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Seat Comfort Prediction with Pressure and Posture

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Abstract

The proposed study presents a novel hybrid tool that integrates virtual and real environments to evaluate seat comfort, focusing on contact pressure, joint angles, and overall body posture. It addresses the research question of how such a hybrid approach can enhance the accuracy and efficiency of seat comfort assessments compared to traditional methods that often rely on subjective feedback and neglect sitting posture comfort. The proposed tool employs Computer-Aided Design (CAD) for human mannequins and seat designs, using Finite Element Analysis (FEA) to measure contact pressure and human factors simulation software for posture and joint angle analysis. Validation involves pressure mapping and motion capture systems in real-world settings, while an Analytical Hierarchy Process (AHP) determines optimal sitting configurations. This integrated approach offers a comprehensive assessment framework of seat comfort to evaluate various postures and assess comfort levels across different seat designs.

Keywords
Computer-aided design, contact pressure, finite element analysis, human factors, motion capture, seat comfort analysis

1. Introduction
The evolution of technology and dependence on computers keeps enforcing sedentary lifestyles more than ever. Such modern advancements introduced a wide variety of activities that can be performed whether working in offices, telecom- muting, using public transportation, or traveling. According to the American Heart Association (AHA), sedentary jobs have increased by 83% since 1950, and a normal office worker sits a shocking 15 hours every single day, and even more for people who undergo long commutes. This alludes to the fact that people spend most of their day seated for a significant amount of time and need a comfortable seat that provides the necessary support and balance without continuing to feel any discomfort (S. Amer & Onyebueke 2013)

Throughout the years, numerous studies have been done on seats and the evaluation process depends on an individual's feedback after a prototype of the seat is made (R. Lueder & Noro 1994). If the evaluation identifies issues in terms of seat comfort or long-term discomfort, retrofitting is the way forward. This is a complex process as it is not easy to rework a seat due to resource limitations and the cost involved (S. T. Amer & Onyebueke 2013). Another shortcoming of the traditional process is the variability in the subjective opinion based on how a person sits or feels at that time. One way to overcome this is to use a very large sample size of a very heterogeneous population so that different people of differing anthropometry are included (Arrowsmith 1986). But then again, it is not easy to arrive at conclusions unless the sitting posture is controlled. This is because everyone has a preferred way of sitting based on their habit unless preferred postures are to be evaluated that can later be accommodated through adjustability. As a result of such complexities, advancements in the evaluations of seats have included the psychophysics of seating by relating the objective and subjective ratings (Gross et al. 2020). Therefore, traditional seat comfort evaluations are influenced by individual preferences, body types, and health conditions. This subjectivity makes it challenging to create objective metrics for assessing comfort that are universally applicable across diverse user groups. Another challenge that the evaluators face is that comfort is not limited to physical aspects like cushioning and support but also includes factors like thermal comfort, posture support, vibration isolation, and ergonomic design. Integrating these multifaceted aspects into seat design requires a holistic approach (Song et al. 2019).

Quattelbaum et al. (2021) conducted a study to evaluate sitting comfort based on digital visual cues and concluded that comfort can be predicted with visual cues (Helander and Zhang 1997), (Helander 2003), (Quattelbaum et al. 2021). There appears to be an emergence of digital simulations to assess seat comfort in recent years (Gowtham et al. 2020). Moreover, with advancements in technology, there's a growing interest in incorporating smart materials, sensors, and adaptive features into seats for enhanced comfort. However, integrating these technologies seamlessly and cost-effectively remains a challenge (Tack et al. 2011). This research is focused on digital evaluations based on the biomechanical and anthropometric aspects. In an effort to reduce the dependence on subjective data, We propose a system to predict seat comfort and human body posture for combinations of seat features. The assessment is hybrid, consisting of virtual models built using Computer Aided Design (CAD) and simulations to model seats and a person in a sitting posture. The system is validated in a real environment using pressure mapping and a motion capture system. This method will help develop a framework to exploit the ideal integration of valid technologies to predict a general comfort index so that the seats can then be fine-tuned with actual participants, making retrofitting a straightforward exercise.

2. Literature Review

Our literature review is summarized under three sections, starting with literature on the relation between posture and anthropometry on seat comfort.

