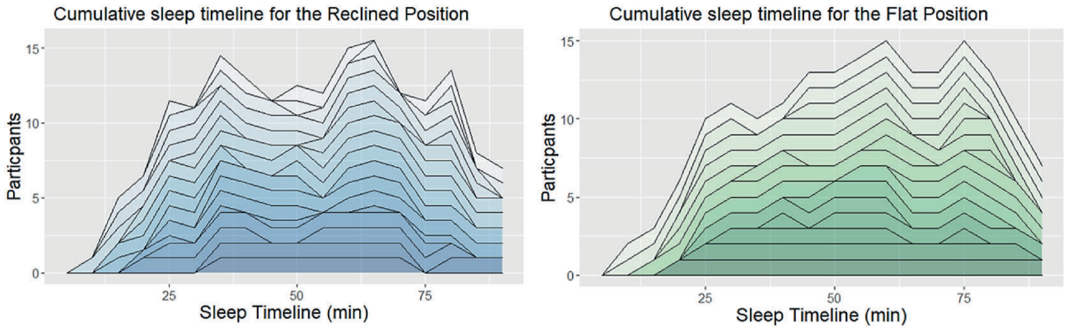


Fig. 12. Self-reported cumulative timelines for reclined (left) and flat (right) seat conditions. Three participants reported that they did not sleep in the flat seat condition.

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$\sim$0.40), large (d$\sim$0.80) or very large (d$\sim$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%

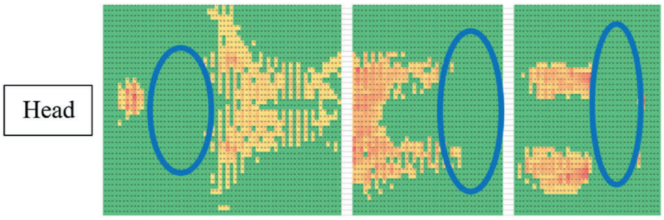


Fig. 13. Pressure heat map example with non-contact areas highlighted.

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).

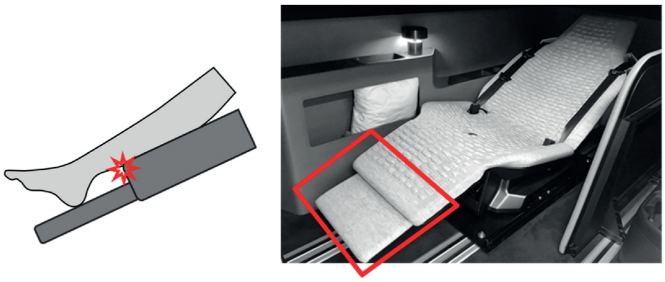


Fig. 14. Diagram of hanging feet effect by the seat prototype. The red start shape indicated the location of the increased pressure by the edge of the leg support. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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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2.3. Article C. Sleep quality and comfort in fully automated vehicles: A comparison of two seat configurations

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Sleep quality and comfort in fully automated vehicles: A comparison of two seat configurations

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A R T I C L E I N F O

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A B S T R A C T

As autonomous driving technology advances, the possibility of using vehicles as sleeping environments becomes increasingly relevant. To investigate the feasibility of this concept, a sleep study was conducted with twelve participants who were given a 4-h opportunity window to sleep in both reclined and flat seat configurations. The evaluation involved both objective measures, including polysomnographic (PSG) data analysis, and subjective measures through questionnaires, assessing sleep quality and comfort. While the sleep quantity results were comparable between the two sleeping positions, the reclined position showed a slight advantage in sleep quantity (TST and WASO). Interestingly, a trend highlighting a possible difference was found between the seat positions regarding non-rapid eye movement stage 3 (NREM 3). NREM 3 tended to be in a higher proportion of total sleep time in the flat seat position. Sleep onset latency (SOL) also showed a trend of a shorter latency by participants in the flat position. Additionally, most participants reported a preference for the flat position over the reclined position. These findings suggest that a flat seat configuration could offer a more comfortable and restful sleep environment for passengers in autonomous vehicles.

1. Introduction

Increasingly higher levels of vehicle automation are currently being developed (Audi, 2023, Moia, 2023, Nissan Motor Co., 2023, Tesla, 2023; Daimler, 2023; SAE, 2021). With the upcoming release of fully automated vehicles, there will be plenty of new opportunities for occupants. In this context, several studies have explored alternative use cases that people wish to engage in while travelling in these vehicles (Becker et al., 2018; Cyganski et al., 2015; Kyriakidis et al., 2015; Östling and Larsson, 2019), with sleeping being identified as one of the most popular priorities.

Sleep is one of our fundamental daily activities. It takes up a third of our daily time; and good sleep is essential for health, well-being and quality of life (Institute of Medicine, Committee on Sleep Medicine and Research, 2006; Watson et al., 2015). Moreover, daily performance depends highly on sleep quality (Barnes and Watson, 2019; Miyata et al., 2013; Vyazovskiy, 2015). Adults are recommended to sleep seven to 9 h daily, although adults often sleep less than recommended (Alonzo et al., 2021; Alsaggaf et al., 2016; Peltzer and Pengpid, 2017; Quick et al., 2016; Steptoe et al., 2006). Short sleep durations have been often associated with poorer health (Franceschini et al., 2020; Steptoe et al., 2006; Wells and Vaughn, 2012; Zee and Turek, 2006). In particular, during the day after a night of poor or abnormal sleep, there are immediate negative physical and cognitive effects, such as concentration and vigilance detriments, memory blanks and irritability (World Health Organization, 1998).

An optimal sleep environment is key to achieving good sleep quality (Caddick et al., 2018). In a car interior, accomplishing this ideal sleeping environment is troublesome due to limited space and car movement. However, one of the opportunities in this scenario is the high level of control over the sleep environment. This includes lighting (Albahri, 2012; Bertolini, 2017; Garcia et al., 2019; Heuer et al., 2002; Lam et al., 2015; Schofield et al., 2016; Solari, 1997; Tonar et al., 2012), temperature and air quality, as well as the creation of a specific car seat for the purpose of sleeping, addressing the seat angles, as it is one of the main differences between today's car seat and a bed.

In the context of travelling in a car, a few studies have investigated

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Abbreviations

EEG	Electroencephalography: an electrodiagnostic technique to measure the electrical activity produced by the brain
EMG	Electromyography: an electrodiagnostic technique to measure the electrical activity produced by skeletal muscles
EOG	Electrooculography: an electrodiagnostic technique to measure the electrical activity produced by eye movements
PSG	Polysomnogram/polysomnographic: multiparameter diagnosis and study technique in sleep medicine. It monitors many body functions, including brain activity (EEG), eye movements (EOG) and muscle activity (EMG)

sleep and seating positions. Stanglmeier et al. (2020) argue that a reduced seat tilt is the most optimal solution for sleeping in a vehicle in order to reduce space use. This reclined position, of 40° seat pan and 65° backrest with respect to the horizontal and vertical, respectively, was also optimal regarding biomechanical quality, i.e. the interface pressure score. However, when participants were asked about their preferred position for sleeping, they chose the flattest option of 20° seat pan and 75° backrest. People choosing the seat position closer to a flat lying position for sleeping or relaxing were also observed by Smulders et al. (2016) and Bohrmann and Bengler (2020).

PSG has been defined as the gold standard of sleep evaluation yet, there is limited literature including PSG in the evaluation of sleep in the car context. Roach et al. (2018) evaluated through PSG the quantity and quality of sleeping in three different seat positions, upright (20° backrest from the vertical), reclined (40° backrest) and flat (87° backrest). The study findings revealed that sleep quality improved with the increase of backrest angle, but no significant differences were found between the reclined and flat seat positions.

In the present study, the effect of two different seat positions, reclined (60° backrest from the vertical, 20° seat pan from the horizontal) and flat (87° backrest and 90° seat pan from the vertical) on sleep quality is investigated. The experiment includes objective sleep evaluation techniques (PSG including EEG, EOG and EMG), as well as subjective methods, which are based on sleep medicine and previous established research framework (Caballero-Bruno et al., 2022a, 2022b). Based on preceding research, the main hypothesis is that the quantity and quality of sleep in a seat increase as the seat tilt increases towards horizontal.

2. Material and methods

2.1. Participants

Twelve participants (7 women, 5 men) volunteered to be part of the study (Table 1). Exclusion criteria included neurological, psychiatric or psychosomatic diseases, sleep disorders, intake of central nervous substances, increased alcohol, caffeine and/or taurine consumption, pregnancy, prone position sleep preference, uncomfortable feeling to sleep in a vehicle, back problems and/or definite or moderate evening chronotypes according to Horne and Östberg (1976). These criteria aimed to minimize the risk of poor sleep due to external factors during the testing as well as avoiding poor electrode readings. Moreover, due to prototype seat limitations, only participants with a height in range between 160 cm and 185 cm and weight under 100 kg were recruited. Finally, due to the COVID-19 pandemic, COVID risk groups according to RKI definition (Rommel et al., 2021) were also excluded.

Table 1
Anthropometric measurements of the participants.

Participants [n = 12]	Mean	SD
Age (years)	25.9	4.6
Height (cm)	172.3	6.6
Body weight (Kg)	66	10.6

A pre-screening was implemented, including demographic questions, questions regarding sleeping habits, like the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) and the Morningness–eveningness questionnaire (Horne and Östberg, 1976). No sleep deprivation was used to observe a more natural sleep behaviour.

This study was approved by Ethics Committee of the Medical Faculty of the Eberhard Karls University Tübingen (Number: 184/2022BO2) and followed the guidelines of the Declaration of Helsinki. Informed consent has been obtained from all the participants prior to the experiment.

2.2. Test conditions

The seat prototype used in the study was positioned inside of a Volkswagen T6.1 Multivan. The interior surrounding of the seat prototype (Fig. 1) was built to be a comfortable, private space, resembling that of a first-class long-distance airplane cabin. For the testing purpose, the belt system visible in the picture was not used.

The purpose of the study was to compare the sleep achieved in two different seat positions, a reclined and a flat seat position. The reclined position at 60° from the vertical, close to position prior described and studied by Smulders et al. (2016) and Stanglmeier et al. (2020), and a lying position at 87°, resembling a flat bed angle (Fig. 3). The researchers conducted pilot tests to determine the most comfortable angles for the seat pan and leg support for each backrest position. The seat pan angles were set at 20° and 0° relative to the horizontal, while the leg support angles were adjusted to 65° and 90° from the vertical, for the reclined and the flat position, respectively. Therefore, the seat could be set up in those two positions as illustrated in Fig. 2.

Previous studies (Caballero-Bruno et al., 2022a, 2022b) suggest that foam stiffness might be one of the critical aspects when it comes to improving sleep quality. Therefore, a foam optimization process was executed by experts, considering previous studies comfort evaluation and participants' feedback comments. The result of this process was a two layered surface with different foam characteristics (Fig. 3). The under layer is made from a traditional foam of 3.9 kPa and 20 mm thickness and the over layer is made from viscoelastic foam of 1.6 kPa of 30 mm thickness.

Fig. 1. Prototype seat and environment inside the vehicle in the flat position.

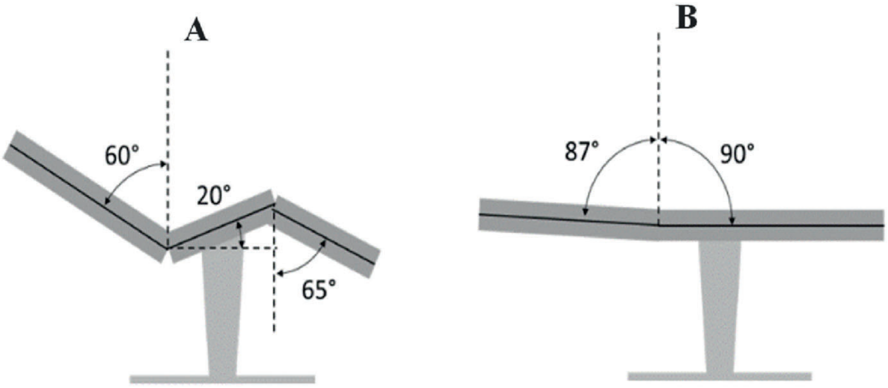

Fig. 2. Configurations for reclined and flat seat conditions. (A) Reclined (B) Flat.

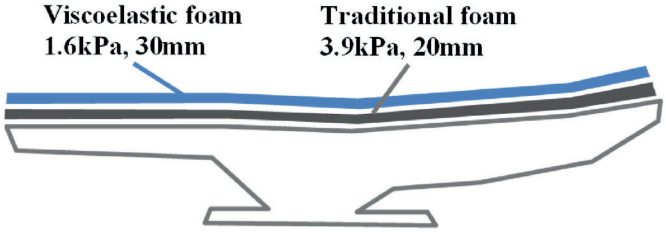

Fig. 3. Side view diagram of seat prototype in flat condition. Blue area represents the 1.6 kPa layer of foam and grey area represents the 3.9 kPa layer of foam. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.3. Sleep environment

The Volkswagen T6.1 Multivan vehicle, containing the seat prototype, was located inside a laboratory. In order to get a clean and good electrode signal for the objective sleep assessment, the vehicle was static during the experiment (Benbadis, 2005).

In order to provide a comfortable and comparable temperature inside of the vehicle, the laboratory was cooled with an air conditioning unit before the start of the test sessions. The temperature inside the room and inside the vehicle was measured and recorded at the start time of each trial. Temperature inside de car had a mean (±ST) of 20.6 (±2.59 °C).

To ensure a realistic simulation of the driving experience, the car windows were covered to prevent the participants from seeing outside of the vehicle. The light sources from the room and the vehicle were turned off, to provide a dark light situation in the vehicle that is suitable for sleeping (<10 lx).

In addition, a realistic acoustic environment was provided by playing audio from a real vehicle driving at 100 km/h on a smooth road surface through the car's speakers. This audio was played throughout all sessions, including the familiarization phase, and helped to create a sense of immersion for the participants. To minimize any external disruptions, sound from outside the vehicle was kept to a minimum. Any environmental disturbances, such as loud noises from outside the vehicle, were recorded.

2.4. Subjective measurements

Sleep diaries are widely used as a powerful tool for subjective sleep assessment (Buysse et al., 1989). In this study sleep diaries were used as an instrument to understand influencing factors, such as special sleep events previous to the data collection. Participants started recording sleep diaries two days before the first data collection and continued until the date of the second data collection. The sleep diary was based on the extended version of the consensus sleep diary (Carney et al., 2012). When relevant, notes on subjective data related to sleep specific rare events were done. Furthermore, the PSQI was used to determine the sleep quality at home before the study (Buysse et al., 1989).

On the day of the study session, a collection of subjective questionnaires was done before and after sleeping. The goal of these questionnaires was to find out the opinion of the participant, as well as subjectively evaluate the sleep and the seat position. This was of special importance when interpreting the objective sleep parameters and identifying the underlying reason of possible discomfort and disturbances. Participants rated five items on a 7-point Likert scale as to how comfortable or uncomfortable they felt (−3 = strong discomfort, 0 = neutral, +3 = strong comfort). The five items were head/neck, back, buttocks, legs/feet and general comfort. Participants rated their comfort initially before lights out time and again 4 h later after waking up while sitting/lying on the seat.

Other relevant factors that might influence the quantity and quality of sleep are sleepiness and mood. Therefore, the Karolinska Sleepiness Scale (KSS) (Akerstedt and Gillberg, 1990; Kaida et al., 2006) and the Multidimensional Mood Questionnaire (MDMQ) (Steyer et al., 1994) were also provided before and after sleeping. To explore participants' perception regarding their experienced sleep in the car, a self-reported sleep timeline was filled by the participants retrospectively. This method was used in previous research (Caballero-Bruno et al., 2022b) to compare the self-reported and PSG-based sleep hypnograms.

A final questionnaire was requested after participants have tested both of the conditions. This final questionnaire includes: seat condition preference, the extension of the User Experience Questionnaire (UEQ+) (Laugwitz et al., 2008; Schrepp and Thomaschewski, 2019) and the opportunity to give general remarks about the study, the sleep and/or the seat.

2.5. Objective sleep measures

In this study, PSG was included as the main way to evaluate sleep objectively, by determining the sleep phases. PSG is current gold standard, as it provides the most accurate information on sleep architecture (Rundo and Downey, 2019). The neurophysiological data obtained from PSG allows for a more in-depth understanding of sleep quality, which cannot be achieved through subjective methods alone, making it a preferred method in sleep medicine (Ibáñez et al., 2018).

Sleep recording and evaluation followed the American Academy of Sleep Medicine rules (Berry et al., 2012a, 2012b, 2017). However, since the objective of the study was not the diagnosis of sleep related disorders, electrocardiogram and pulse oximetry were excluded. EEG signals were recorded from eight scalp electrodes (F3, F4, C3, C4, P3, P4, TP9 and TP10 according to the 10–20 system). The Fz was used as common reference and EEG was grounded to AFz. EOG was recorded from 4 channels which were bilaterally referenced (left HEOG-right HEOG2, left VEOG1-right VEOG2). EMG was collected using two bilaterally referenced electrodes at the chin (EMG1-EMG2) (Fig. 4). All the signals were digitized at 1 kHz, high pass filtered with a time constant of 10 s and stored. High-quality Ag/AgCl gel-based passive electrodes and amplifier from Brain Products (Brain Products GmbH, 2022) were used for this purpose.

To identify the different sleep and wake stages, the automated sleep algorithm YASA (Vallat, 2018; Vallat and Walker, 2021) was used, instead of traditionally manually human scoring, which is often related with human errors (Berthomier et al., 2020; Fiorillo et al., 2019; Rosenberg and van Hout, 2013). This algorithm is an unsupervised machine learning which has demonstrated a median accuracy of 87.46% using a dataset of 585 full-night manually scored sleep hypnograms (Vallat and Walker, 2021). Vallat and Walker (2021) suggested choosing a central electrode for the scoring. Neurophysiological signals were down sampled to 100 Hz and a single central EEG channel C4, the EOG channels and EMG channel were used for the automated sleep scoring. Previous to the automated sleep scoring, EEG signals were re-referenced to the electrode on the mastoid TP9, opposite to C4, and the signals were bandpass-filter with 0.40 and 30 Hz as cutoffs (Vallat, 2018; Vallat and Walker, 2021). The YASA-based hypnograms were manually reviewed for misclassifications by two trained technicians using 30 s windows of the down-sampled, filtered PSG signals. Hypnograms were inspected individually and any anomalies that could be observed in the plots were identified and noted. To objectively evaluate sleep quality, various sleep parameters (Table 2) were obtained using the YASA-based hypnograms.

2.6. *Familiarization phase*

To familiarize participants with the study setup and ensure their compatibility with the study requirements, a familiarization protocol was conducted. During this familiarization phase participants were informed about the study, as well as experienced the interior, the seat and electrodes setup.

After the participant signed the informed consent and data protection agreement, demonstration and explanation of the sleeping environment and the measuring equipment followed. Moreover, further explanation of the EEG, EMG, EOG were also done by the test experimenter. To create an inviting, calm and relaxing atmosphere, relaxing ambient music (Entspannungsmusik für Schlaf, 2017) was used while the attachment of the electrodes on the scalp. Earlier studies revealed that such music can reduce anxiety and improve subjective sleepiness (Cordi et al., 2019; Dickson and Schubert, 2019; Holm and Fitzmaurice, 2008; La Torre-Luque et al., 2017). After the electrodes were set up and while sitting in the test environment, participants were instructed to relax, try to rest and imagine sleeping 4 h in the car for 5–10 min. Finally, the participants were asked if they could imagine sleeping inside the vehicle while wearing the electrodes. If the participants agreed and no issues were detected during the familiarization, they were scheduled their data collection appointments for the first and second session.

2.7. *Experimental procedure*

To ensure participants experienced both test conditions (Chapter 2.2.), two experimental sessions were conducted for each participant, separated by a wash-out period of at least one week. To avoid sequence effects, the order of sessions was systematically changed between participants, with one half of the participants starting in condition A and the other in condition B. Participants were scheduled to arrive at the location of the study at around 18:30 h and had a 4-h long opportunity to sleep, from approximately 20:00 h to 00:00 h, during each session.