Relation Between Posture and Anthropometry on Seat Comfort

Seat comfort is a complex interaction between the various seat parameters and the person sitting (Hiemstra-van Mastrigt, Brauer, et al. 2017). On one side, the seat height, seat pan features such as seat depth (Goonetilleke and Feizhou, 2001), seat pan angle, material stiffness and resilience (Moon et al. 2020), backrest angle and backrest material and shape D. Kim et al. 2015 have been found to influence the human body and seat comfort (R. Lueder and Noro, 1994). Then, the characteristics of the person sitting and how the person sits and moves on the chair will also influence the perception of seat comfort (Fasulo et al. 2019). When seats are tested and evaluated, most of these factors are controlled and only comparative analysis tends to be done to evaluate the "best" seat among a mix of seats. Then comes the transient effects, where the sitter adopts different postures as some part of the body experiences discomfort (D. Y. Kim et al. 2018), (Van Rosmalen et al. 2009).

Whether posture is related to one's anatomy of the seat or a combination is another difficult question. To accommodate the postural changes that take place when sitting, researchers have proposed intelligent seats (Choi et al. 2021), (Gross et al., 1992). The intelligent-seat patent by Gross et al. (1992) has 16 adjustments and the identical adjustments are in the Porsche Macan except that they are still not autonomous even though the patented system is 30 years old. So, it is clear that changes in the automotive industry are rather sluggish as seat designs are based on the perceived feel of participants. A study by Van Veen et al. (2014) showed that the overall comfort and the neck region comfort can be increased by significantly reducing the passengers' neck flexion angle using specially designed armrests (Van Veen et al., 2014). Another study found that a slumped posture with the head against the headrest, which is a very common posture, had the highest comfort rating (Groenesteijn et al.2014). So, there is no doubt that posture plays a significant role in seat comfort (Brogioli et al.2011).

Anthropometry is undoubtedly an important aspect in chairs and seats (R. K. Lueder 1983). Anthropometry is necessary for static evaluations. Branton and Grayson (1967), were the first to report after observing train passengers that short people sat mostly with their feet on the floor, and they spent less time sitting with knees crossed than tall people, especially when in a slumped position. Alternately, short people in a slumped posture had less foot contact with the floor or with the backrest when compared with tall people during a study on home furniture by (Teraoka et al.2004). Such postures do affect a person, and thus, shorter participants are likely to feel discomfort in the feet and lower legs, while taller participants experience discomfort in the head and neck regions (Hiemstra- van Mastrigt, Brauer, et al. 2017). So, anthropometry does have an effect on interface pressure. Furthermore, various studies have underscored the correlation between posture and seat comfort under varying contexts. For example, one of the studies states that seating situations with a relatively restricted position and poor posture can lead to discomfort and fatigue among drivers (Khamis et al.2019). Moreover, a well-designed seat can prevent various painful disorders, including low back pain, often associated with poor posture (Cappetti and Manso 2021). Whereas another study stated that determination of the postures that individuals will assume on specific seat configurations can facilitate preliminary assessments of potential comfort levels (Gowtham et al., 2020). An in-flight sitting mockup with 30 volunteers revealed the seat pitch to be the most influential factor in seating comfort (Habibillah et al. 2022).

Relation between Seat Features and Contact Pressure

A prominent methodology to assess seat comfort is conducted by detecting the pressure distribution of contact points between the human and the seat. According to literature surveys, more comfort or a reduction of discomfort is brought by reducing this contact pressure (De Looze et al., 2003). Hostens et al. (2001) found that submaximal pressure was higher on the seat pan but smaller on the backrest when the inclination angle of the backrest was small. It is documented that differences in pressure measurements were due to differences in postures in the driver seats, where the peak pressure ratio at the upper back was higher in an upright than in a reclined driving posture due to more support provided (Kyung & Nussbaum, 2008). Another study confirmed that higher seat pan comfort with a larger contact area (Carcone & Keir, 2007), while another study found that less discomfort is accompanied by lower average pressure (Noro et al., 2005). Zemp et al. (2015) studied the relationship between pressure measurements and subjective comfort/discomfort while sitting in office chairs and discovered that there are reliable measures between the backrest and the pressure pattern changes for quantifying comfort or discomfort.

Seat Comfort Analyses

Traditionally, the comfort evaluation process is done in postproduction, meaning that any significant input from the customer is not taken into consideration during the design stage, which leads to the consumption of resources in case any alteration is needed. It takes about three years to implement survey outcomes into a new seat design due to the retrofitting that the changes entail (Kolich, 2008).

Researchers have come up with various methods to ensure a proper and consistent comfort measurement while reducing the consumption of resources. In many cases, these methods were associated with the subjective assessment of comfort and discomfort. In spite of the participant's satisfaction with the overall seat comfort, a study by Park et al. (2015) on the posture of drivers using 3D scanning found that the pressure distribution revealed the opposite, highlighting the need for manufacturers to take the pressure distribution into account in addition to the preferred driving postures when designing an automobile seat. S. T. Amer and Onyebueke (2013) took another approach to transform customer needs using Quality Function Deployment (QDF) and CAD and ensure seat comfort is built into the design before production. Another study investigated the seat comfort of a vehicle by setting up a human finite element model, which was first validated by experimenting with human pressure distribution over a rigid seat under three postures (Huang et al. 2015).

The results revealed that the simulation was consistent with the experiment data. So, a human model was used to predict the interaction between the person and the seat, including pressure distribution, allowing the assessment of comfort in a virtual phase of seat development. M. M. Verver et al. (2005) used a numerical seat model to accelerate the development of a safe and comfortable car seat instead of using prototypes by simulating a seat model that consisted of a headrest, seat backrest, and seat cushion on Mathematical Dynamic Models (MADYMO) software. Validation of the model based on experimenting with rigid loading devices with mannequins in terms of force-deflection characteristics responded well to the experimental tools; hence the method could be used in early design stages. Romli and Aminian (2018) analyzed a typical passenger seat on a Malaysian aircraft to highlight if it is comfortable for its passengers. The tool used was Rapid Upper Limb Assessment (RULA) ergonomic analysis using Jack® software based on the anthropometry of Malaysians. Results showed potential improvement opportunities to seat design and seat pitch to ensure better comfort for the Malaysian population.

A literature presented by Hiemstra-van Mastrigt, Groenesteijn, et al. (2017) summarized the correlation and association of human, seat and content on the perception of comfort as shown in Figure 1. As evident, interface pressure (contact pressure), and movement have varying degrees of effect on comfort. To this end, researchers have utilized various tools such as mockup runs in real life, virtual environments Gowtham et al. (2020), computer-aided designs Bermamet et al. (2022), motion capture,Qing et al. (2017), etc., to assess different variables affecting the comfort. However, we did not identify any research that proposes a methodology to assess seating comfort by analyzing the contact pressure as well as comfort from the posture acquired by the person while sitting. Thus, our work aims to propose a framework using virtual environments and motion capture that can assist in predicting the comfort of new seat designs in different sitting postures.

3. Methodology

The proposed methodology in this study is a hybrid system that includes two experimental environments: real and virtual, as illustrated in Figure 2. The virtual environment consists of two software programs, CAD and a human factors simulation, to model people sitting and the seats, assessing comfort level and investigate various features that pertain to the reduction of comfort or discomfort when seated in different postures. The real environment consists of pressure mapping and a motion capture system to validate the virtual assessment. The step-by-step methodology for the study involves initially setting up a virtual environment, which includes the creation of human models using CAD. The modeling of humans is achieved with correct materials exhibiting quasi-linear viscoelastic properties and based on a particular anthropometry. This work uses the Asian-Indian percentiles for males and females to represent the UAE population. The seat models are designed to maximize contact area for improved comfort, using various seat designs from predefined CAD libraries.

Using Finite Element Analysis (FEA), different sitting postures are simulated with the correct types of cushions, seat contouring, and body pressure distribution to identify the high-contact pressure regions. The output from the CAD module is then collected in a metadata file and entered into the Human Factors Simulation module to be used to mimic the sitting posture with the correct seat model and human measurements. The scenario is further analyzed through Human Factors Software, which is equipped with tools like the Krist and Dreyfuss 2D comfort assessment tools, using a comfort scale of 0 to 80. The output is further collected and augmented to the metadata file.