In each session, initial participant's state and opinion were first gathered through questionnaires regarding the current comfort, mood and sleepiness. The attachment of electrodes was done as in the familiarization session while relaxing music was playing.

At that time, vehicle audio was turned on and participants could start their sleep. The precise time of lights out was noted for each participant. For safety, participants could at any point communicate with the test experimenter through a provided baby-phone. Furthermore, the experimenter was always in the adjacent room monitoring the EEG, EMG and EOG signals.

After 4 h, participants were awoken by the experimenter through the baby-phone and the light was turned on. Once the participants were awake and ready, they answered the post sleep questionnaire consisting of current comfort, mood, sleepiness and sleeping experience and timeline questions.

Once participants completed the two sessions in both seat positions, the final questionnaire was submitted as an online questionnaire the morning after the second data collection session.

2.8. *Statistical analysis*

R Studio version 1.2.5042 (RStudio Team, 2020) was used to perform all the statistical analysis. ANOVAs were performed using the package *rstatix*, while *t*-tests, Wilcoxon tests and Pearson correlations were calculated using the R packages *stats* and *coin* (Hothorn et al., 2021). All visualizations of the data were created using the R package *ggplot2* (Wickham, 2011). Data assumptions were checked before the significance tests were performed. Statistically significant differences in this study refer to a $p < 0.05$.

Wilcoxon tests were performed regarding comfort and discomfort evaluation. Wilcoxon tests were used to compared pairwise two factors: seat position (60° vs. 87° from the vertical) and time (0 min vs. 240 min).

Paired t-tests were performed in all normally distributed sleep parameters, including TST, W, N1, N2, N3, R, %N1, %N2, %N3, %R, SE and SME. The rest of sleep dependent variables (i.e., SPT, SOL, N3L, REML, WASO, WASF and SS), which were non-normally distributed,

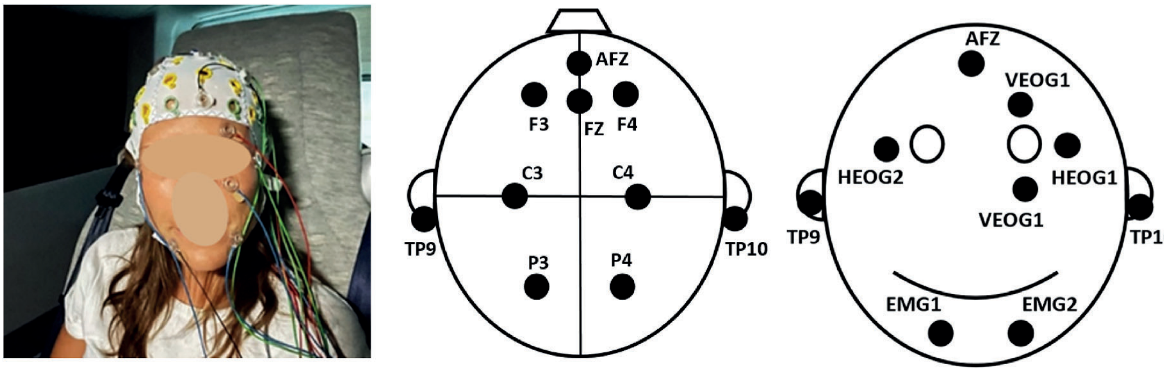

Fig. 4. Participant wearing the electrodes set up and top and front view diagrams of electrode placement.

Table 2
Sleep parameters used to evaluate sleep quantity and quality from the PSG data. Good sleep quality characteristics are included as reference (Boulos et al., 2019; Carskadon and Dement, 2005; Carskadon and Rechtschaffen, 2005; Dykierek et al., 1998; Ohayon et al., 2017; Shrivastava et al., 2014).

Acronym	Sleep Parameter	Meaning	Good sleep quality criteria
SPT	Sleep Period Time	Duration from first to last period of sleep	A longer SPT is generally better. It can also be the indication of other sleep issues, such as fragmentation or long Wake After Sleep Offset (WASF).
TST	Total Sleep Time	Total time spent in any of the stages of sleep during SPT TST = NREM1 + NREM2 + NREM3 + REM	Longer TST is better.
W, N1, N2, N3, REM	Sleep stages total times	Total time in each individual sleep stage	Each sleep stage has a function. Healthy sleeps include all of them, in specific proportions and orders (typically: W, N1, N2, N3, REM) during a full night sleep.
%W, %N1, %N2, %N3, %REM	Percentage of sleep stages	Proportion of the sleep stage of TST in % E.g.: (N3/TST) * 100	During a full night sleep N1 accounts for 2–5%, N2 for 45–55%, N3 for 10–20% and REM for 20–25%. A larger %N3 and smaller %REM is expected due to shorter study time.
SOL	Sleep Onset Latency	Time taken after lights out to start sleep activity	Shorter SOL is better. Less than 30 min is considered good sleep quality.
N3L	N3 Latency	Latency to first N3 Stage from the lights out	A normal, healthy N3L ranges from 10 to 70 min.
REML	REM Latency	Latency to first REM Stage	A normal, healthy REML ranges from 50 to 100 min.
WASO	Wake After Sleep Onset	Duration of wake periods within SPT	Shorter WASO is better. ≤20 min is considered good sleep quality, >40 min is considered bad sleep quality.
WASF	Wake After Sleep Offset	Duration of wake period after sleep offset	Shorter WASF is better, ideally 0 min.
SE	Sleep Efficiency	TST/TIB (Time in Bed) * 100 (%) TIB ≈ 240 min	Higher SE is better.
SME	Sleep Maintenance Efficiency	TST/SPT *100 (%)	Higher SME is better.
SS	Sleep Stability	Average of the transition probability of N1, N2, N3 and REM	Higher SS is better.

Wilcoxon tests were performed. Due to the small number of participants in this study ($N = 12$), type II errors are quite likely. To provide an indication of the size of the difference between conditions, Cohen's *d* was calculated for each dependent variable (Cohen J., 1988; Sawilowsky, 2009). Effect sizes were taken into consideration when they exceeded a moderate level ($d > 0.40$).

Finally, additional analysis was done to find possible explanations of different results, as well as validate subjective methods. Data comparison was done through the creation of Pearson correlation matrices. Significant moderate, strong or very strong correlation coefficients ($r > 0.4$) (Schober et al., 2018; Taylor, 1990) were identified for further exploration. Boxplots or scatter plots were used in order to find plausible explanations and, if appropriate, possible causalities.

3. Results

3.1. Self-reported assessment

3.1.1. Comfort

The subjective comfort and discomfort ratings for general and the different body parts comfort were plotted and visually examined (Fig. 5). Generally, the ratings indicated a positive experience, and the participants did not report strong discomforts (−3) at any point. Wilcoxon tests were performed to find significant differences. In terms of the seat position, there were no significant effects present. However, time was shown to have a significant effect on the back area, where comfort rating improved with time for both seat positions. ANOVAs for KSS and MDMQ scores did not reveal differences between the positions.

3.1.2. Self-reported sleep

Participants' perception of their own sleep resulted in different subjective sleep data (Fig. 6). In general terms, reported sleep was similar among the two conditions and large standard deviations can be observed. Although visually we can observe differences in the SOL and WASF between the conditions, there were no significant effects found between the positions (Table 3). Nonetheless, *t*-test and Cohen's *d* test showed that there is a trend for the reported SOL to be shorter in the flat position.

3.1.3. Preference

A final evaluation after both sessions included the question regarding the preference of the condition for sleeping (Fig. 7 - A). Although the reported sleep TST and quality was similar for both positions, most of the participants, 9 out of 12, chose the flat seat position as their preferred one for sleeping while travelling. The preference regarding the seat position seems to be related to the reported subjective TST and sleep quality. Participants chose the seat position in which they perceived longer and higher quality sleep (Fig. 7 - B).

3.2. Objective neurophysiological data

Several sleep parameters were calculated for evaluation (Table 4). Compared to ideal sleep parameter values (Table 2), TST and SE are slightly reduced. Regarding sleep stage proportion, a slightly elevated %N1 was observed. Stages %N2 and %N3 show expected proportions and %REM levels are slightly low. Regarding latencies, SOL was for most participants healthy and a sign of good sleep quality. N3L was elevated in the case of the reclined position and within the good sleep quality range for the flat position. REML was mostly within the range of good sleep quality, yet some participants showed reduced or prolonged REML. WASO and WASF are quite elevated especially for the flat condition, with three participants with WASF of over 90 min in this

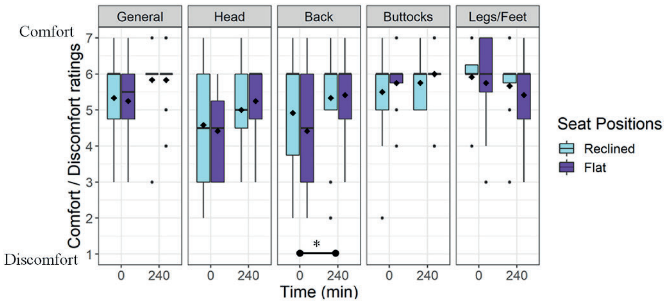

Fig. 5. Boxplot with different body part comfort ratings for flat and reclined seat conditions over time ($N = 12$, ◆ mean, ● outliers). Time in minutes. Main effects in Wilcoxon (*<0.05).

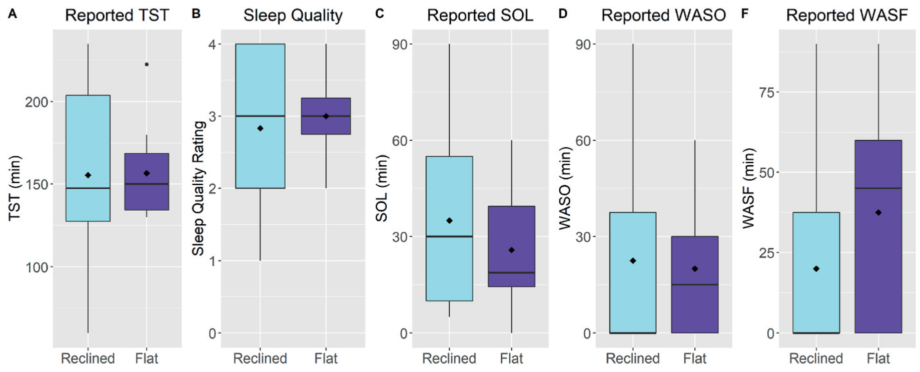

Fig. 6. Reported perceived sleep parameter boxplots for the reclined and flat seat conditions. (N = 12, ◆ mean, ● outliers).

Table 3
Effects of seat angle and time on dependent variables related to reported sleep. * indicates significant effects ($p < 0.05$) and+indicates tendency ($p < 0.1$).

Dependent variables	Significance		Effect Size	
	Two-sided unpaired *t*-test		Cohen's	95% Confidence Interval
	t	*p*	*d*	[lower, upper]
Reported TST	0.062	0.951	0.027	[-0.83, 0.96]
Reported SOL	−1.941	0.078$^+$	−0.559	[-1.25, 0.29]
	Two-sided, unpaired Wilcoxon test		Cohen's	95% Confidence Interval
	z	*p*	*d*	[lower, upper]
Sleep Quality	3.9937	0.664	0.185	[-0.61, 1.03]
Reported WASO	1.6947	1	−0.090	[-0.92, 0.9]
Reported WASF	1.6958	0.357	0.509	[-0.26, 1.62]

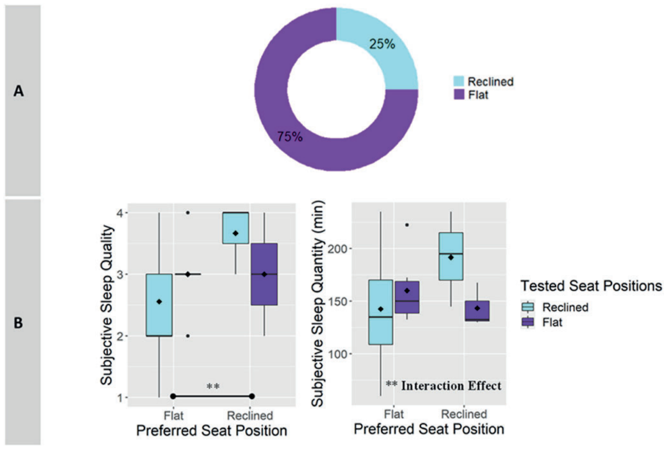

Fig. 7. (A) Preferred seat position for sleeping according to the participants (N = 12) (B) Subjective sleep quantity and quality by preferred seat position for sleeping boxplots as reported by participants (N = 12, ◆ mean, ● outliers). Significant main effects in ANOVA (*<0.05, **≤0.01).

condition. SS was optimal, except for one participant. Regarding individual hypnograms, most of them (91.67%) presented a normal, healthy stage progression and fragmentation of sleep stages for a 4-h sleep opportunity, though individual differences were present.

Sleep parameters were plotted for further examination (Fig. 8). On one hand, SPT, TST and WASF graphs indicated that the sleep quantity was slightly higher in the reclined position. On the other hand, the parameters related to slow wave sleep, %N3 and N3L, indicated a higher proportion and an earlier latency of this stage in the flat position. Moreover, it is also apparent that SOL tended to be shorter in the flat position. Nevertheless, there were no significant effects found (Table 5). Through *t*-tests, Wilcoxon test and Cohen's *d*, trends were identified for %N3 and SOL (Table 5). Both the %N3 and SOL trends indicated that participants obtained better sleep quality in flat position, with higher %N3 and a lower SOL than in the reclined position.

Reported sleep graphs were visually compared with the corresponding real sleep hypnograms (Fig. 9). Some participants reported quite accurate simplified hypnograms (Fig. 9 - A). 5 out of 12 participants had visually similar hypnograms in the reclined positions and 3 out of 12 in the flat position. While other participants' self-reported hypnograms had less in common with the real sleep hypnogram estimated from the PSG (Fig. 9 - B). It was observed that generally participants (91.67%) correctly reported whether they were mostly asleep or awake during the last time slot (minute 210–240). It was also perceived that SOL was generally (75%) reported longer, with a mean of (±ST) 23.6 min (±26.09) longer of reported SOL compared with real SOL. Some of the reported SOLs (41.67%) were closer to N3L time than to real SOL time. Lastly, participants would report if they were on longer period of wake between sleep periods, but not always at the correct time. To confirm these visual similarities between the sleep hypnograms, correlations between the objective and reported parameters were obtained. TST, SOL and WASF sleep parameter were moderately correlated with the PSG-based objective data (Table 6).

4. Discussion

4.1. Main findings

The evaluation of sleep quality in vehicles is an emerging area of research and the present study represents a pioneering effort in this field. To comprehensively assess sleep quality, a multi-method approach was used, combining both subjective and objective data. The analysis of sleep metrics such as SPT, TST, and WASF revealed a non-significant marginal increase in sleep quantity for individuals adopting the reclined position. However, objective data also showed statistical trends in the %N3 and SOL measures, indicating that sleep quality might have been better in the flat position than in the reclined position. Specifically, %N3, representing the percentage of slow-wave sleep (SWS), was higher in the flat position, while SOL, representing the time taken to fall asleep, was lower in the flat position. These specific differences were not observed in previous research (Ogata et al., 2022; Roach et al., 2018). SWS is essential for adequate cognitive functioning, immune system strengthening and memory consolidation (Diekelmann and Born, 2010; Halson and Juliff, 2017; Léger et al., 2018; Maquet, 1995). The role of this stage in sleep is crucial and its presence is necessary to achieve good quality sleep (Datta and O'Malley, 2013). Therefore, these findings suggest that the flat position may be more contributing to achieving deeper and more restful sleep.

In addition to objective data, subjective evaluation of comfort,

Table 4
Descriptive statistics for objective sleep quantity and quality ($N = 12$, except $N = 11$ in REM Latency in the reclined position due to lacking REM stage).

Variables (min, unless specified)	Reclined seat position (60°)				Flat seat position (87°)			
	mean	SD	min	max	mean	SD	min	max
Sleep Period Time (SPT)	222	15	189	235	201	47	120	236
Total Sleep Time (TST)	173	35	115	228	156	42	85	212
WAKE (W)	67	35	14	126	84	42	29	156
N1	25	17	9	64	23	23	6	86
N2	93	29	44	141	79	31	37	140
N3	35	22	5	69	38	18	13	78
REM	19	13	0	46	16	13	1	36
Proportion of NREM1 (%N1)	15%	10%	4%	36%	15%	13%	4%	48%
Proportion of NREM2 (%N2)	54%	12%	38%	81%	50%	9%	38%	67%
Proportion of NREM3 (%N3)	20%	11%	3%	34%	26%	12%	7%	40%
Proportion of REM (%REM)	11%	8%	0%	25%	10%	8%	0%	25%
Sleep Onset Latency (SOL)	15	11	6	41	11	6	5	23
N3 Latency (N3L)	73	58	20	196	50	31	21	130
REM Latency (REML)	101	41	55	197	91	70	9	208
Wake After Sleep Onset (WASO)	53	36	7	108	74	43	16	147
Wake After Sleep Offset (WASF)	4	10	0	36	28	48	0	111
Sleep Efficiency (SE)	72%	14%	48%	94%	65%	18%	35%	88%
Sleep Maintenance Efficiency (SME)	78%	15%	51%	97%	79%	17%	37%	98%
Sleep Stability (SS)	85%	14%	46%	94%	85%	10%	61%	95%

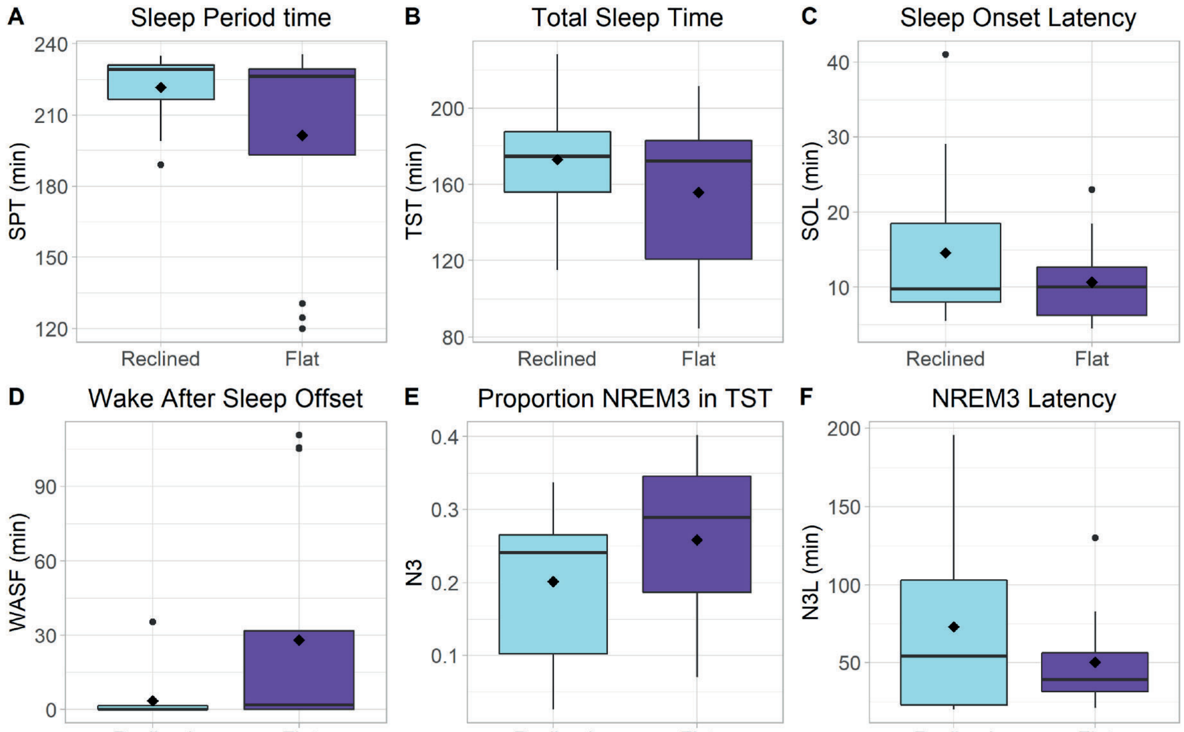

Fig. 8. Sleep parameter boxplots for the reclined and flat seat conditions gathered by PSG ($N = 12$, ◆ mean, ● outliers).

preference, and experience was also conducted. Prior to the study, the comfort of the seat prototype had already been assessed for sleeping use (Caballero-Bruno et al., 2022b), and the results were used to optimize the seat design. The comfort and discomfort evaluation was conducted both before sleep and after the 4-h session. The long-term comfort evaluation in this study indicates the accomplishment of the optimization since ratings were improved in both reclined and flat positions compared to previous results.