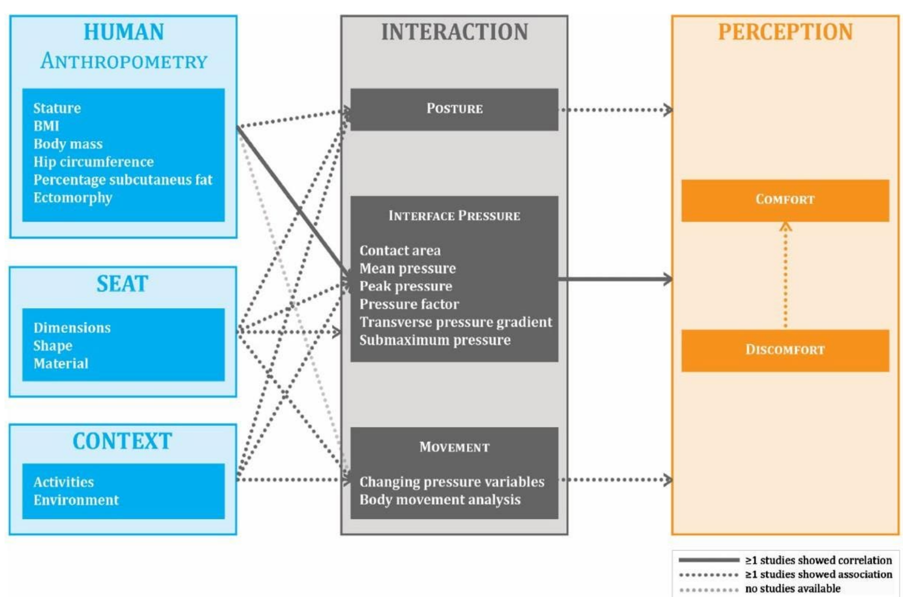

Figure 1. Hybrid system for seat comfort assessment (Hiemstra- van Mastrigt, Groenesteijn, et al.,2017)

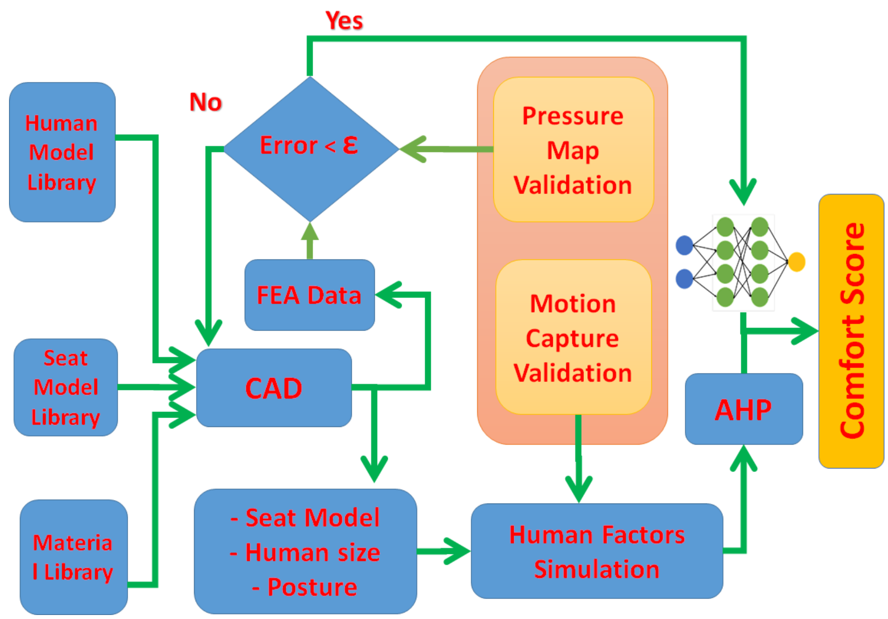

Figure 2 . Hybrid system for seat comfort assessment

3.1 Virtual Environment

The first step in the virtual environment is building mannequins and seat models with different postures and designs using Computer Aided Design tools.

3.2 The Human Models:

With the right quasi-linear viscoelastic material properties, it was possible to simulate the interaction of external loads on the human skin and bone (Tang & Tsui, 2006). The human models were based on anthropometric data on the UAE population to maintain realistic outcomes. This study constructed human models with Asian-Indian anthropometry of 5th, 50th, and 95th percentiles for males and females (Chakrabarti, 1997). The human models are constructed by sketching the skeleton using the Sketch tool to create a 2D representa- tion, and basic geometric shapes are used to outline the main body parts. Each body part is modeled with the Extrude Boss/Base feature, saved as a separate part file, and assembled in a new assembly file using the Mate feature to align them correctly. Joints and additional features are added for flexibility and realism, and materials and appearances are applied to enhance the mannequin's look.

The Seat Model: Multiple seat models with correct dimensions and materials were constructed as CAD assemblies exhibiting the different features and adjustment options. Having seat features allows more contact area between the seat and the subject, which seems to promote comfort (Hix et al., 2000), so it is eminent that the effect of the seat features on comfort is included during the process of comfort assessment. Libraries containing various seat features were used to build seat models to accommodate diverse seating configurations without losing the function of the seat. Seat models are designed based on the customer's needs and follow the correct health and safety standards, with the aim of enhancing comfort. The system constituted a library that stored around 75 seat models with different seat features. Furthermore, the CAD system employs libraries for different human models and cushion materials. The CAD assembly tools allow staging multiple sitting scenarios to be validated and tested.

Simulation of Sitting Posture:

The sitting posture in this study refers to how the human body is positioned on the seat surface and how it is supported to feel and fit in the seat. The support features consider all aspects of seat contouring to reduce body pressure distribution (Helander & Zhang, 1997). Seven different postures are used to train and evaluate the system. Figure 3 depicts the three of the different sitting postures that were modeled with CAD software and then validated in lab experiments. The scenarios are arranged so that seat features are added gradually to bring more of the body's surface areas into contact with the seat surface to reduce the contact pressure.

The Finite Element Analysis Simulation Technique:
FEA displays the reaction of an object to excitations that may be force loading, contact pressure, thermal excitations, fluid motions, and more (Pileicikiene et al. 2007). This simulation requires the precise selection of boundary conditions, such as the defined type of contact between the components, friction, fixed geometry, and gravity, to correctly recognize each surface and its interaction with other surfaces. The outcome of the FEA analysis is graphically visualized using colored contours that reflect the different stress levels of the model. This is vital to this study as the results not only show the magnitude of pressure points but also their locations to fix them (M. Verver et al., 2004). It has been documented that FEA analysis using CAD software can be utilized instead of a physical pressure mapping system to measure the expected contact pressure with an acceptable accuracy (Bermamet et al. 2022.).

Human Factors Simulation:
A simulation software used for generating 3D environments and modeling human bodies that have proper biomechanical, anthropometric, and ergonomic characteristics (Jack Base Manual, 2016). The comfort assessment tool in human factors simulation software helps to determine if the human is seated with natural joint angles and if extremities are positioned in a comfortable posture. Krist 1994 comfort assessment tool was used for rating the comfort of various body parts based on the body posture. The comfort scale ranges from 0 to 80, with 80 being the least comfortable. Alternately, Dreyfuss 2D comfort assessment tool measures the joint angles depending on the human posture and indicates whether it falls within the comfort range or not. The value that is observed most often is the statistical 'mode.' The bar graphs are centered on this value to better indicate the deviation from this 'typical' value.

Real Environment
It is essential that the simulated model gets validated to ensure accurate seat comfort evaluation. The seats that were correctly modeled in the CAD module were then used to set up a test bed in the lab. Five test subjects with recorded anthropometric dimensions were employed to test the contact pressure and the sitting posture's comfort using pressure mapping and motion capture. The main goal of the real environment implementation is the calibration of the virtual environment, which is considered the skeleton of the proposed framework.