Notably, the majority of participants (75%) preferred the flat sleeping position after trying both of the positions for sleeping. The higher %N3 observed in the flat position could have contributed to the participants' preference for this position. Moreover, this result supports the understanding that subjective factors also influence sleep experience, and sleep should not only be evaluated objectively.

4.2. *Secondary findings and methodology*

Overall, the sleep quantity and quality of participants were found to be adequate, despite the short duration of sleep chance and early bedtime, i.e. ~20:00. The participants slept generally similar amounts in any of the seat positions, with a mean (±ST) 173 min (±35) in the reclined and 156 min (±42) in the flat position. This results were consistent with previous research (Caballero-Bruno et al., 2022b; Roach et al., 2018). Marginally reduced sleep parameters, such as TST and SE, show an acceptable quantity for a 4-h sleep opportunity without sleep deprivation, at an earlier than usual bed time (Roach et al., 2018). While

Table 5
Paired t-tests, Wilcoxon tests and effect size analyses for sleep parameters gathered by PSG ($N = 12$). * Indicates significant effects ($p < 0.05$) and+indicates tendency ($p < 0.1$).

Dependent variables	Two-sided paired t-test		Cohen's	95% Confidence Interval
	t	*p*	*d*	[lower, upper]
SPT	−1.327	0.211	−0.59	[-1.26, 0.26]
TST	−0.939	0.368	−0.45	[-1.28, 0.41]
N1	−0.382	0.709	−0.07	[-1.15, 0.67]
N2	1.498	0.162	−0.49	[-1.59, 0.28]
N3	0.363	0.724	0.13	[-0.81, 1.03]
R	−0.770	0.457	−0.25	[-1.17, 0.57]
%N1	−0.140	0.891	−0.03	[-0.96, 0.76]
%N2	−1.722	0.113	−0.37	[-1.21, 0.46]
%N3	2.140	0.055^{+}	0.50	[-0.35, 1.35]
%R	−0.615	0.551	−0.18	[-1.19, 0.66]
SE	−0.966	0.355	−0.45	[-1.35, 0.36]
SME	0.233	0.820	0.07	[-0.69, 1.10]
SS	−0.033	0.974	−0.01	[-1.03, 0.70]
	Two-sided paired Wilcoxon test		Cohen's	95% Confidence Interval
	z	*p*	*d*	[lower, upper]
SOL	4.288	0.071^{+}	−0.45	[-1.17, 0.43]
N3L	4.287	0.266	−0.49	[-1.34, 0.33]
REML	4.197	0.607	−0.18	[-1.14, 0.70]
WASO	4.286	0.850	−0.09	[-1.15, 0.65]
WASF	0.101	0.194	0.71	[-0.21, 1.35]

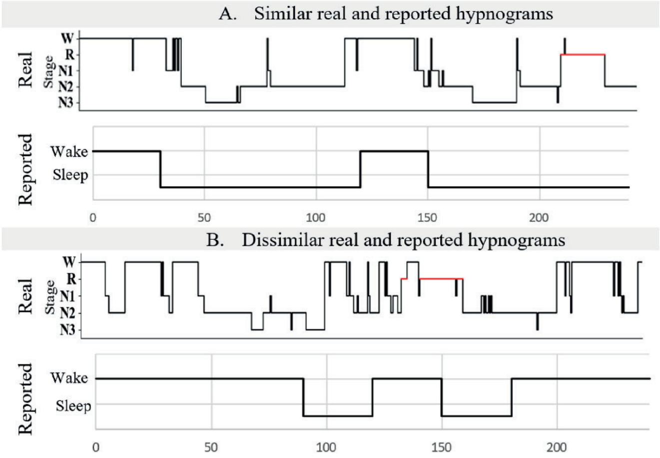

Fig. 9. Examples of a similar (A) and a dissimilar (B) comparison between real and reported sleep hypnograms. X axis: Time (min).

Table 6
Correlations between the objective and reported parameters. Significant correlations indicated as * $p < 0.05$.

Variables	Pearson Correlation	
	r	p
TST	0.57	<0.001*
SOL	0.59	<0.001*
WASO	0.25	0.005*
WASF	0.62	<0.001*

slightly elevated N1 and reduced REM levels were observed, these findings were expected given the reduced sleep duration and environmental conditions.

The evaluation of long-term comfort and discomfort revealed an uncommon behaviour in which the comfort/discomfort score tended to remain stable or even improve over time, as opposed to the usual trend of discomfort increasing over time (El Falou et al., 2003; Lantoine et al., 2022; Vink et al., 2017). This trend could be attributed to the improved seat design and lack of vibration and movement in the car.

The subjective evaluations of sleep were found to be moderately correlated with objective sleep measures. Specifically, self-reported TST, SOL, and wake after sleep onset (WASO) were significantly moderately correlated with their PSG counterparts. These results are consistent with previous studies (Argyropoulos et al., 2003; Matthews et al., 2018). However, it is noteworthy that participants consistently reported longer SOL than objectively measured, even though self-reported TST was within the real TST parameters.

4.3. Limitations and outlook

Environmental factors that could influence sleep were carefully considered in this study. Discomfort points and sleep disturbances caused by real driving movement were excluded from the study. By minimizing the impact of such factors, the focus was able to be on the sleep quality of participants and the differences between the seat positions. The current testing setup with a real car, modified interior and driving sound was designed to give the participants the opportunity to imagine themselves in a real-world scenario. Some participants declared feeling “like the car was really driving”. Since the participants had no visual stimuli, this was probably due to the addition of the driving sound. However, the lack of movement and vibration in the scenario probably had an impact on psychological factors, such as trust (Paddeu et al., 2020; Payre et al., 2014) and comfort (Basri and Griffin, 2013; Bubb and Bengler; Chen and Gao, 1990). Specifically, vibration has been classified as one of the main comfort influencing factors when travelling (Mellert et al., 2008). Presumably, normal driving movement would also affect sleep and possibly induce motion sickness (Iskander et al., 2019). Future studies could investigate the impact of a dynamic scenario on sleep quality, comfort, trust and other psychological factors.

One of the main sleep-influencing factors of this study is the early starting time of the sleep opportunity. The starting time was chosen to better represent a realistic driving scenario and due to organizational advantages. However, this was not the usual sleep time for any of the participants. Circadian and homeostatic process are responsible for regulating sleep (Borbély and Achermann, 1999; Saper et al., 2005). The homeostatic process is the process that increases the propensity to sleep during waking time and dissipates it during sleep. This means that participants, who woke up between 06:00AM and 8:00AM, would have had a relatively low sleep pressure at 08:00PM (Cajochen et al., 2006). Also, the circadian process, which reflects the time-of-day-dependent variations of different body functions and correlates closely with sleepiness, was probably in a phase during the sessions that did not provide optimal conditions for the participants to fall asleep (Halberg and Stephens, 1959). Possible solutions for future research include scheduling testing sessions later in the evening or inducing sleep deprivation.

Additionally, to establish a sleep neurological baseline (Gusnard and Raichle, 2001) in a naturalistic setting, including aspects such as habitual bedtime, sleep surface, ambient noise, and light levels, could offers valuable insights for future research. By facilitating a comparison between study sleep hypnograms and typical sleep patterns in home environments, further understanding of the subject can be achieved.

The use of the YASA toolbox as an automated scoring method in this study has demonstrated great potential. These type of methods reveal great potential due to high classification accuracy (Vallat, 2018). Automated methods are user-friendly, less time-consuming and reduce the chances of human error, compared to traditional manual scoring methods. Although automated methods are not yet established as a standard in the research field (Fiorillo et al., 2019; Vallat, 2018), the use of YASA toolbox in this study provides significant benefits in applied sleep research. Therefore, the YASA toolbox could be a valuable tool in future studies.

The study's small sample size may have contributed to the lack of significant effects of seat positions on sleep parameters. Additionally, the study's limited age range, which consisted of a young population free from factors that could potentially influence sleep and comfort evaluations, represents a limitation. Therefore, it is uncertain whether similar results could be obtained from other potential users, including older populations or individuals with impairments.

To further investigate and obtain a more targeted evaluation of comfort and discomfort, future studies could consider using separate rating scales for comfort and discomfort (Looze et al., 2003; Vink and Hallbeck, 2012; Zhang et al., 1996). Furthermore, the seat comfort evaluation could be based on mattress comfort methodology (Buckle and Fernandes, 1998; Naddeo et al., 2015; Wong et al., 2019), which may provide more detailed insights into the comfort level of the seat. It should also be noted that this study only assessed the comfort level during one designated use case: sleeping. However, as seats are often designed for a range of use cases, future research should investigate how other uses for a vehicle seat affect comfort evaluation.

Even though majority of the participants favoured the flat position for sleeping and this result is in line with previous research on this topic (Caballero-Bruno et al., 2022b; Östling and Larsson, 2019; Smulders et al., 2016; Stanglmeier et al., 2020; Yang et al., 2019), the reason for this preference cannot be fully justified by the objective results. This preference seems to be influenced by other factors, beyond those found by objective sleep analysis (Kaplan et al., 2017). Making adjustments to your body position is essential to avoid putting excessive pressure on soft tissues and to prevent your muscles from becoming stiff (Haex, 2004; Koninck et al., 1992). It is crucial to adjust your posture to a reasonable and natural extent to ensure a positive and comfortable sleep experience. The preference for the flat seat position is likely influenced by this factor as well. Previous experience and expectation may also have a significant impact on preference (Naddeo et al., 2015), as most participants chose the angle they already knew for sleeping. Therefore, the study highlights the need for further research in this area and emphasizes the importance of considering both subjective and objective data when evaluating sleep quality.

Overall, this study contributes to the understanding of sleep quality in vehicles and its evaluation. The use of a multi-method approach enabled the collection of comprehensive data from different sources, providing a more complete picture of sleep quality in this context. Subsequent studies can expand on this knowledge by investigating the variables that impact sleep quality in vehicles. Specifically, future research should explore alternative backrest angles, seat pan angles, and different foam materials and hardness. Through this investigation, there is potential for the development of improved ergonomic designs and better sleep quality, which could provide valuable insights in promoting enhanced sleep comfort and alleviating discomfort. Additionally, as new seat angles and body positions are introduced, it is imperative that safety and restraint systems are adapted and updated accordingly.

5. Conclusion

In summary, this study provides a comprehensive understanding of sleep quality and quantity in the context of travelling in a fully automated car. By using a real environment instead of a typical lab, the study provided a more realistic view of sleep in this new context. The study's multi-method approach combining subjective evaluations based on questionnaires and multimodal neurophysiological recordings evaluated with machine learning provided a holistic picture of individual comfort and sleep quality. The findings of this study fill some current knowledge gaps in the field of sleeping while travelling by car and have important implications for the development of new technologies and design of car seats. While this study represents a first step towards a better understanding of sleeping while travelling by car, future research is needed to explore the factors that influence sleep quality in vehicles and develop interventions to improve it.

In conclusion, this study has contributed to the understanding of sleep quality in vehicles and its evaluation. Sleep quality was generally within optimal sleep ranges in both seat positions, with the flat position resulting in deeper sleep and quicker sleep onset for participants. The findings suggest that the flat position may be more conducive to achieving deeper and more restful sleep. Moreover, each participant had the opportunity to sleep in both tested seat positions. The majority of participants preferred the flat position for sleeping in the travelling context.

These findings may have implications for future car seat designs, suggesting that a flat position may be more conducive to sleep quality while travelling. A future where people can comfortably sleep inside a car while commuting or going on holidays might be possible with further developments in car seat designs and technology.

Declaration of competing interest

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 the user study and is responsible for the conceptualization, methodology, formal analysis, resources, data curation, writing the original draft, visualization and project administration. ICB, MW and TW are employed by Volkswagen AG, Wolfsburg. KL, DP and MV are employed by Fraunhofer Institute of Industrial Engineering, Stuttgart. NT and DP are employed by Institute of Human Factors and Technology Management, Stuttgart. The objective of this paper was to define the best seat configuration for sleeping during a car journey. Data were collected by and at the Fraunhofer Institute of Industrial Engineering (IAO) in Stuttgart, Germany. This study was financially supported and leaded by Volkswagen AG. The results, opinions and conclusions expressed in this article are not necessarily those of Volkswagen Aktiengesellschaft.

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3. Conclusions and Future Works

The primary goal of this doctoral thesis has been an extensive evaluation of the role of sleep in the context of fully automated cars. Investigating the dynamic requirements and inclinations of users within the framework of new car interiors and seating arrangements has been the central focus of this study. Specifically, this research has delved into the analysis of seat adjustments, placing particular emphasis on identifying and establishing ideal seat angles to facilitate an enhanced sleep experience while riding in a vehicle. The research adopted a participant-centred approach, testing in a realistic environment and continuously refining the car seat and interior based on participant feedback.

The main contributions of this work entail the conception and execution of four user studies, carefully crafted to address the pertinent research inquiries and contemporary developments in the field. Each study incorporated a diverse array of techniques, questionnaires, and both objective and subjective methodologies for the examination of comfort and sleep. This approach provided several advantages, including direct participant engagement for first-hand feedback, a thorough understanding of how design elements impact human behaviour and comfort, and the development of more ergonomic and intuitive car interiors. Additionally, the approach facilitated the collection of empirical data, enabling the establishment of quantifiable metrics for evaluation, thus supporting evidence-based decision-making in the design process.

The findings corresponded closely with the research objectives, confirming the feasibility of achieving restful and comfortable sleep in a vehicle. Notably, variations in comfort, drowsiness, and the percentage of deep sleep highlighted the advantages of a flat lying position for prolonged periods of sleep. Initial limitations in the seat prototype design resulted in discomfort across various areas such as the head, neck, legs, and feet, prompting continuous refinements to alleviate these issues. These limitations in the first studies encompassed a restricted participant pool, a limited study duration, and the potential influence of COVID-19 protocols on the outcomes of the first experiment. Furthermore, scheduling constraints, such as early or irregular study start times, could have disrupted participants' natural sleep patterns, suggesting the necessity for future investigations at different times. In the first and last studies, small sample size and limited age range may have influenced the findings, emphasizing the importance of incorporating a more diverse population in subsequent research endeavours. Additionally, the study considered environmental factors, although the absence of movement and vibration in the last study might have affected psychological aspects.

This thesis has excluded certain research aspects as they fall beyond its scope. In the context of the doctoral thesis, the exclusion of user studies on restraint systems was deliberate, with the primary emphasis placed on enhancing user comfort and sleep quality. Notably, despite this exclusion, the thesis includes the proposal of mechanisms for a movable, flexible planar restraint element as part of a patent, included in the appendix (4.1 Restraint system mechanism patent). Safety evaluation of the restraint system for sleep in a lying posture was as well excluded, with potential crash safety concerns left for further research. Specific seat optimizations and detailed foam or seat contour research were outside the scope to maintain a concentrated investigation on the seat's fundamental function and characteristics. Additionally, the analysis of motion sickness, driving comfort, and vibrations was omitted as the primary focus was on assessing sleep experiences. The thesis also did not include a specific evaluation of sleep environment conditions like temperature, light, and air quality, as these parameters were solely controlled to ensure the integrity of the user studies. These research topics are relevant and can be the subject of future research in the sleep use case for fully automated vehicles.

Throughout the conducted research, consistent efforts were made to enhance the prototype, methodology, and overall user experience. Particularly, insights and limitations identified in the first and second user studies, such as pressure distribution observations, suboptimal comfort of the prototype seat, and the absence of objective sleep measurements, informed the design of subsequent studies. Additionally, the need for an appropriate restraint system was present during the research, underscored by the recognition of discomfort related to the 7-point seatbelts near the neck and shoulder regions in the second study. The patent (4.1 Restraint system mechanism patent) describing proposals for mechanisms for a movable, flexible planar restraint element aligns with the research undertaken in this thesis, particularly in the context of the sleep in transit use case. By focusing on the feasibility of utilizing such a mechanism in both reclined and flat seat positions, the research emphasizes the importance of ensuring comfort and safety during travel. The findings from the sleep and comfort research shed light on the specific requirements for achieving optimal rest and relaxation while in transit, thereby reinforcing the significance of implementing innovative solutions, such as the proposed movable and flexible planar restraint element, to enhance the overall travel experience. This convergence of the patent proposal and the research insights underscores the comprehensive approach taken in this thesis, highlighting the practical implications for the development of advanced seating systems tailored to the specific needs of passengers during automated travel.

This doctoral thesis inquiry has benefitted significantly from conducting research in collaboration with an esteemed and experienced car manufacturer. Furthermore, the utilization of high-quality materials and prototypes in the conducted studies facilitated the creation of realistic scenarios for the participants, ensuring the acquisition of precise and reliable data and outcomes. As a whole, the opportunities offered by the industrial partnership were maximized, thereby enhancing the credibility and robustness of the research findings.

The entirety of the research and its contributions have been disseminated in high-quality peer-reviewed journals, emphasizing the significance of the thesis's contribution and helping to address knowledge gaps in the field. The combined findings imply the feasibility of achieving both comfortable and meaningful sleep during future travel. Additionally, the obtained results suggest that a flat seat position may facilitate deeper and more restful sleep. This study sets the stage for forthcoming advancements in car seat designs and technology, ultimately enhancing the overall travel experience, promoting optimal sleep quality, and ensuring passenger satisfaction in fully automated vehicles, ultimately shaping the future of transportation and mobility.

4. References

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5. Appendix

5.1. Patent. Restraint device for securing vehicle occupants on a seat-lying device, comprising a movable, flexible surface element

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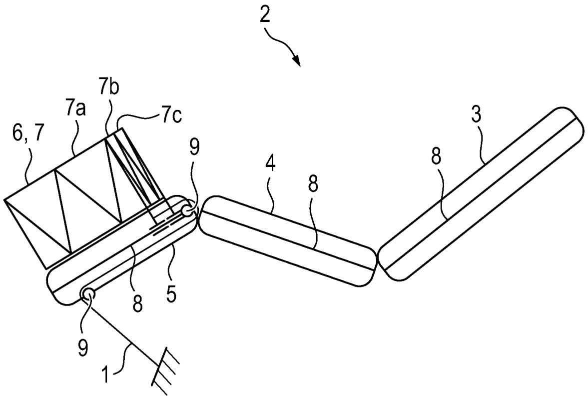
Prüfungsantrag gemäß § 44 PatG ist gestellt.

Rechercheantrag gemäß § 43 PatG ist gestellt.

Die folgenden Angaben sind den vom Anmelder eingereichten Unterlagen entnommen.

(54) Bezeichnung: **Rückhaltevorrichtung zur Sicherung von Fahrzeuginsassen auf einer Sitz-Liege-Vorrichtung aufweisend ein verfahrbares flexibles Flächenelement**

(57) Zusammenfassung: Die Erfindung betrifft eine Rückhaltevorrichtung zur Sicherung von Fahrzeuginsassen auf einer Sitz-Liege-Vorrichtung (2) aufweisend ein verfahrbares flexibles Flächenelement (6), welches in einer Gebrauchsposition mit zumindest einem Abschnitt (7) einen Teilbereich des Fahrzeuginsassen bedeckt und in einer Ruheposition den Fahrzeuginsassen nicht bedeckt.



Beschreibung

[0001] Die Erfindung betrifft eine Rückhaltevorrichtung zur Sicherung von Fahrzeuginsassen auf einer Sitz-Liege-Vorrichtung aufweisend ein verfahrbares flexibles Flächenelement, welches in einer Gebrauchsposition mit zumindest einem Abschnitt einen Teilbereich des Fahrzeuginsassen bedeckt und in einer Ruheposition den Fahrzeuginsassen nicht bedeckt.