Pressure Mapping: Tekscan™ pressure mapping system was used in this study to validate the proposed technique by examining the contact pressure between the human and the seat for different sitting postures by mapping the pressure points in a computer program that presents the location and magnitude of the pressure points. The pressure score was then obtained using the machine learning approach proposed by (S. T. Amer et al. 2023)

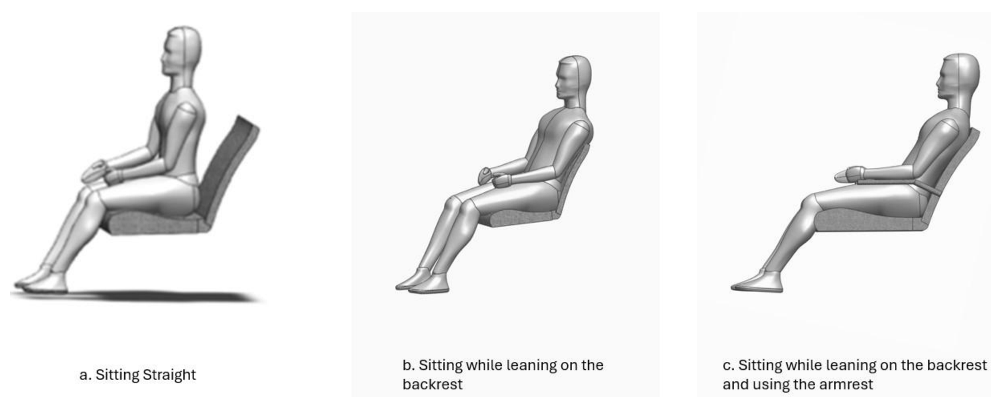

Figure 3. Different seat designs and sitting postures

- Motion Capture System: Human factors simulation was carried out using two different motion capture systems, markerless and inertial sensor-based motion capture systems. After that, the comfort assessment tools were selected to detect the comfort of the sitting posture of the animated figure in real time. This study's motion capture tool is vital to accurately mimic awkward and uncommon sitting postures such as slouching, leaning on one side, and crossing legs.

3.3 Analytic Hierarchy Process (AHP)

As this study proposes a system of methods to assess sitting comfort, the Analytic Hierarchy Process (AHP) method was used to decide the weight of each factor and integrate them into one equation. Since the scale of each factor is different, the results for each factor are normalized into a scale of 0 to 10, where 0 represents the lowest comfort, and 10 represents the highest comfort.

- Contact pressure: 0 refers to a contact pressure of 0.05 MPa, and 10 refers to a contact pressure of 0.0 MPa.
- Comfort rating due to posture: 0 refers to a rating of 80, and 10 refers to a rating of 0 on Krist comfort scale. The average rating of different body parts was calculated and the corresponding value on a 0 to 10 scale was derived.
- Comfort rating due to joint angle: for each joint angle, different extremities of comfort rating are presented on the Dreyfuss 2D scale. For each joint angle, 0 refers to the extreme end of the comfort range, and 10 refers to the mode of the comfort range. The corresponding comfort rating on a scale of 0 to 10 was calculated for each joint angle and then averaged to get a single normalized score.

Table 1. Pairwise comparison of different factors affecting seat comfort

-	Contact Pressure	Posture Analysis	Joint Angle
Contact Pressure	1	3	2
Posture Analysis	0.33	1	0.50
Joint Angle	0.5	2	1

After normalizing the rating scores, the weight of each factor is decided using AHP. FEA is the major contributor towards seat comfort, followed by comfort due to the joint angle and then comfort due to sitting posture, as seen in Table 1.After obtaining the relative scores, a normalized pairwise comparison matrix is derived, and the criteria weight factor is calculated. The derived weights of the factors shown in Table 2 are obtained with team years of experience in the seat comfort subject.

Table 2. Relative weights of different factors affecting seat comfort

Contact Pressure	Posture Analysis	Joint Angle
0.5	0.3	0.2

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The study further reinforces the robustness of the proposed framework by exploiting an intelligent predictive model presented by Amer et al., which is based on Machine Learning. The model constitutes an Artificial Neural Networks (ANN) approach that maps the contact pressure and the Human Factors data into Seat comfort ratings ranging from 1 to 10, where 10 is the most comfortable. The data was collected from thirteen test subjects who volunteered to sit for 3, 6, 9, and 12 hours. The main advantage of the ANN model over the heuristic/deterministic models is its ability to learn from examples and tolerate noisy data (S. T. Amer et al. 2023).