[0002] Bekannte Rückhaltevorrichtungen, wie insbesondere Sicherheitsgurte, sind für Fahrzeuginsassen in aufrecht sitzender Position ausgelegt und können für Insassen in liegender Position durch weitere Rückhaltevorrichtungen ergänzt werden. Gestiegener Fahrkomfort in Kraftfahrzeugen, wie zum Beispiel in Personenkraftwagen, Kleinbussen, Bussen oder Flugzeugen, führt zum Bedarf an komfortableren Sitz-Liege-Positionen der Fahrzeuginsassen.

[0003] Eine solche Rückhaltevorrichtung ist aus der DE 10 2018 206 090 A1 bekannt, die zur Sicherung von Fahrzeuginsassen in einer stark geneigten Position translatorisch entlang von Führungsschienen in eine Gebrauchsposition verfährt und die Fahrzeuginsassen mit einem flexiblen Flächenelement bedeckt. Zum Verfahren weist die Rückhaltevorrichtung einen Linearantrieb auf, der sich bevorzugt entlang der Führungsschiene erstreckt und als Riemenantrieb oder Teleskopantrieb ausgebildet sein kann.

[0004] Aus der DE 10 2019 201 307 A1 ist eine Fahrzeugsitzanordnung mit einer Rückhaltevorrichtung für liegende Personen bekannt, die in einem fußseitigen Endbereich des Fahrzeugsitzes eine an eine Köpergröße der Person anpassbar verstellbare Rückhaltevorrichtung aufweist, die sich in einer Unfallsituation im Kontakt mit der Person befindet.

[0005] Es ist weiterhin durch die DE 10 2019 201 302 A1 eine Rückhaltevorrichtung für Kraftfahrzeuge für stark geneigte Personen bekannt, die manuell in eine Gebrauchsposition überführbar ist, in der sie mit einem Flächenelement einen Teil der Körperoberfläche der Person bedeckt, wobei die Rückhaltevorrichtung zur Straffung des Flächenelements mit mehreren, jeweils einzelnen Körperregionen zugeordneten gasbefüllbaren Airbags versehen ist.

[0006] Vor diesem Hintergrund liegt der Erfindung die Aufgabe zugrunde, eine Rückhaltevorrichtung der eingangs genannten Art derart auszuführen, dass ein flexibles Flächenelement zuverlässig und komfortabel einen liegenden Fahrzeuginsassen auf einer Sitz-Liege-Vorrichtung bedeckt sowie den sitzenden Fahrzeuginsassen freigibt, wobei die Herstellungskosten und das Gewicht des Antriebmittels gering sind.

[0007] Diese Aufgabe wird gelöst mit einer Rückhaltevorrichtung gemäß den Merkmalen des Patentanspruchs 1. Die Unteransprüche betreffen besonders zweckmäßige Weiterbildungen der Erfindung.

[0008] Erfindungsgemäß ist also eine Rückhaltevorrichtung zur Sicherung von Fahrzeuginsassen auf einer Sitz-Liege-Vorrichtung vorgesehen, aufweisend ein verfahrbares flexibles Flächenelement, welches in einer Gebrauchsposition mit zumindest einem Abschnitt einen Teilbereich des Fahrzeuginsassen bedeckt und in einer Ruheposition den Fahrzeuginsassen nicht bedeckt, wobei das Verfahren des flexiblen Flächenelements an das Verfahren der Sitz-Liege-Vorrichtung zwangsgekoppelt ist.

[0009] Eine Sitz-Liege-Vorrichtung ist ein Fahrzeugsitz, der eine aufrecht sitzende Position sowie eine liegende Position, bevorzugt flach liegend, ermöglicht. Zwischenpositionen, also liegend mit erhöhtem Oberkörper und/oder mit tiefer gelagerten Füßen, sind selbstverständlich möglich und werden folgend als sitzend oder als liegend bezeichnet. Befindet sich der Fahrzeuginsasse in einer Zwischenposition, kann das flexible Flächenelement eine Gebrauchsposition einnehmen, die nicht der liegenden Gebrauchsposition entspricht. Die Zwangskopplung kann so ausgebildet sein, dass die Sitz-Liege-Vorrichtung um eine Teilstrecke verfahren werden kann, ohne dass das Flächenelement verfahren wird. Es ist also möglich, dass das Flächenelement nur verfahren wird, wenn die Sitz-Liege-Vorrichtung sich in bestimmten Positionen befindet. Die Zwangskopplung des flexiblen Flächenelements an die Sitz-Liege-Vorrichtung macht ein manuelles Verfahren des flexiblen Flächenelements entbehrlich und erhöht hierdurch den Komfort sowie die Sicherheit, da ein Verfahren des flexiblen Flächenelements nicht unterlassen werden kann. Des Weiteren wird ein zusätzlicher Antriebsmotor sowie dessen Ansteuerung und Regelung verzichtbar, sodass ein leichtes sowie günstig herstellbares Antriebsmittel realisierbar wird.

[0010] Es sind flexible Flächenelemente für Bereiche der Fahrzeuginsassen, wie zum Beispiel die Unterschenkel, vorsehbar, wobei die Rückhaltevorrichtung auch mehrere Abschnitte von flexiblen Flächenelementen für verschiedene Bereiche vorsehen kann, die mittels eines Antriebsmittels oder mehreren, jeweils mit der Sitz-Liege-Vorrichtung zwangsgekoppelten Antriebsmitteln verfahren werden können.

[0011] Bevorzugt weist die Rückhaltevorrichtung einen Abschnitt des Flächenelements auf, das entlang von an der Sitz-Liege-Vorrichtung vorgesehenen Führungsschienen, an die das Flächenelement angebunden ist, durch das Verfahren der Sitz-Liege-Vorrichtung verfahren wird. Durch das Verfahren des

Flächenelements entlang einer Führungsschiene ist ein einfaches sowie definiertes Verfahren möglich, wobei eine sichere Anbindung des Flächenelements über die Führungsschiene ermöglicht wird.

[0012] In einer besonders praxisrelevanten Ausführungsform weist das Flächenelement einen Abschnitt, bevorzugt einen Beinauflagenabschnitt zum Verfahren über die Beinablage, ein Sitzflächenabschnitt oder Sitzlehnenabschnitt zum Verfahren über die Sitzfläche oder die Sitzlehne der Sitz-Liege-Vorrichtung auf, die mit einem Zugmittel, das über Umlenkungen geführt wird, durch ein Verfahren einer Beinauflage oder einer Sitzlehne der Sitz-Liege-Vorrichtung angetrieben wird, wobei das Zugmittel bevorzugt eine fahrzeugfeste, beinauflagenfeste oder sitzlehnenfeste Anbindung aufweist. Das Zugmittel kann zum Beispiel ein Seil, ein Band oder eine Kette sein, wobei die Umlenkung entsprechend geeignet ausgeführt ist, zum Beispiel als ein Gleit- oder Rollenlager. Die Umlenkung kann bevorzugt eine Übersetzung, beispielsweise in Form eines Flaschenzugs aufweisen, wodurch eine kleinere Bewegung der Sitz-Liege-Vorrichtung einen großen Verfahrweg des Flächenelements ermöglicht. Durch eine feste Anbindung des Zugmittels im Zusammenwirken mit der Umlenkung wird in einfacher Weise die Zwangskopplung von Abschnitten des flexiblen Flächenelements mit der Sitz-Liege-Vorrichtung realisiert.

[0013] Eine bevorzugte Ausführungsform weist eine Rückhaltevorrichtung mit einem Abschnitt auf, der weiter bevorzugt ein Beinauflagenabschnitt, ein Sitzflächenabschnitt oder ein Sitzlehnenabschnitt ist, der mit einem Zugmittel angetrieben wird, wobei das Zugmittel an einer Armlehne angebunden ist, die mit der Sitzlehne zwangsgekoppelt verfährt. Hierdurch wird eine Relativbewegung zwischen der Sitz-Liege-Vorrichtung und dem Abschnitt des flexiblen Flächenelements in besonders einfacher Form realisierbar, da die Armlehne von der Sitzlehne abragt.

[0014] In einer besonders praxisrelevanten Ausführungsform wird ein Abschnitt, bevorzugt ein Beinauflagenabschnitt, ein Sitzflächenabschnitt oder ein Sitzlehnenabschnitt, mit einem Zugmittel angetrieben, wobei das Zugmittel mit einem Führungselement in Verbindung steht, das mittels einer, bevorzugt von der Sitzlehne angetriebenen Koppelstange verfahren wird.

[0015] Wird die Sitz-Liege-Vorrichtung verfahren, wird hierdurch die daran befestigte Koppelstange und das am Ende der Koppelstange befindliche Führungselement verfahren, womit das Zugmittel gespannt wird. Dies ermöglicht bei ausreichend gegebenem Bauraum ein besonders einfaches Spannen des Zugmittels, wobei in einfacher Weise durch ein fahrzeugfestes Anbringen des Zugmittels eine Übersetzung und somit ein größerer Verfahrweg des Abschnitts ermöglicht wird.

[0016] Eine bevorzugte Ausführungsform weist einen Abschnitt, bevorzugt ein Beinauflagenabschnitt, ein Sitzflächenabschnitt oder ein Sitzlehnenabschnitt, der mit einem Zugmittel angetrieben wird, auf, wobei das Zugmittel mittels eines, bevorzugt an der Sitzlehne befestigten Stempels, bevorzugt gegen eine Federkraft, ausgelenkt wird. Bevorzugt kann durch Umlenkungen des Zugmittels beidseits des Stempels ein vergrößerter Verfahrweg des Abschnitts erzeugt werden. Ein Verfahren auch um große Verfahrwege des Abschnitts wird in einfacher Weise ermöglicht.

[0017] Bevorzugt weist die Rückhaltevorrichtung einen Abschnitt des Flächenelements auf, bevorzugt ein Beinauflagenabschnitt, ein Sitzflächenabschnitt oder ein Sitzlehnenabschnitt, das mit einem Zugmittel angetrieben wird, wobei das Zugmittel an einer rotierbar gelagerten Rolle angebunden ist, die mittels eines Ritzels mit einer Zahnstange, bevorzugt einer gebogenen oder geraden Zahnstange, in Wirkverbindung steht. Die zumindest überwiegend translatorische Bewegung der Zahnstange wird in eine Rotationsbewegung umgewandelt, die zu einem Aufwickeln des Zugmittels und einem Verfahren des Abschnitts führt. Der Antrieb kann in einer Ausführungsform die Rolle antreiben, die wiederum die Zahnstange antreibt. Es kann somit eine besonders effiziente und einfache Zwangskopplung des Flächenelements mit der Sitz-Liege-Vorrichtung realisiert werden.

[0018] In einer besonders praxisrelevanten Ausführungsform verfährt ein an der Sitzlehne fixiertes Zahnsegment eine Zahnstange linear, wobei die Zahnstange mittels eines Gelenks und einer Lagerung über einen Längenausgleich einen Abschnitt, bevorzugt einen Beinauflagenabschnitt, einen Sitzflächenabschnitt und/oder einen Sitzlehnenabschnitt antreibt. Das Gelenk bewirkt zusammen mit der Lagerung eine Veränderung der Bewegungsrichtung, sodass die Bewegung des Abschnitts gegenläufig zur Bewegung der Zahnstange ist. Der Längenausgleich ist ein flexibles Mittel, das ausreichend steif ist, um einen Abschnitt zu verfahren, jedoch ausreichend nachgiebig ist, um sich den geometrischen Anforderungen anzupassen. Es kann zum Beispiel eine Feder oder ein Dämpfer sein. Eine kompakte sowie leichte und kostengünstig herstellbare Zwangskopplung wird realisierbar.

[0019] In einer bevorzugten Ausführungsform wird durch ein Verfahren der Sitzlehne eine an der Sitzlehne fixierte, bevorzugt hydraulische oder pneumatische erste Kolben-Zylinder-Einheit betätigt, die mittels einer Druckleitung eine zweite Kolben-Zylinder-

Einheit antreibt, die mittels eines Gelenks und einer Lagerung über einen Längenausgleich einen Abschnitt des flexiblen Flächenelements, bevorzugt ein Beinauflagenabschnitt, ein Sitzflächenabschnitt und/oder ein Sitzlehnenabschnitt, antreibt. Das Gelenk wirkt zusammen mit der Lagerung und dem Längenausgleich, wie oben beschrieben, zu einer gegenläufigen Bewegung des Abschnitts zum Kolben des Zylinders. Eine besonders kompakte und flexibel anordenbare Zwangskopplung wird ermöglicht.

[0020] Eine besonders praxisrelevante Ausführungsform sieht ein flexibles Flächenelement vor, dass beidseitig an der Sitz-Liege-Vorrichtung gelagert ist und bevorzugt Gewebeteile mit integrierten Airbagkammern und/oder integrierten Gurten aufweist. Die beidseitige Lagerung des Flächenelements ermöglicht eine einfache sowie sichere Lagerung des Flächenelements, wobei dies mittels Gurten und/oder Airbagkammern Fahrzeuginsassen in Unfallsituationen effektiv zurückhält.

[0021] Das flexible Flächenelement kann an dem zu verfahrenden Ende einen Abstandshalter aufweisen, der beim Verfahren des flexiblen Flächenelements das flexible Flächenelement von dem Fahrzeuginsassen beabstandet. Dazu kann der Abstandshalter schwenkbar, zum Beispiel an der Führungsschiene, befestigt und mittels einer Feder gegen den Fahrzeuginsassen vorgespannt sein. Wird das Flächenelement angetrieben, erfolgt dies am Abstandshalter, der sich durch die Antriebskraft aufstellt und das Flächenelement vom Fahrzeuginsassen beabstandet. Der Abstandshalter kann aus zwei mittels eines Gelenks verbundenen Teilen bestehen, die durch die Antriebskraft auseinanderschwenken. Bevorzugt weist der Abstandshalter am Flächenelement eine Verdickung auf, sodass ein Verhaken am Fahrzeuginsassen beim Verfahren vermindert wird.

[0022] Die Erfindung lässt zahlreiche Ausführungsformen zu. Zur weiteren Verdeutlichung ihres Grundprinzips sind mehrere Ausführungsformen in den Zeichnungen dargestellt und werden nachfolgend beschrieben. Diese zeigen in

Fig. 1a bis **Fig. 1d** eine Rückhaltevorrichtung mit einem fahrzeugfesten oder fußteilfesten Zugmittel;

Fig. 2a bis **Fig. 2e** eine Rückhaltevorrichtung mit einem fahrzeugfesten Zugmittel;

Fig. 3a bis **Fig. 3d** eine Rückhaltevorrichtung mit einem sitzlehnenfesten Zugmittel;

Fig. 4a bis **Fig. 4c** eine Rückhaltevorrichtung mit einem armlehnenfesten Zugmittel;

Fig. 5a bis **Fig. 5c** eine Rückhaltevorrichtung mit einem mit einer Koppelstange in Verbindung stehenden Zugmittel;

Fig. 6a bis **Fig. 6b** eine Rückhaltevorrichtung mit einem mit einem Stempel in Verbindung stehenden Zugmittel;

Fig. 7a bis **Fig. 7f** eine Rückhaltevorrichtung mit einem mit einer Rolle in Verbindung stehenden Zugmittel;

Fig. 8a bis **Fig. 8d** eine Rückhaltevorrichtung mit einem Zahnsegmentantrieb;

Fig. 9 eine Rückhaltevorrichtung mit einem Kolben-Zylinder-Element;

Fig. 10a bis **Fig. 10c** eine Rückhaltevorrichtung mit Abstandshalter.

[0023] **Fig. 1a** bis **Fig. 1d** zeigt eine Rückhaltevorrichtung mit einem fahrzeugfesten oder fußteilfesten Zugmittel 1, wobei **Fig. 1a** bis **Fig. 1c** eine Rückhaltevorrichtung mit einer Sitz-Liege-Vorrichtung 2 in drei Positionen zeigt. Die Sitz-Liege-Vorrichtung 2 weist eine Sitzlehne 3 auf, die mit einer Sitzfläche 4 schwenkbeweglich verbunden ist. Die Sitzfläche 4 ist mit einer Beinauflage 5 schwenkbeweglich verbunden. Die Sitz-Liege-Vorrichtung 2 dient zur Aufnahme eines Fahrzeuginsassen in einer sitzenden oder liegenden Position. In **Fig. 1a** ist die Sitz-Liege-Vorrichtung 2 für eine sitzende Position eingestellt, sodass ein flexibles Flächenelement 6 bestehend aus mehreren Abschnitten 7, nämlich einem Beinauflagenabschnitt 7a, einem Sitzflächenabschnitt 7b und einem Sitzlehnenabschnitt 7c, sich in einer Ruheposition befinden, in der sie bogenförmig am Fußende verstaut sind, und einen Fahrzeuginsassen nicht bedeckt, sodass ein einfaches Aufstehen oder Hinsetzen möglich ist. Das Flächenelement 6 befindet sich zusammengefaltet beziehungsweise zusammengezogen im Fußbereich der Sitz-Liege-Vorrichtung 2 und ist beidseitig an Führungsschienen 8 verfahrbar gelagert. Der Beinauflagenabschnitt 7a des Flächenelements 6 ist mit einem Zugmittel 1 verbunden, durch das es entlang der Beinauflage 5 verfahrbar ist. Das Zugmittel 1 wird durch eine Umlenkung 9, die sich am oberen Ende der Beinauflage 5 befindet, sowie eine weitere Umlenkung 9, die sich am Fußbereich befindet, umgelenkt und ist am Fahrzeug befestigt. Verfährt die Sitz-Liege-Vorrichtung 2, wird ein Beinauflagenabschnitt 7a und mit ihm ein Sitzflächenabschnitt 7b und ein Sitzlehnenabschnitt 7c, wie in **Fig. 1b** ersichtlich, verfahren. In der dargestellten Zwischenposition ist die Beinauflage 5 durch den Beinauflagenabschnitt 7a und den Sitzflächenabschnitt 7b sowie den Sitzlehnenabschnitt 7c bedeckt. Befindet sich die Sitz-Liege-Vorrichtung 2 in der Liegeposition, kann der Sitzlehnenabschnitt 7c händisch über die Sitzfläche 4 sowie über einen Teilbereich der Sitzlehne 3 verfahren werden, wie in **Fig. 1c** dargestellt.

[0024] In **Fig. 1d** ist die gleiche Ausführungsform wie in den **Fig. 1a** bis **Fig. 1c** dargestellt, jedoch ist die Führung des Zugmittels 1 alternativ ausgeführt. Das Zugmittel 1 wird von dem Beinauflagenabschnitt 7a kommend über eine Umlenkung 9 am oberen Ende der Beinauflage 5 umgelenkt und über eine oder zwei fahrzeugfeste weitere Umlenkungen 9 zum Fußbereich geführt, sodass ein Verfahren der Beinauflage 5 zu einem Verfahren des Beinauflagenabschnitts 7a und Sitzflächenabschnitts 7b führt. Das Zurückverfahren von Abschnitten 7 des Flächenelements 6 kann manuell nach einem Entriegeln des Abschnitts 7 geschehen oder aber auch beim Verfahren der Sitz-Liege-Vorrichtung 2 in eine aufrechtere Position, zum Beispiel mittels eines nicht dargestellten Federelements. Das beschriebene Zurückverfahren von Abschnitten 7 ist zumindest bei allen Ausführungsformen mit einem Zugmittel 1 anwendbar.

[0025] **Fig. 2a** bis **Fig. 2e** stellen eine Sitz-Liege-Vorrichtung 2 wie oben beschrieben dar sowie ein oberhalb der Sitz-Liege-Vorrichtung 2 am Fahrzeug fixiertes Zugmittel 1 zum Verfahren von Flächenelementen 6. **Fig. 2a** und **Fig. 2b** zeigen eine Ausführungsform in der Ruheposition sowie in der Gebrauchsposition. Das Zugmittel 1 wird vom oberen Befestigungspunkt über eine Umlenkung 9 geführt, die am unteren Ende der Sitzlehne 3 angebracht ist, sowie zu einem am oberen Ende der Sitzlehne 3 befindlichen Beinauflagenabschnitt 7a geführt, das beim Verfahren der Sitzlehne 3, wie in **Fig. 2b** ersichtlich, verfahren wird. **Fig. 2b** zeigt des Weiteren beispielhaft einen Beinauflagenabschnitt 7a und einen Sitzflächenabschnitt 7b, die wie in **Fig. 1a** dargestellt angetrieben werden können.

[0026] **Fig. 2c** bis **Fig. 2e** entsprechen den **Fig. 2a** und **Fig. 2b**, deren Ausführungsformen kombinierbar sind, wobei mittels des Zugmittels 1 ein Beinauflagenabschnitt 7a über die Beinauflage 5 verfahren wird. Hierzu wird das Zugmittel 1 über eine zusätzliche Umlenkung 9, die am oberen Ende der Beinauflage 5 angeordnet ist, geführt, sodass, wie in **Fig. 2d** und **Fig. 2e** ersichtlich, das Verfahren der Sitzlehne 3 und der Sitzfläche 4 sowie der Beinauflage 5 zu einem Verfahren des Beinauflagenabschnitts 7a führt.

[0027] **Fig. 3a** bis **Fig. 3d** zeigen eine Ausführungsform der Sitz-Liege-Vorrichtung 2, die der in **Fig. 1a** beschriebenen Ausführungsform entspricht, jedoch ein feststehendes Seitenteil 10 mit Umlenkungen 9 aufweist, wobei das Zugmittel 1 jeweils am oberen Ende der Sitzlehne 3 fixiert ist.

[0028] **Fig. 3a** und **Fig. 3b** zeigen eine Ausführungsform in zwei Positionen. Das Zugmittel 1 ist vom Fixierungspunkt über eine in dem Seitenteil 10 oberhalb der Sitzfläche 4 angeordnete Umlenkung 9 geführt und wird mittels einer am oberen Ende der Beinauflage 5 angebrachten Umlenkung 9 zum Beinauflagenabschnitt 7a geführt, sodass der Beinauflagenabschnitt 7a, wie in **Fig. 3b** dargestellt, verfährt, wenn die Sitzlehne 3 verfährt.

[0029] In der in **Fig. 3c** und **Fig. 3d** dargestellten Ausführungsform weist das Seitenteil 10 im Kopfbereich eine weitere Umlenkung 9 auf, über die das Zugmittel 1 geführt wird, wodurch ein vergrößerter Verfahrweg des Beinauflagenabschnitts 7a realisiert wird.

[0030] **Fig. 4a** bis **Fig. 4c** stellen eine Ausführungsform einer Sitz-Liege-Vorrichtung 2 wie in **Fig. 1a** beschrieben dar, die zusätzlich eine Armlehne 11 aufweist, die an der Sitzlehne 3 schwenkbeweglich befestigt ist. Am von der Sitzlehne 3 abragenden Ende der Armlehne 11 ist ein Zugmittel 1 fixiert, das über eine am oberen Ende der Beinauflage 5 befestigte Umlenkung 9 zu einem Beinauflagenabschnitt 7a eines Flächenelements 6 geführt ist. Wird die Sitz-Liege-Vorrichtung 2 von der in **Fig. 4a** dargestellten sitzenden Position in eine in **Fig. 4b** dargestellten Zwischenposition verfahren, verfährt der Beinauflagenabschnitt 7a durch das Zugmittel 1 betätigt entlang der Beinauflage 5 in Richtung der Sitzfläche 4. Wird die Sitz-Liege-Vorrichtung 2 in eine Liegeposition verfahren, wie in **Fig. 4c** dargestellt, wird in gleicher Weise der Beinauflagenabschnitt 7a weiter über den Fahrzeuginsassen verfahren. Um einen zusätzlichen Verfahrweg des Beinauflagenabschnitts 7a zu realisieren, kann die Armlehne 11 relativ zum oberen Bereich der Sitzlehne 3 verschwenkt werden. Dies kann zwangsgesteuert durch die Bewegung der Sitzlehne 3 oder aber durch einen weiteren Antrieb realisiert werden.

[0031] **Fig. 5a** bis **Fig. 5c** stellen eine Ausführungsform einer Sitz-Liege-Vorrichtung 2 wie in **Fig. 1a** beschrieben dar, wobei der Beinauflagenabschnitt 7a und der Sitzflächenabschnitt 7b des Flächenelements 6 mit einem Zugmittel 1 angetrieben werden, wobei das Zugmittel 1 an einem Führungselement 12 angebunden ist, das mittels einer Koppelstange 13 verfahren wird. Die Koppelstange 13 wird durch das Verfahren der Sitzlehne 3 angetrieben, wodurch das Zugmittel 1, das über Umlenkungen 9 zur Beinauflage 5 verläuft, gespannt wird und das Flächenelement 6 verfährt. In **Fig. 5b** und **Fig. 5c** ist das Zugmittel 1 am Führungselement 12 fixiert, wohingegen das Zugmittel1 in **Fig. 5a** fahrzeugfest befestigt ist und am Führungselement 12 umgelenkt wird, wodurch der Verfahrweg des Flächenelements 6 erhöht wird. Eine Erhöhung des Verfahrwegs des Flächenelements 6 durch ein Umlenken des Zugmittels 1 ist auf die weiteren Ausführungsformen mit dem Zugmittel 1 übertragbar.

[0032] **Fig. 6a** und **Fig. 6b** offenbaren eine Ausführungsform einer Sitz-Liege-Vorrichtung 2 wie in **Fig. 1a** beschrieben, wobei das Flächenelement 6 mittels eines Zugmittels 1 angetrieben wird, das mittels eines Stempels 14, der das Zugmittel 1 zwischen zwei Umlenkungen 9 verfährt, gespannt wird. Der Stempel 14 ist an der Sitzlehne 3 befestigt und wird durch deren Verfahren angetrieben. Verfährt die Sitzlehne 3 und damit der Stempel 14 entlang von zwei Umlenkungen 9, wird das Zugmittel 1 entgegen einer Federkraft einer Feder 15 gespannt und verfährt das Flächenelement 6.

[0033] In **Fig. 7a** bis **Fig. 7f** ist eine Ausführungsform einer Sitz-Liege-Vorrichtung 2 wie in **Fig. 1a** beschrieben dargestellt, wobei das Zugmittel 1 zum Verfahren des Beinauflagenabschnitts 7a und des Sitzflächenabschnitts 7b durch das Rotieren und Aufwickeln auf einer rotierbar gelagerten Rolle 16 gespannt wird. An der Rolle 16 ist hierzu ein Ritzel 17 fixiert, das mit einer Zahnstange 18 angetrieben wird. Die Zahnstange 18 kann, wie in **Fig. 7a** bis **Fig. 7c** dargestellt, gebogen sein oder, wie in **Fig. 7d** bis **Fig. 7f** dargestellt, eine gerade Zahnstange 18 sein. Die Zahnstange 18 ist an der Sitzlehne 3 befestigt und wird durch deren Verfahren angetrieben. Verfährt die Sitzlehne 3 und damit die Zahnstange 18 entlang des Ritzels 17, rotiert dieses sowie die Rolle 16 und spannt das Zugmittel 1, sodass das Flächenelement 6 verfährt. Die Sitzlehne 3 der Ausführungsform der **Fig. 7a** bis **Fig. 7c** ist ausschließlich mittels eines Drehgelenks 19 rotatorisch beweglich gelagert; der Biegeradius der Zahnstange 18 entspricht dem Abstand der Zahnstange 18 zum Drehpunkt der Sitzlehne 3. Die Sitzlehne 3 der Ausführungsform der **Fig. 7d** bis **Fig. 7f** ist auch translatorisch beweglich gelagert und verfährt zeitgleich translatorisch wie rotatorisch, sodass die Zahnstange 18 geradlinig angetrieben wird.

[0034] In **Fig. 8a** bis **Fig. 8d** ist eine Ausführungsform einer Sitz-Liege-Vorrichtung 2 wie in **Fig. 1a** beschrieben dargestellt, wobei um die Rotationsachse des Drehgelenks 19 ein Zahnsegment 20 rotiert, das an der Sitzlehne 3 fixiert ist. Rotiert die Sitzlehne 3 um das Drehgelenk 19, wird das Zahnsegment 20 verschwenkt und treibt ein Zahnstangensegment 21 an, das horizontal verfährt und mittels einer verschiebbar gelagerten Zugstrebe 22, eines Gelenks 23 und einer Lagerung 24 über einen Längenausgleich 25, wie in den **Fig. 8a** und **Fig. 8b** dargestellt, einen Beinauflagenabschnitt 7a verfährt oder, wie in den **Fig. 8c** und **Fig. 8d** dargestellt, einen Sitzflächenabschnitt 7b antreibt. Der Längenausgleich 25 kann beispielsweise als ein Gasdruckdämpfer oder eine Feder ausgeführt sein und ermöglicht das Verfahren der Beinauflage 5 unabhängig von der Position der Sitzlehne 3. Über eine Variation der Geometrie des Zahnsegments 20 sowie der Positionierung des Gelenks 23 zur Lagerung 24 ist der Verfahrweg des Flächenelements 6 einstellbar.

[0035] In **Fig. 9** ist eine Ausführungsform einer Sitz-Liege-Vorrichtung 2 wie in **Fig. 1a** beschrieben dargestellt, wobei eine erste Kolben-Zylinder-Einheit 26 kolbenseitig an der Sitzlehne 3 gelagert ist, sodass ein erster Kolben zum ersten Zylinder verfährt, wenn die Sitzlehne 3 verschwenkt wird. Der im Zylinder erzeugte Druck wird über eine Druckleitung 27 zu einer zweiten Kolben-Zylinder-Einheit 28 geleitet, die druckabhängig einen zweiten Kolben verfährt. Der zweite Kolben ist über ein Gelenk 23 und einer Lagerung 24 mit einem Längenausgleich 25 verbunden, der einen Beinauflagenabschnitt 7a verfährt.

[0036] In den **Fig. 10a** bis **Fig. 10c** ist eine Sitz-Liege-Vorrichtung 2 mit Abstandshaltern 29 dargestellt. Die Abstandshalter 29 der dargestellten Ausführungsformen sind einerseits mit dem Flächenelement 6 und andererseits schwenkbar gelagert mit der Führungsschiene 8 verbunden. Das Zugmittel 1 zum Antreiben des Flächenelements 6 ist an Streben 30 des Abstandshalters 29 angebracht, sodass der Abstandshalter 29 aufgrund der durch das Zugmittel 1 aufgebrachten Kraft das Flächenelement 6 entgegen der Kraft eines elastischen Elements 31 von dem Fahrzeuginsassen beabstandet. Nach dem Verfahren des Flächenelements 6 verringert sich die Kraft, die das Zugmittel 1 aufbringt und das elastische Element 31 legt das Flächenelement 6 an den Fahrzeuginsassen an.

[0037] **Fig. 10a** weist eine einteilige Strebe 30 auf, wobei das elastische Element 31 die Strebe 30 zur Führungsschiene 8 vorspannt. Die **Fig. 10b** und **Fig. 10c** weisen jeweils eine zweiteilige Strebe 30 mit einem zwischen den Teilen der Streben 30 angeordneten Scharnier 32 auf. Das elastische Element 31 verbindet die Teile der Streben 30 miteinander und spannt diese miteinander vor. In **Fig. 10c** ist des Weiteren ein Verdickungselement vorgesehen, das ein Verhaken des Abstandshalters 29 am Fahrzeuginsassen vermindert.

Bezugszeichenliste

1	Zugmittel
2	Sitz-Liege-Vorrichtung
3	Sitzlehne
4	Sitzfläche
5	Beinauflage
6	Flächenelement
7	Abschnitt
7a	Beinauflagenabschnitt
7b	Sitzflächenabschnitt
7c	Sitzlehnenabschnitt
8	Führungsschiene

9	Umlenkung
10	Seitenteil
11	Armlehne
12	Führungselement
13	Koppelstange
14	Stempel
15	Feder
16	Rolle
17	Ritzel
18	Zahnstange
19	Drehgelenk
20	Zahnsegment
21	Zahnstangensegment
22	Zugstrebe
23	Gelenk
24	Lagerung
25	Längenausgleich
26	erste Kolben-Zylinder-Einheit
27	Druckleitung
28	zweite Kolben-Zylinder-Einheit
29	Abstandshalter
30	Strebe
31	elastisches Element
32	Scharnier

ZITATE ENTHALTEN IN DER BESCHREIBUNG

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Zitierte Patentliteratur

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Patentansprüche

1. Rückhaltevorrichtung zur Sicherung von Fahrzeuginsassen auf einer Sitz-Liege-Vorrichtung (2) aufweisend ein verfahrbares flexibles Flächenelement (6), welches in einer Gebrauchsposition mit zumindest einem Abschnitt (7) einen Teilbereich des Fahrzeuginsassen bedeckt und in einer Ruheposition den Fahrzeuginsassen nicht bedeckt, **dadurch gekennzeichnet**, dass das Verfahren des flexiblen Flächenelements (6) von der Ruheposition in die Gebrauchsposition an das Verfahren der Sitz-Liege-Vorrichtung (2) zwangsgekoppelt ist.

2. Rückhaltevorrichtung nach Anspruch 1, **dadurch gekennzeichnet**, dass ein Abschnitt (7) des Flächenelements (6) entlang von an der Sitz-Liege-Vorrichtung (2) vorgesehenen Führungsschienen (8), an die das Flächenelement (6) angebunden ist, durch das Verfahren der Sitz-Liege-Vorrichtung (2) von einer Liegeposition in die Gebrauchsposition, verfahren wird.

3. Rückhaltevorrichtung nach den Ansprüchen 1 oder 2, **dadurch gekennzeichnet**, dass ein Abschnitt (7), bevorzugt ein Beinauflagenabschnitt (7a) und/oder ein Sitzflächenabschnitt (7b) und/oder ein Sitzlehnenabschnitt (7c), mit einem Zugmittel (1), das über Umlenkungen (9) geführt wird, durch ein Verfahren einer Beinauflage (5) oder einer Sitzlehne (3) der Sitz-Liege-Vorrichtung (2) angetrieben wird, wobei das Zugmittel (1) bevorzugt eine fahrzeugfeste, beinauflagenfeste oder sitzlehnenfeste Anbindung aufweist.

4. Rückhaltevorrichtung nach zumindest einem der vorangehenden Ansprüche, **dadurch gekennzeichnet**, dass ein Abschnitt (7), bevorzugt ein Beinauflagenabschnitt (7a) und/oder ein Sitzflächenabschnitt (7b) und/oder ein Sitzlehnenabschnitt (7c), mit einem Zugmittel (1) angetrieben wird, wobei das Zugmittel (1) an einer Armlehne (11) angebunden ist, die mit der Sitzlehne (3) zwangsgekoppelt verfährt.

5. Rückhaltevorrichtung nach zumindest einem der vorangehenden Ansprüche, **dadurch gekennzeichnet**, dass ein Abschnitt (7), bevorzugt ein Beinauflagenabschnitt (7a) und/oder ein Sitzflächenabschnitt (7b) und/oder ein Sitzlehnenabschnitt (7c), mit einem Zugmittel (1) angetrieben wird, wobei das Zugmittel (1) an einem Führungselement (12) angebunden ist, das mittels einer, bevorzugt von der Sitzlehne (3) angetriebenen Koppelstange (13) verfahren wird.

6. Rückhaltevorrichtung nach zumindest einem der vorangehenden Ansprüche, **dadurch gekennzeichnet**, dass ein Abschnitt (7), bevorzugt ein Beinauflagenabschnitt (7a) und/oder ein Sitzflächenabschnitt (7b) und/oder ein Sitzlehnenabschnitt (7c), mit einem Zugmittel (1) angetrieben wird, wobei das Zugmittel (1) mittels eines, bevorzugt an der Sitzlehne (3) befestigten Stempels (14), bevorzugt gegen eine Federkraft, ausgelenkt wird.

7. Rückhaltevorrichtung nach zumindest einem der vorangehenden Ansprüche, **dadurch gekennzeichnet**, dass ein Abschnitt (7), bevorzugt ein Beinauflagenabschnitt (7a) und/oder ein Sitzflächenabschnitt (7b) und/oder ein Sitzlehnenabschnitt (7c), mit einem Zugmittel (1) angetrieben wird, wobei das Zugmittel (1) an einer rotierbar gelagerten Rolle (16) angebunden ist, die mittels eines Ritzels (17) mit einer Zahnstange (18), bevorzugt einer gebogenen oder geraden Zahnstange (18), in Wirkverbindung steht.

8. Rückhaltevorrichtung nach zumindest einem der vorangehenden Ansprüche, **dadurch gekennzeichnet**, dass ein an der Sitzlehne (3) fixiertes Zahnsegment (20) ein Zahnstangensegment (21) linear verfährt, das mittels eines Gelenks (23) und einer Lagerung (24) über einen Längenausgleich (25) einen Abschnitt (7), bevorzugt ein Beinauflagenabschnitt (7a) und/oder ein Sitzflächenabschnitt (7b) und/oder ein Sitzlehnenabschnitt (7c), antreibt.

9. Rückhaltevorrichtung nach zumindest einem der vorangehenden Ansprüche, **dadurch gekennzeichnet**, dass durch ein Verfahren der Sitzlehne (3) eine an der Sitzlehne (3) fixierte, bevorzugt hydraulische oder pneumatische erste Kolben-Zylinder-Einheit (26) betätigt wird, die mittels einer Druckleitung (27) eine zweite Kolben-Zylinder-Einheit (28) antreibt, die mittels eines Gelenks (23) und einer Lagerung (24) über einen Längenausgleich (25) einen Abschnitt (7), bevorzugt ein Beinauflagenabschnitt (7a), ein Sitzflächenabschnitt (7b) und/oder ein Sitzlehnenabschnitt (7c), antreibt.

10. Rückhaltevorrichtung nach zumindest einem der vorangehenden Ansprüche, **dadurch gekennzeichnet**, dass das flexible Flächenelement (6) beidseitig an der Sitz-Liege-Vorrichtung (2) gelagert ist und bevorzugt Gewebeteile mit integrierten Airbagkammern und/oder integrierten Gurten aufweist.