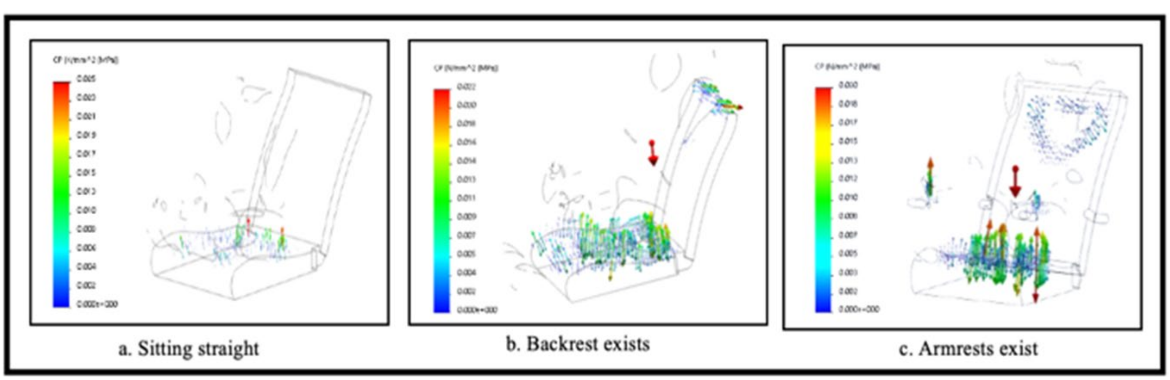


Figure 4. FEA output for different seat models (male, 50th percentile anthropometric measures)

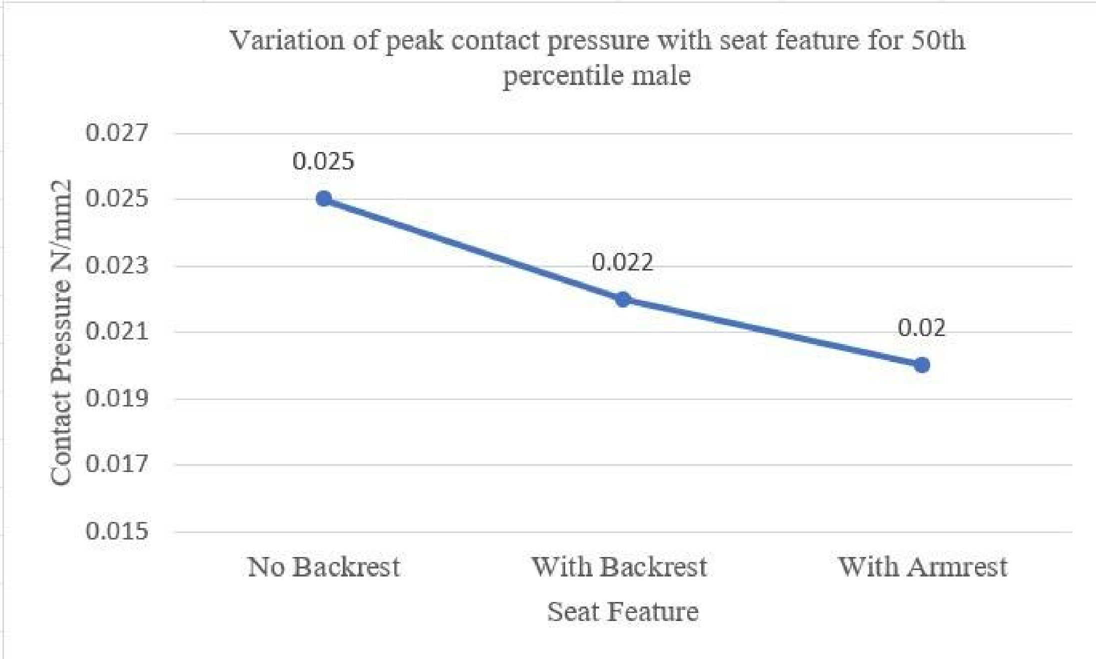


Figure 5. Variation in the peak contact pressure with utilization of seat features for 50th percentile male

The equation followed for assessing the overall seat comfort can be seen below:
Overall Seat Comfort = 0.5 ∗ "*normalized FEA contact pressure value*" + 0.3 ∗ "*average normalized joint angle comfort rating*" + 0.2 ∗ "*average normalized posture comfort rating*"

4. Results and Discussion

Different seat designs, along with different sitting postures, as shown in Figure 3, were simulated and then evaluated in the lab environment to validate the proposed technique. The first section discusses the results of the FEA followed by the validation process.