Es folgen 18 Seiten Zeichnungen

Anhängende Zeichnungen

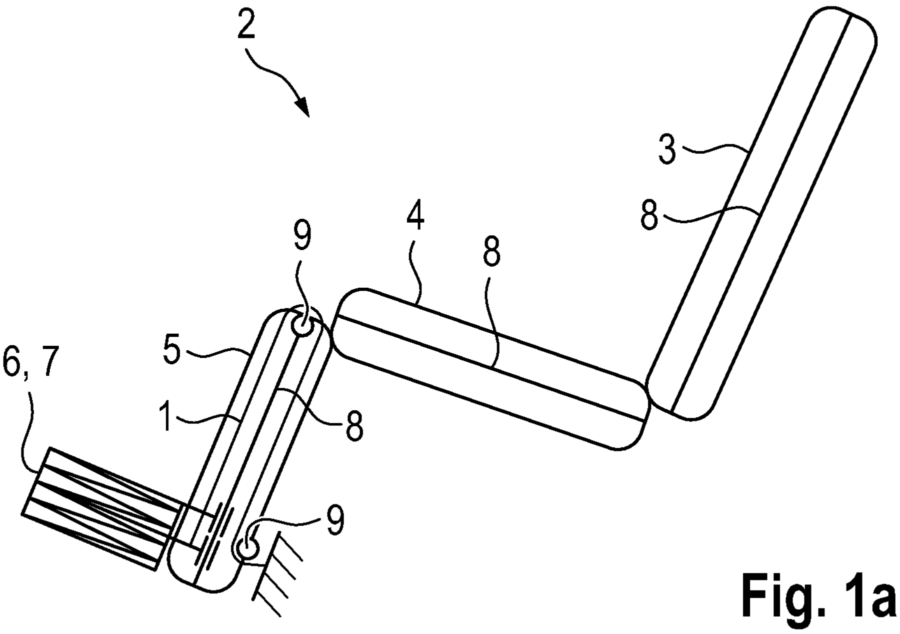

Fig. 1a

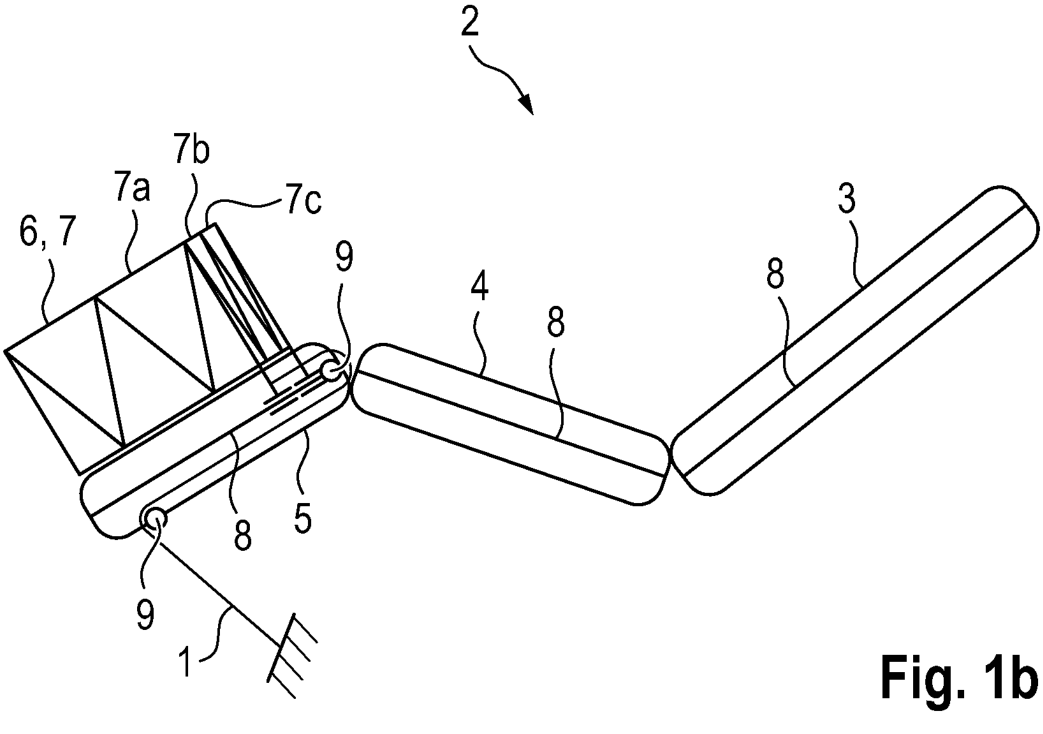

Fig. 1b

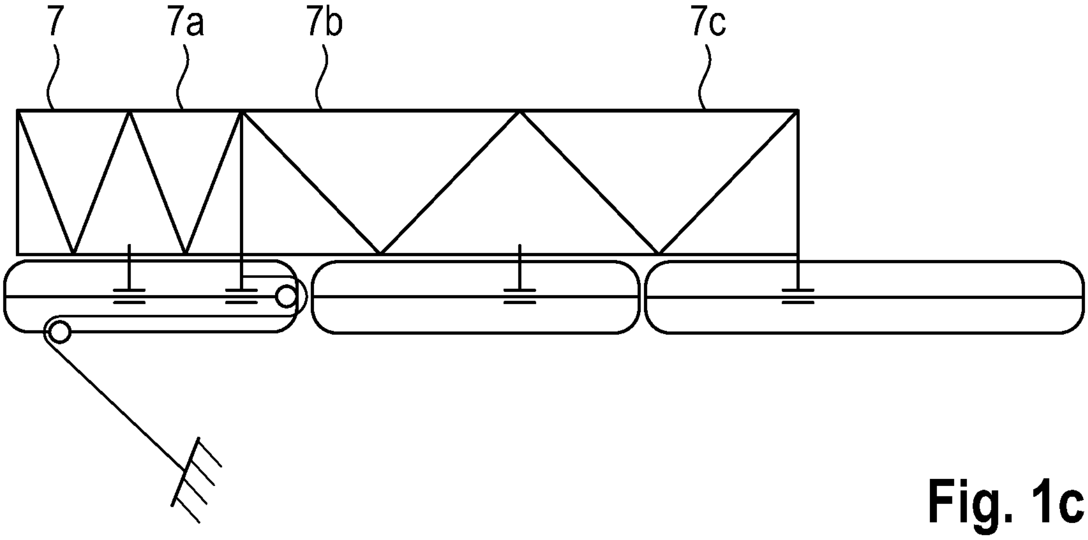

Fig. 1c

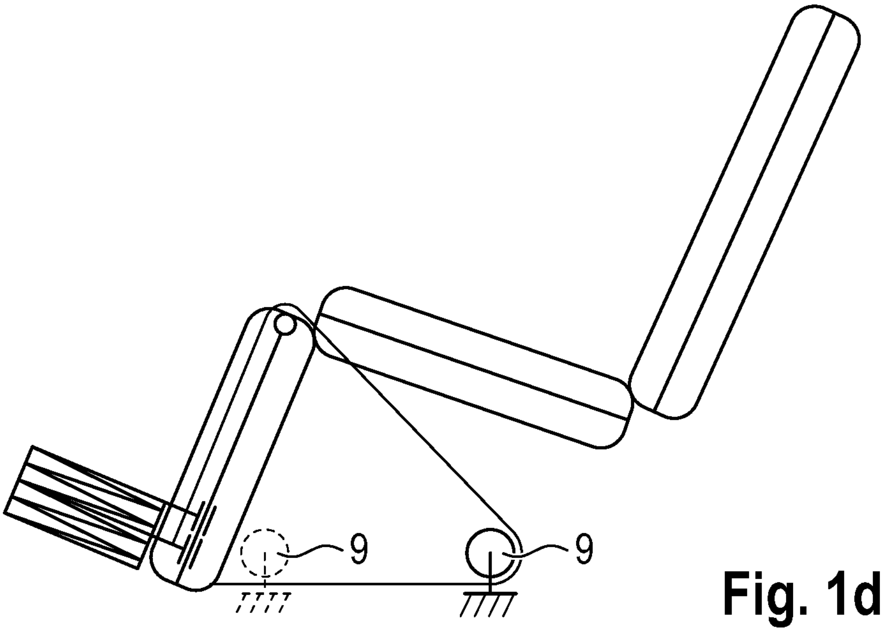

Fig. 1d

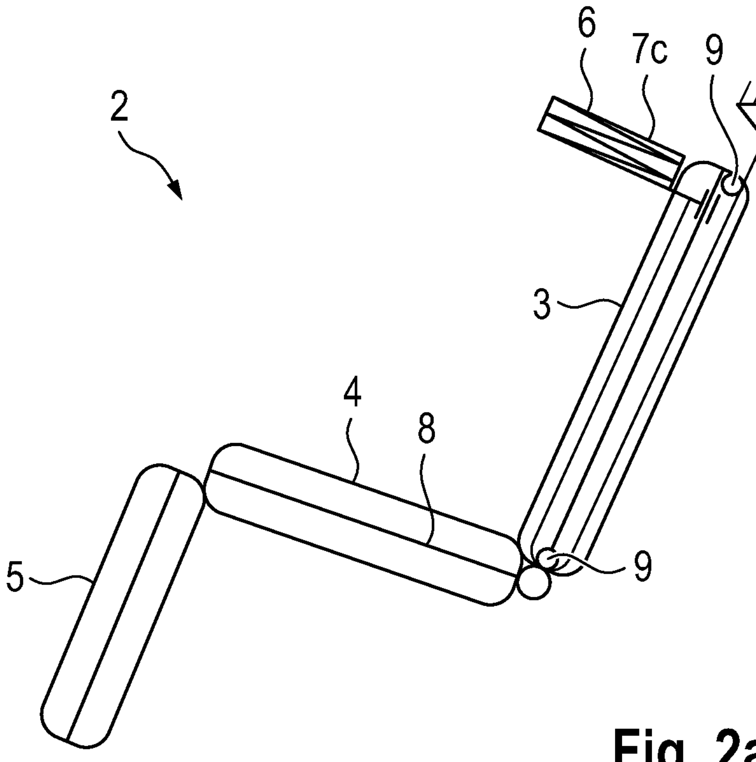

Fig. 2a

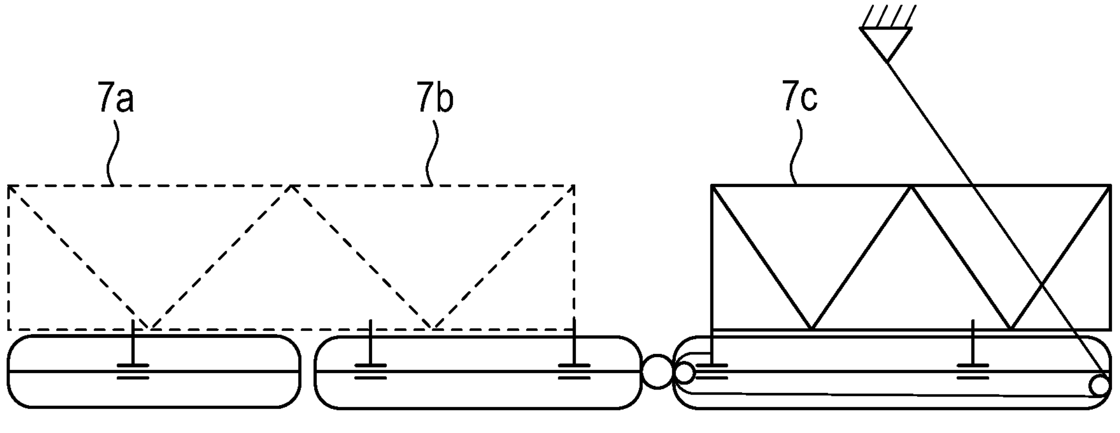

Fig. 2b

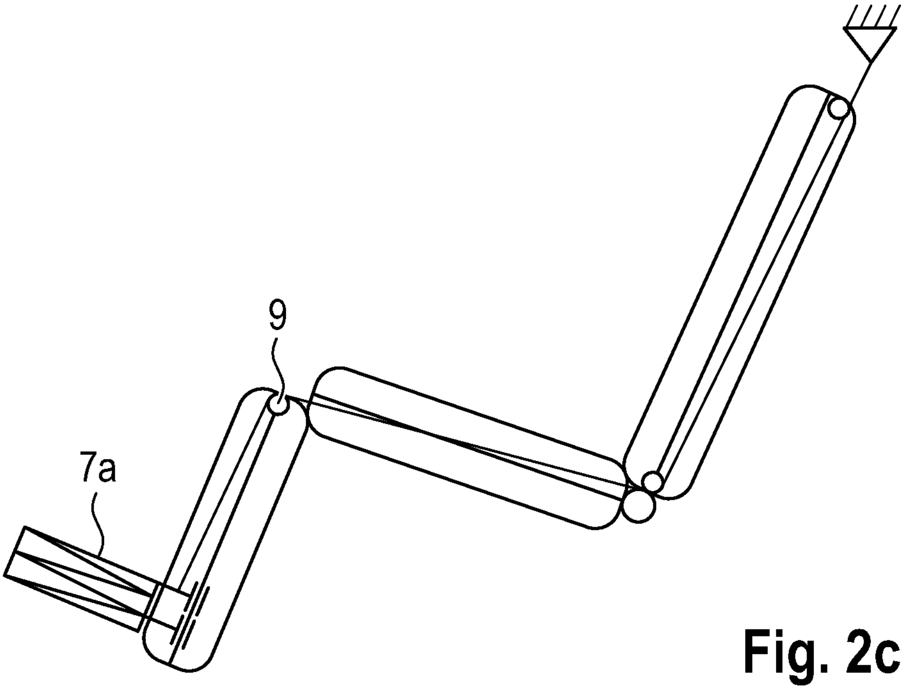

Fig. 2c

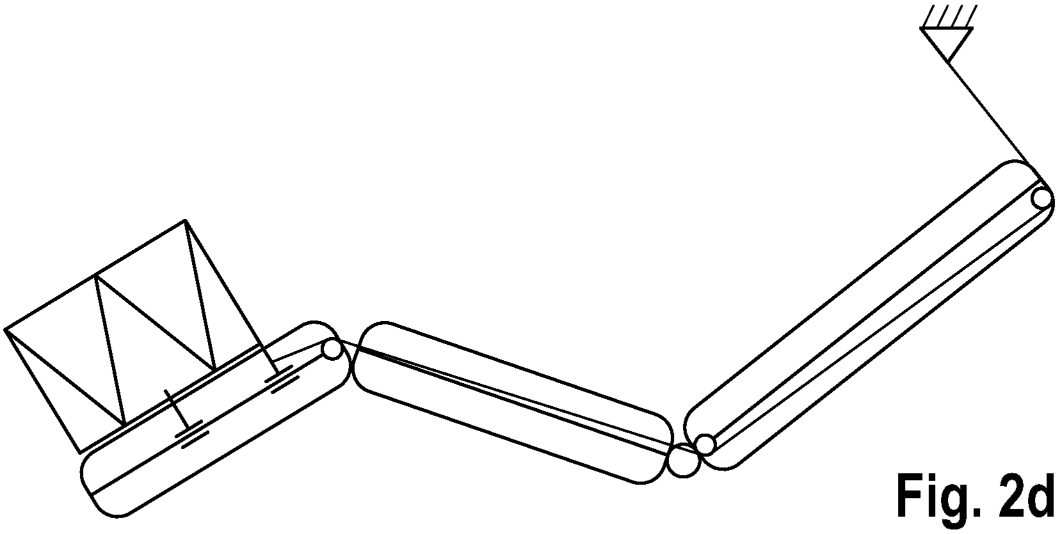

Fig. 2d

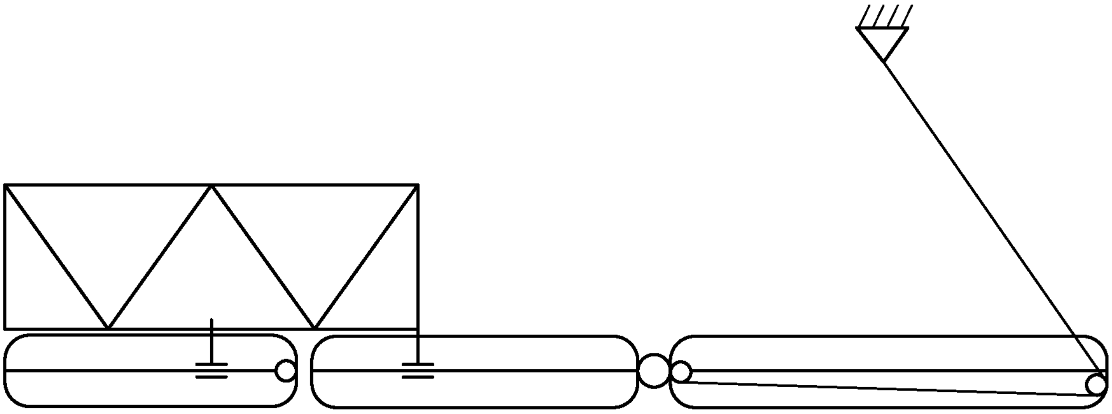

Fig. 2e

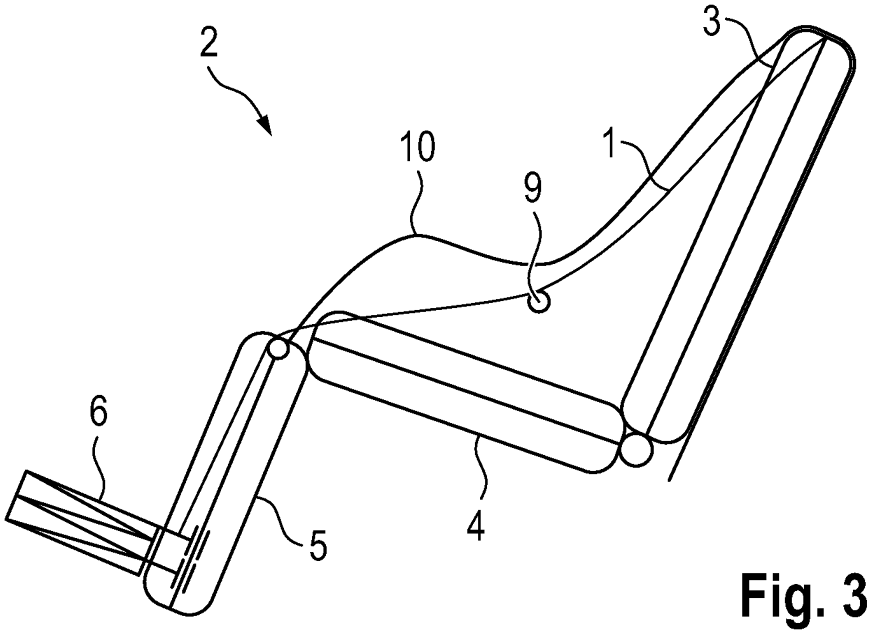

Fig. 3a

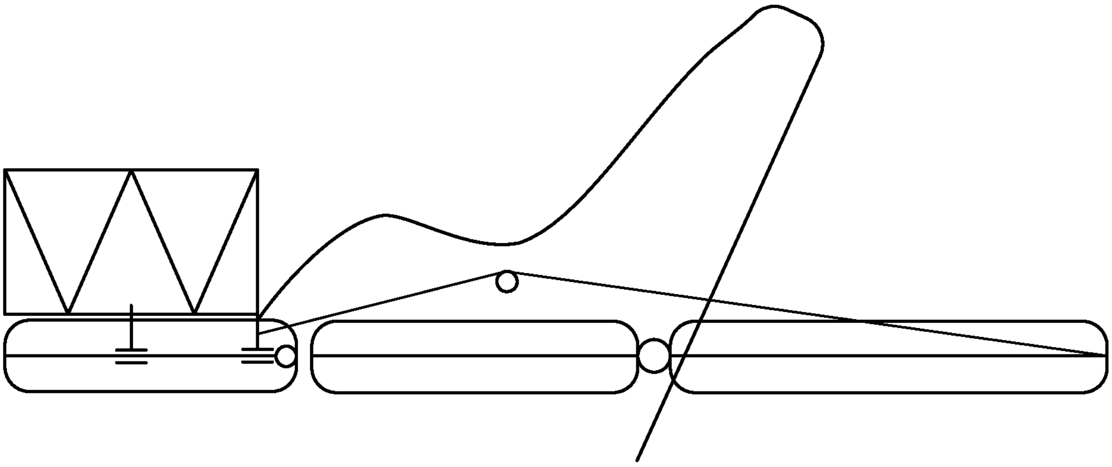

Fig. 3b

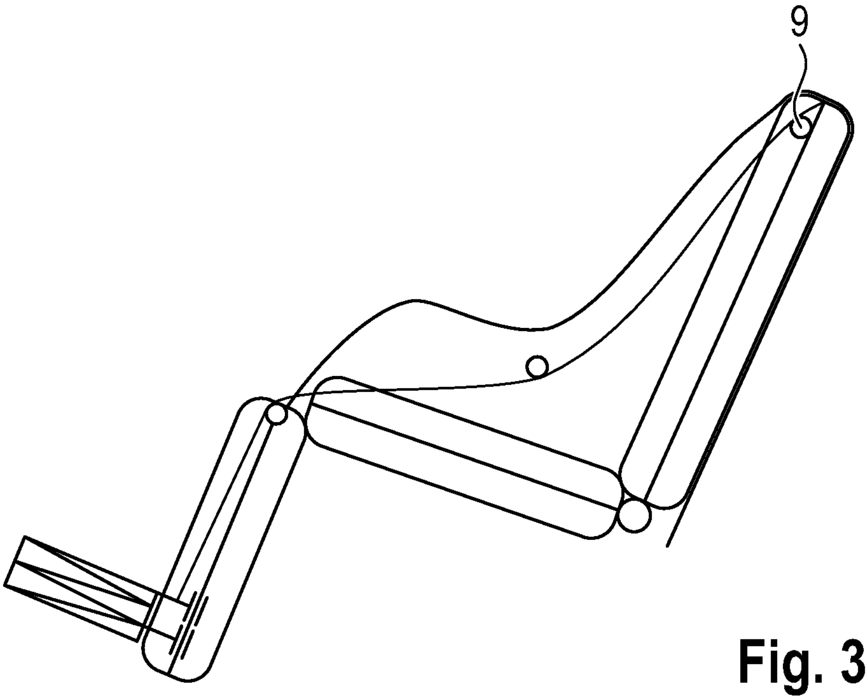

Fig. 3c

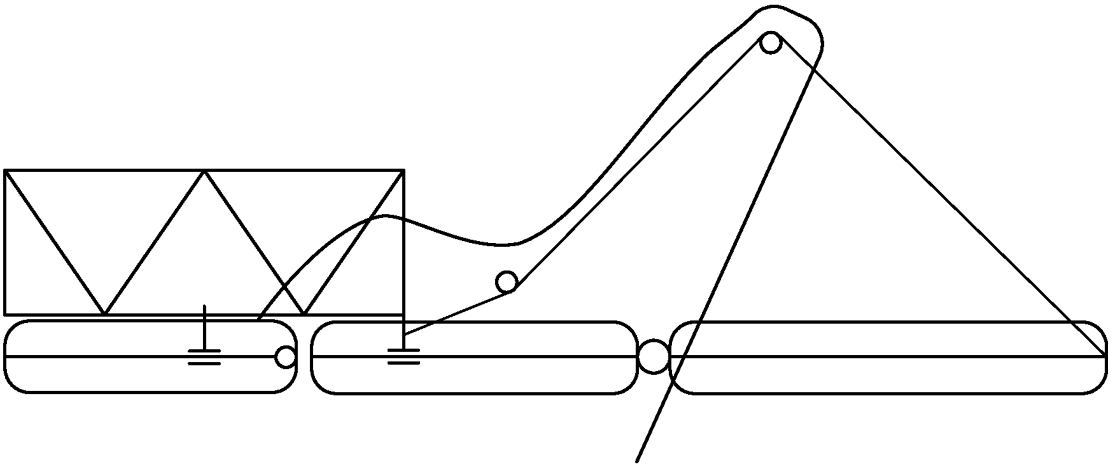

Fig. 3d

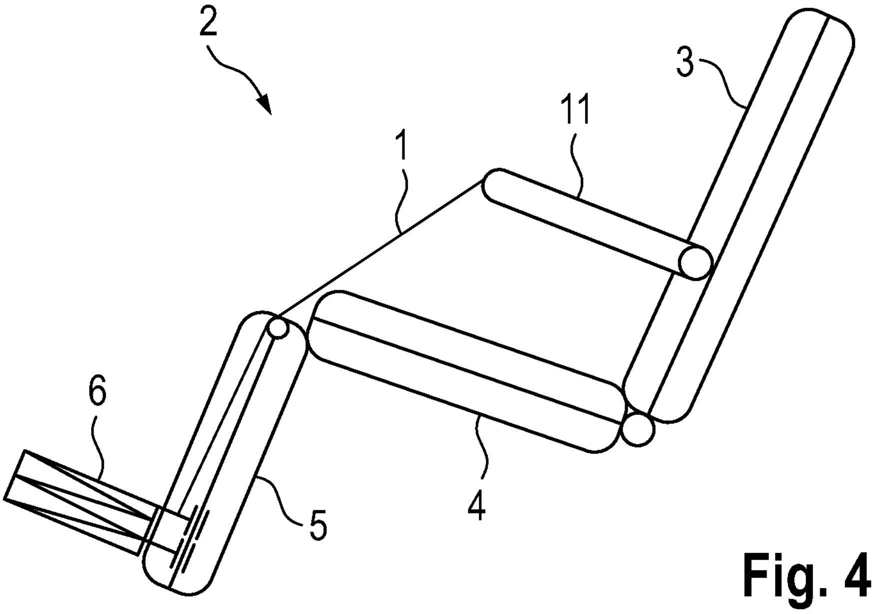

Fig. 4a

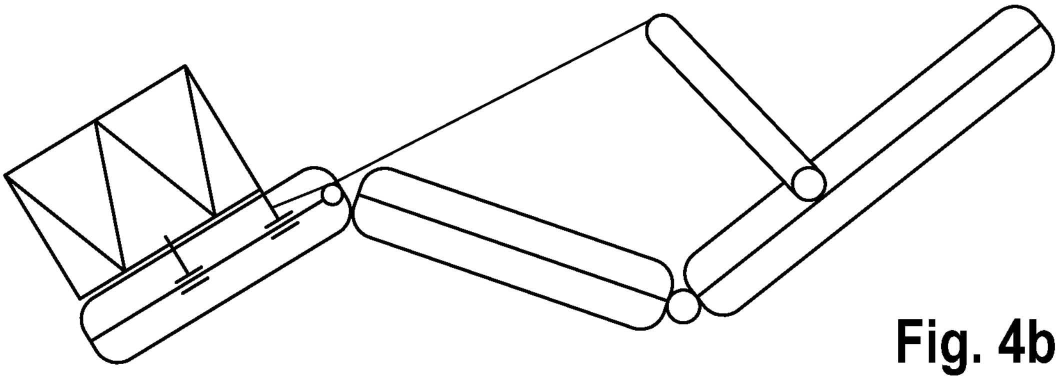

Fig. 4b

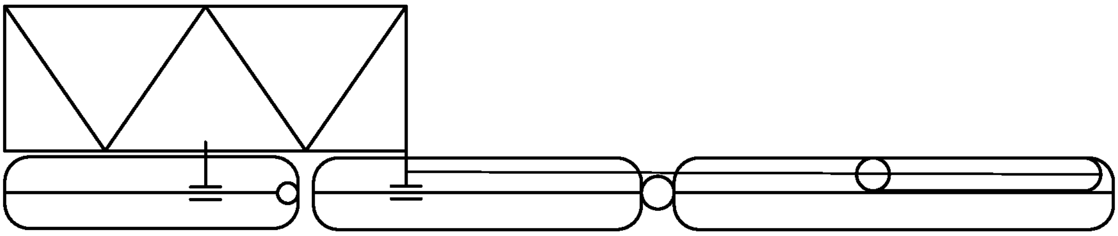

Fig. 4c

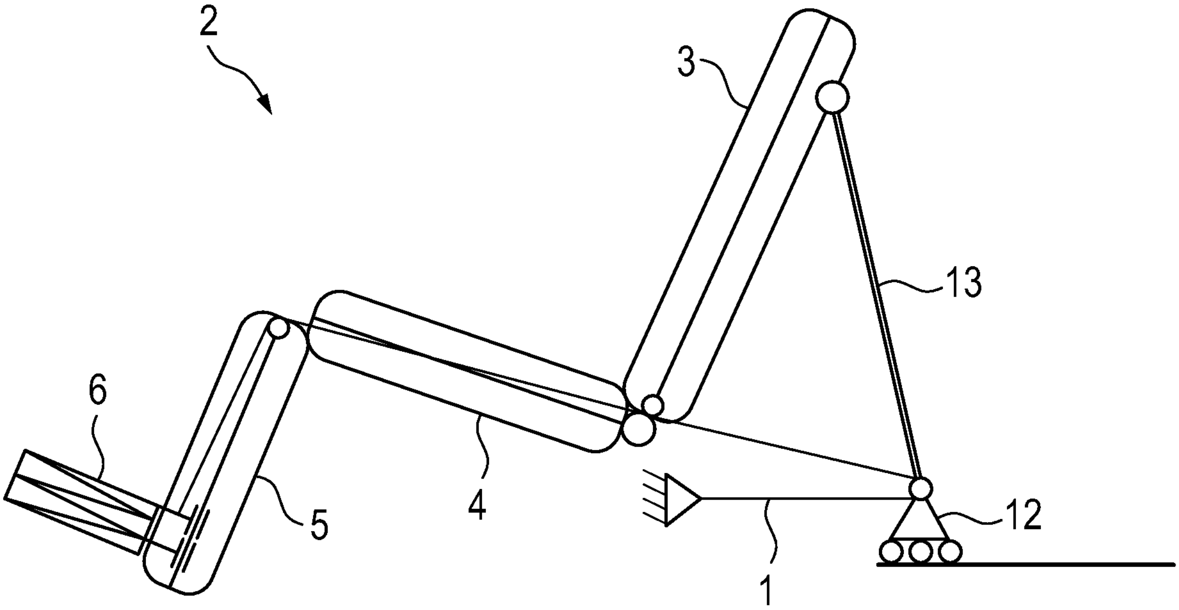

Fig. 5a

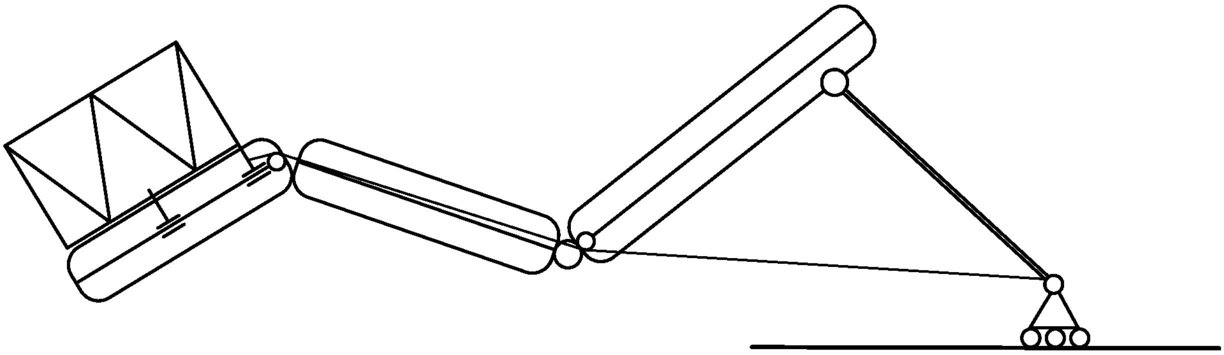

Fig. 5b

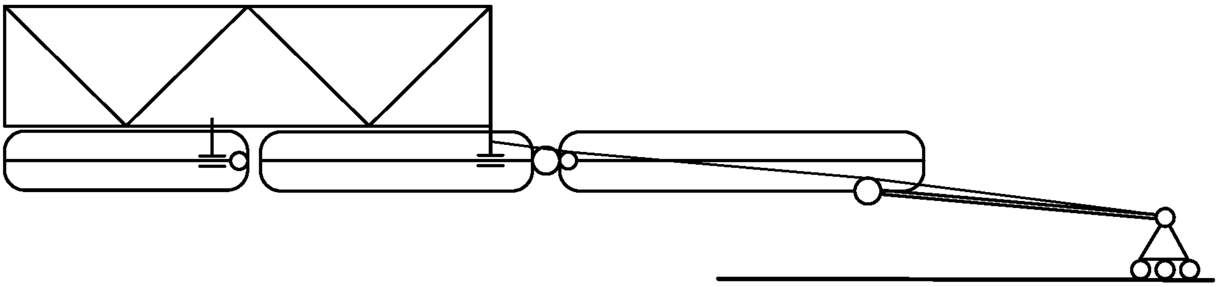

Fig. 5c

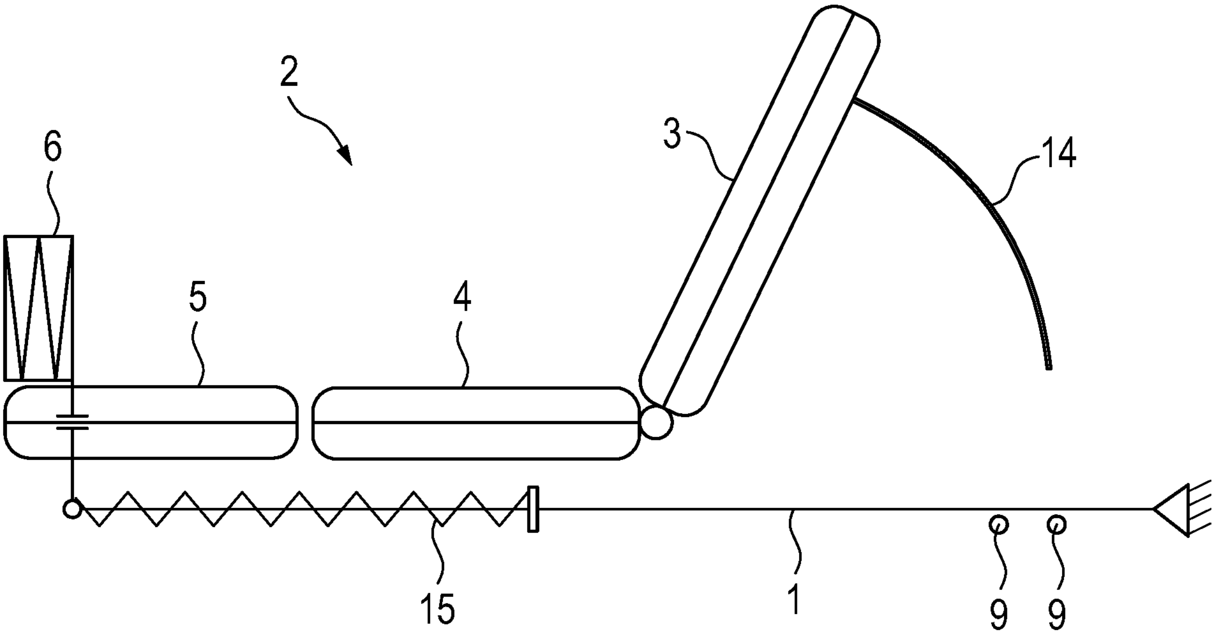

Fig. 6a

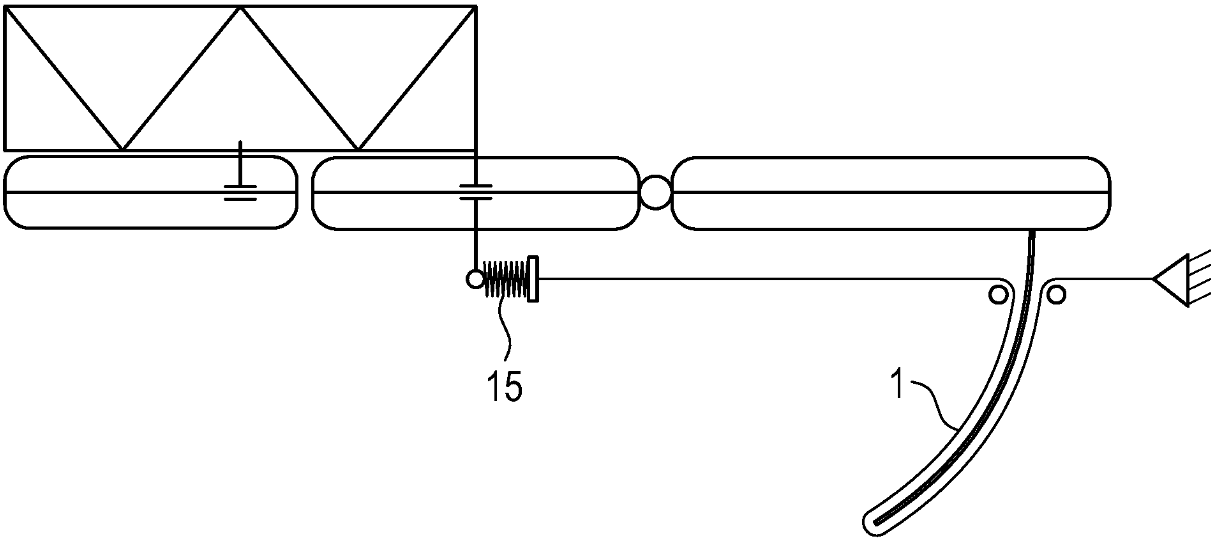

Fig. 6b

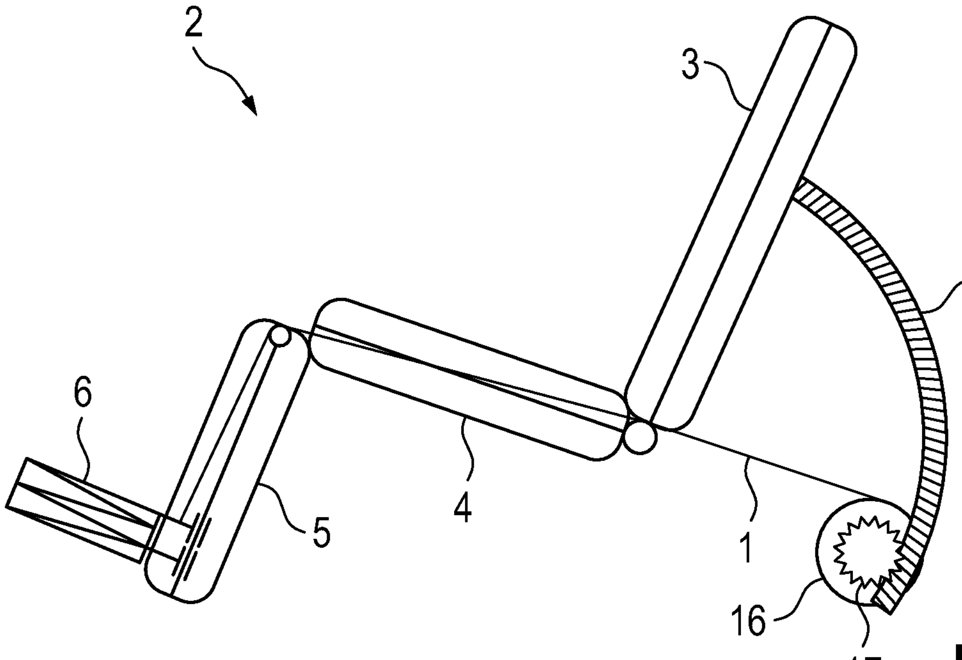

Fig. 7a

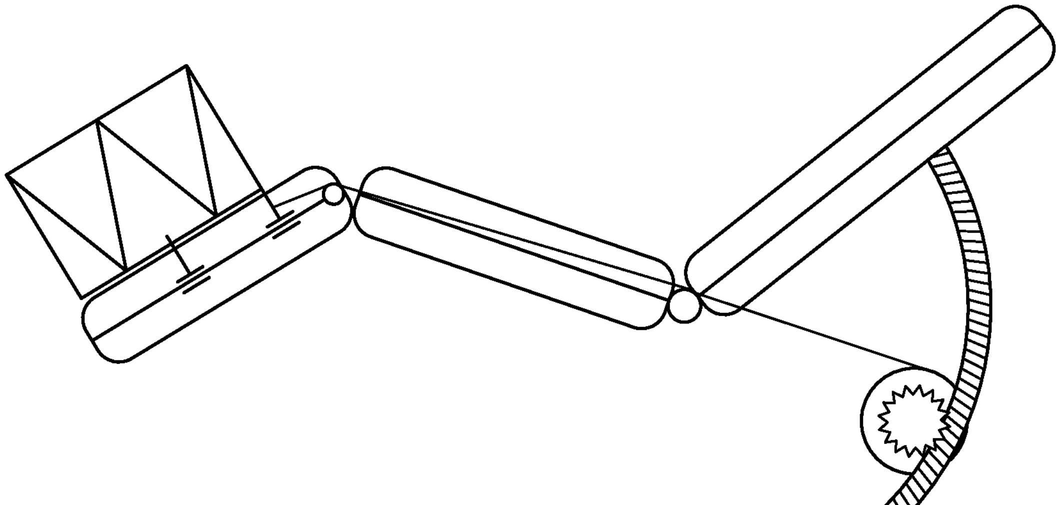

Fig. 7b

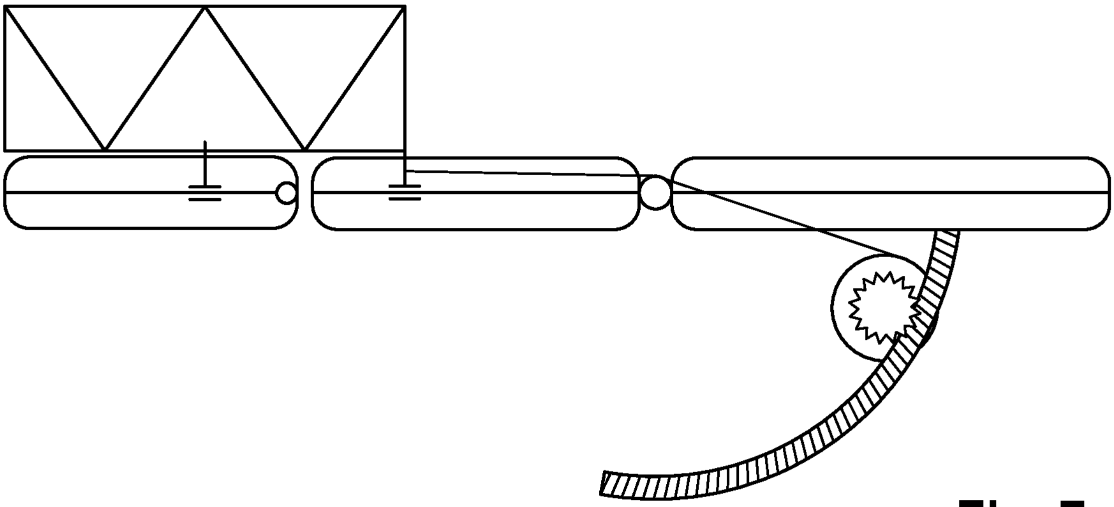

Fig. 7c

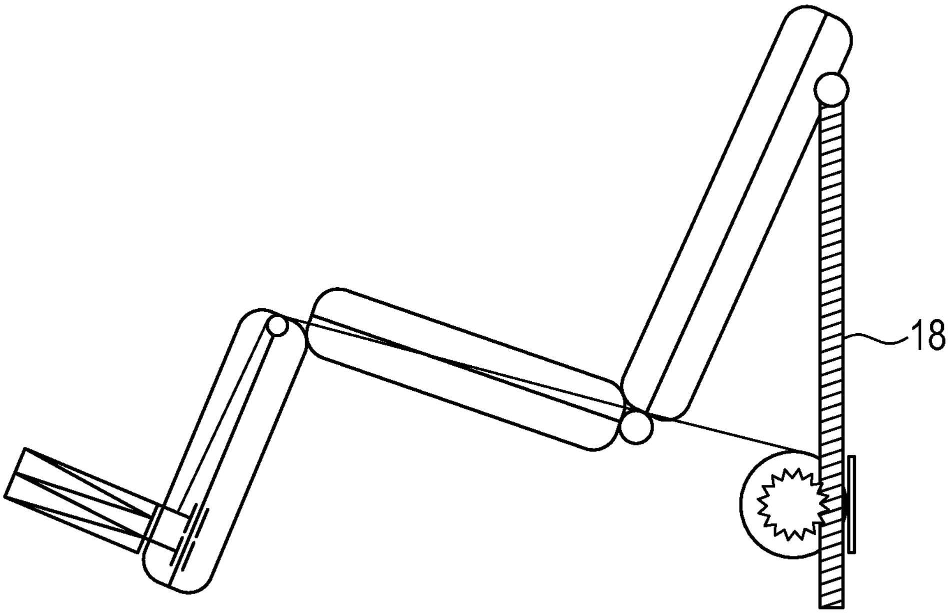

Fig. 7d

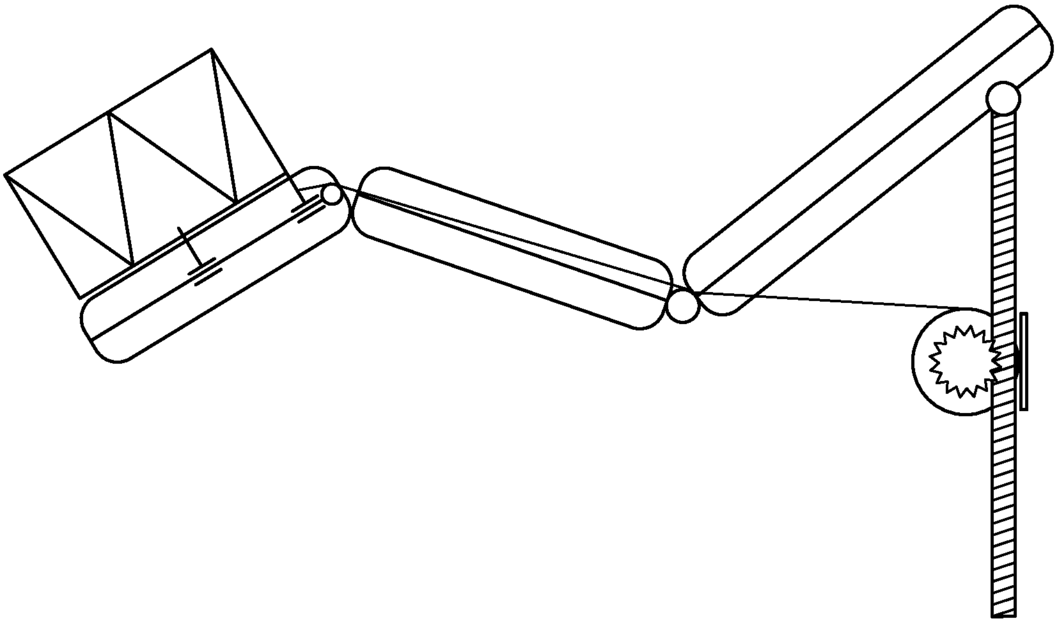

Fig. 7e

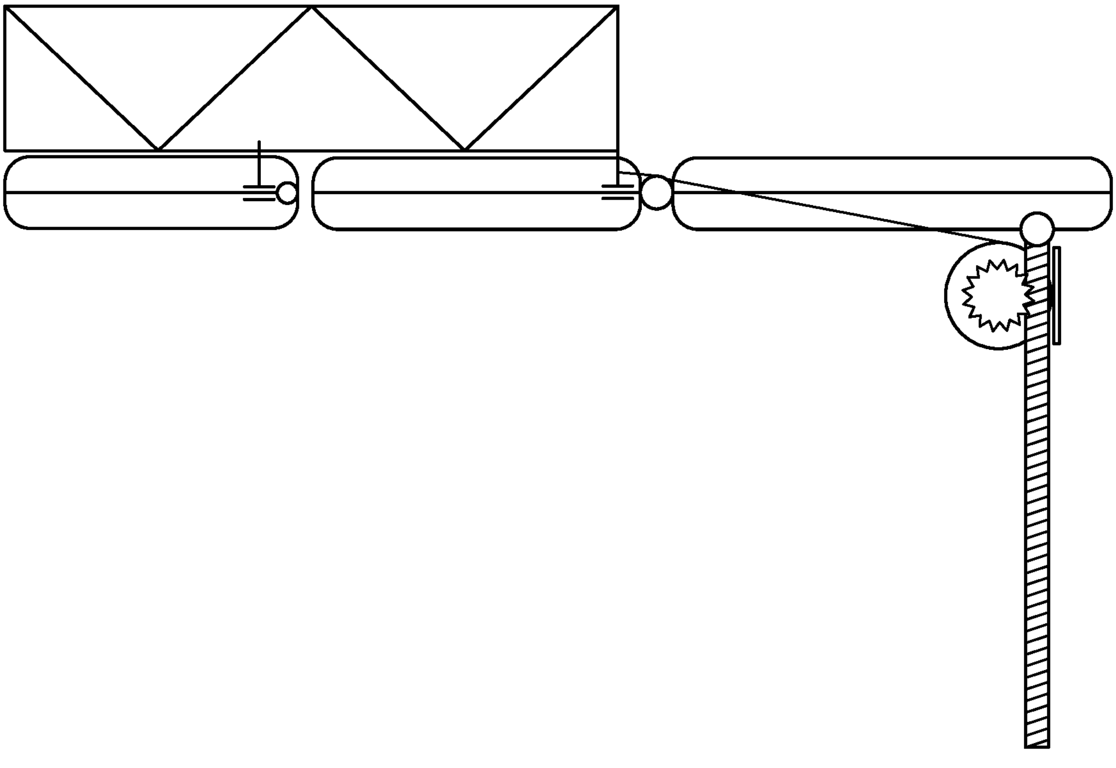

Fig. 7f

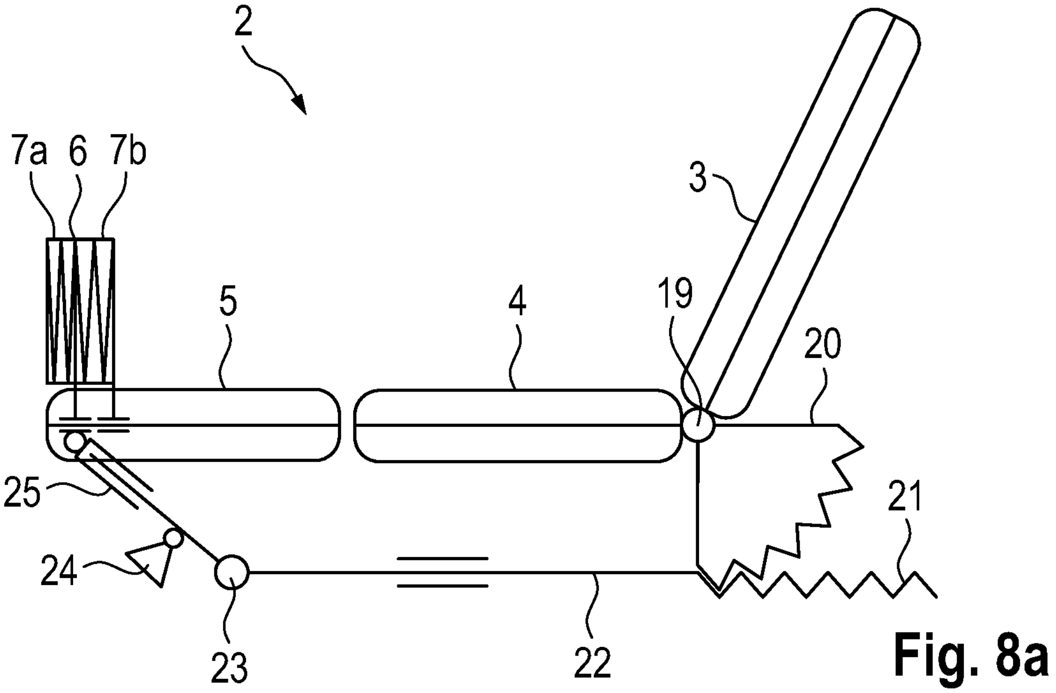

Fig. 8a

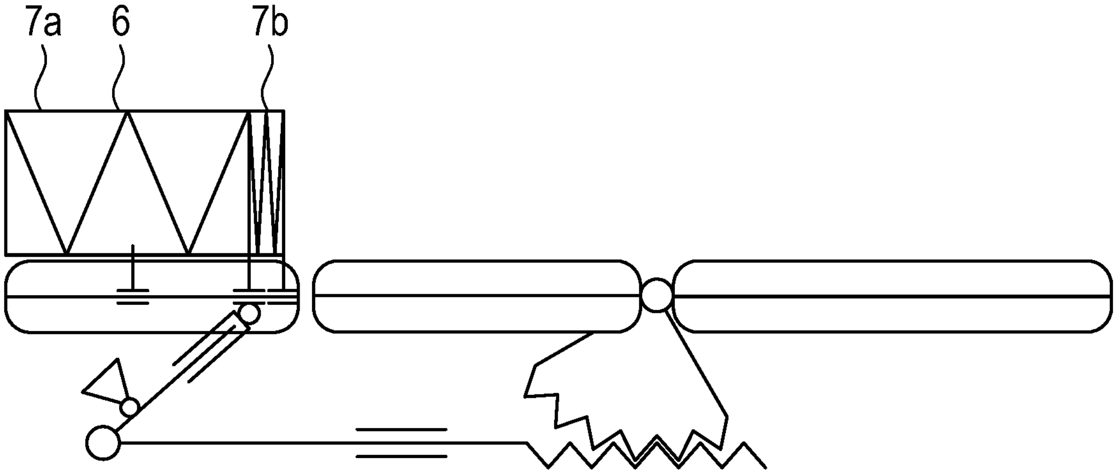

Fig. 8b

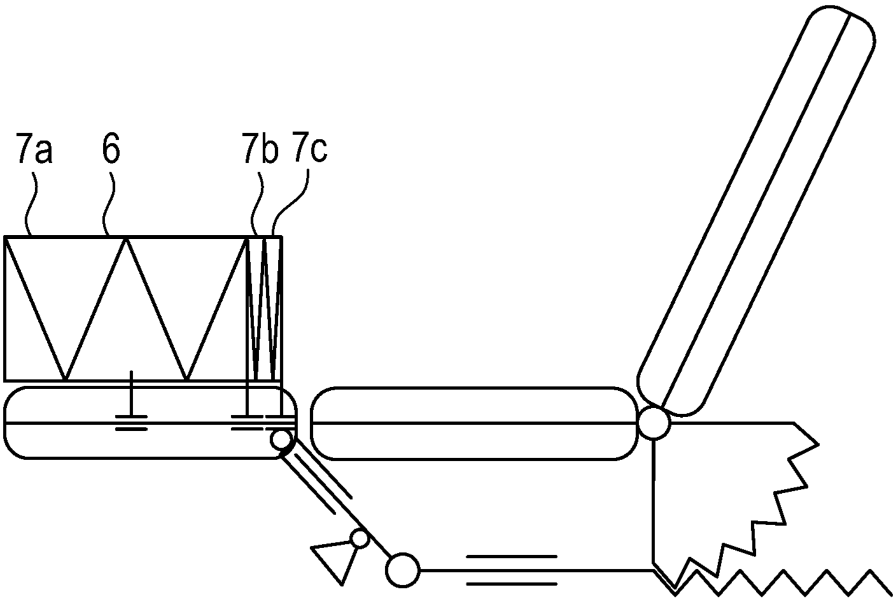

Fig. 8c

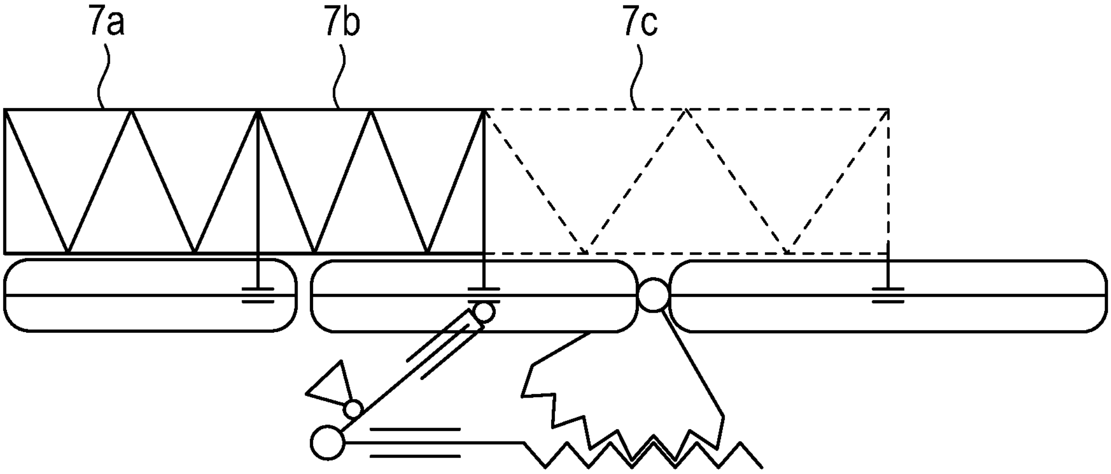

Fig. 8d

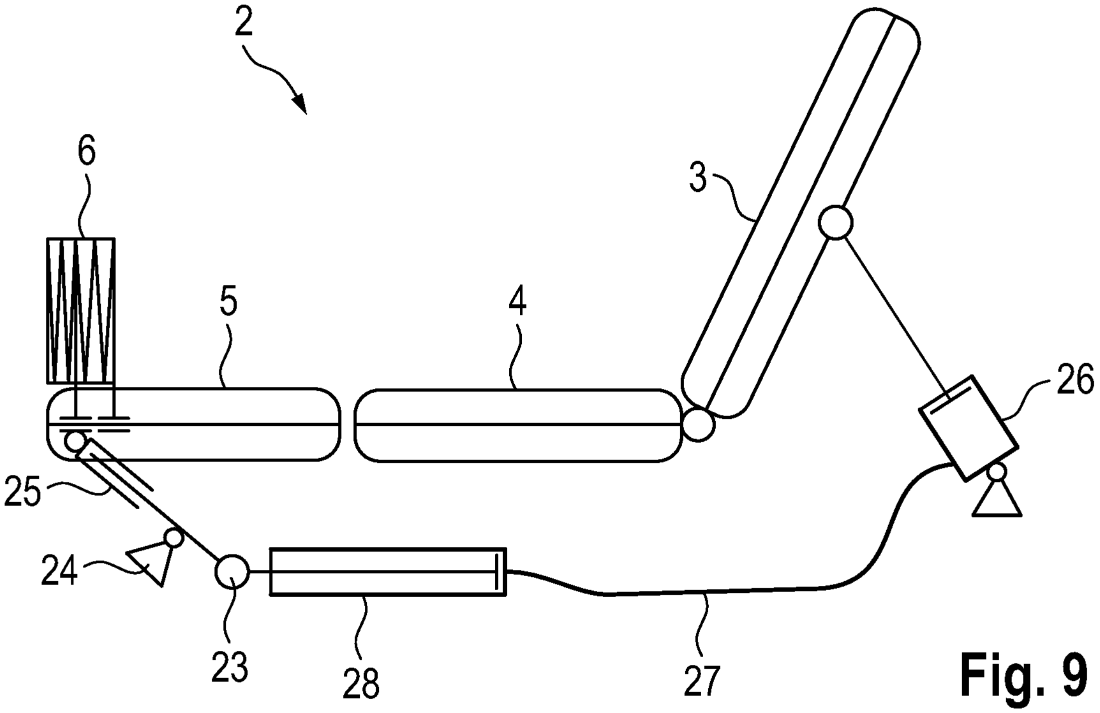

Fig. 9

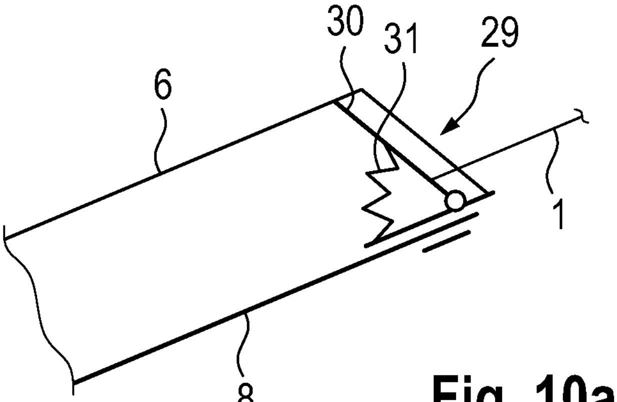

Fig. 10a

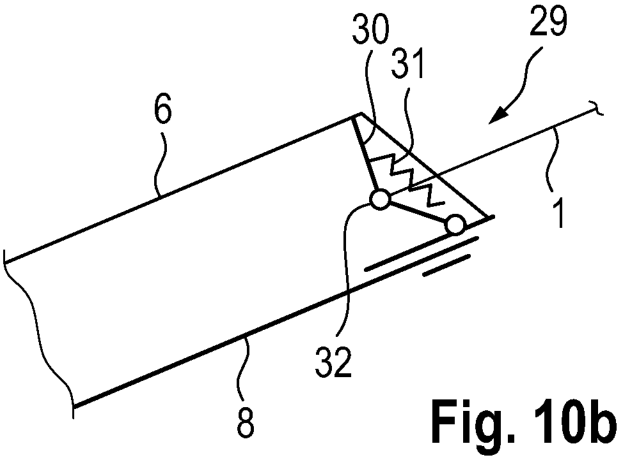

Fig. 10b

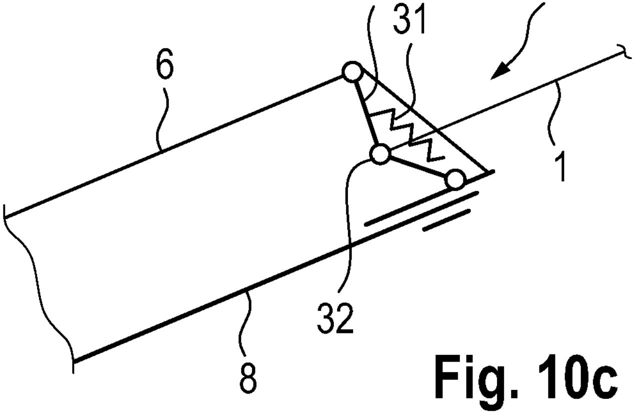

Fig. 10c