4.1 Results Obtained by Running FEA in the CAD Environment

The CAD approach provided an effective visualization of different human postures and different seat features. Furthermore, the CAD combined with the FEA tool uncovered the results obtained by using two strategies for assessing seat comfort. The FEA output showing the peak contact pressure detected on different seats for a male model with 50th percentile anthropometric measures can be seen in Figure 4. Arrows with the darkest color, as per the color map, represent the peak contact pressure and its location.

Figure 6 illustrates how the peak contact pressure detected between the seat and body varies as more features were attached to the seat. For instance, the average peak contact pressure for the 50th percentile male when seated without leaning on the backrest was 0.025 N/mm² but was reduced to 0.02 N/mm² when leaning back with arms placed over the armrests. This indicates a significant impact of seat features on minimizing the contact pressure with lower localized contact pressure on the ischial tuberosity area as expected (Chaffin et al. 2006). Grujicic et al. (2009) also alluded to improving seat comfort with the addition of seat features. This highlights how beneficial it is to model and test different seat designs with different components virtually to select and test the best- performing configuration before building a physical prototype (Volpe et al. 2015).

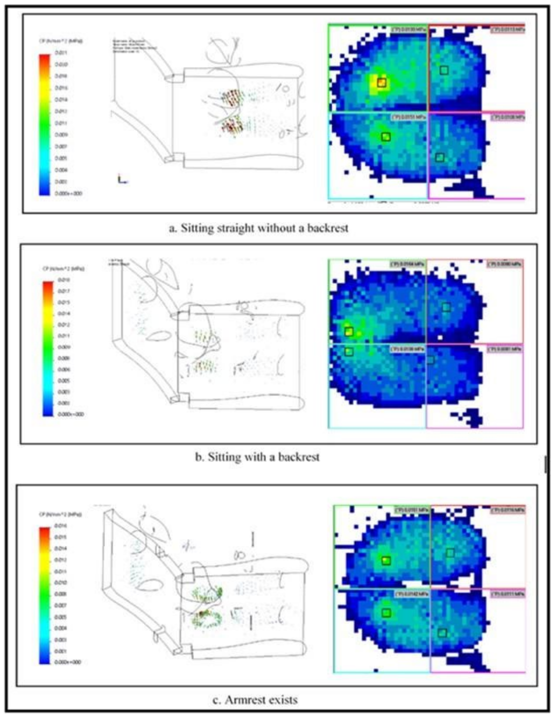


Figure 6 . FEA versus PMS pressure maps for subject

4.2 Validation of the CAD Environment Using Pressure Map- ping System

The validation experiment was carried out with the Tekscan™ pressure mapping system. Subjects chosen to per- form the validation experiments were selected so that they could represent the human models' anthropometry as closely as possible, and they were asked to sit on the pressure mats placed on seats with cushions made of foam but in different postures each time. The results of the Tekscan™ pressure mapping system are displayed along with that of FEA in Figure 4 for a male subject with anthropometric dimensions representing the 50th percentile in Figure 6. When comparing their output to each other, it can be concluded that both systems show a similar distribution of contact pressure in magnitude and location, mostly localized in the ischial tuberosity area. A paired t-test with a 95% confidence interval for the two samples was performed. A correlation of 98.07% and a p-value of 0.913 was observed, indicating that the mean of the two samples was equal without any significant difference. This high correlation and lack of significant difference suggest that the results obtained from both samples are consistent and reliable. Furthermore, Figure 7 represents the peak contact pressure registered for the 5th, 50th and 95th percentile (denoted as Subject 1, 2 and 3 respectively) using CAD and Pressure Mapping system. These findings support the conclusion that the Finite Element Analysis (FEA) approach is effective in recognizing the impact of seat features on contact pressure. The FEA method's ability to identify variations in contact pressure based on different seat features confirms its validity and utility in seat comfort analysis.

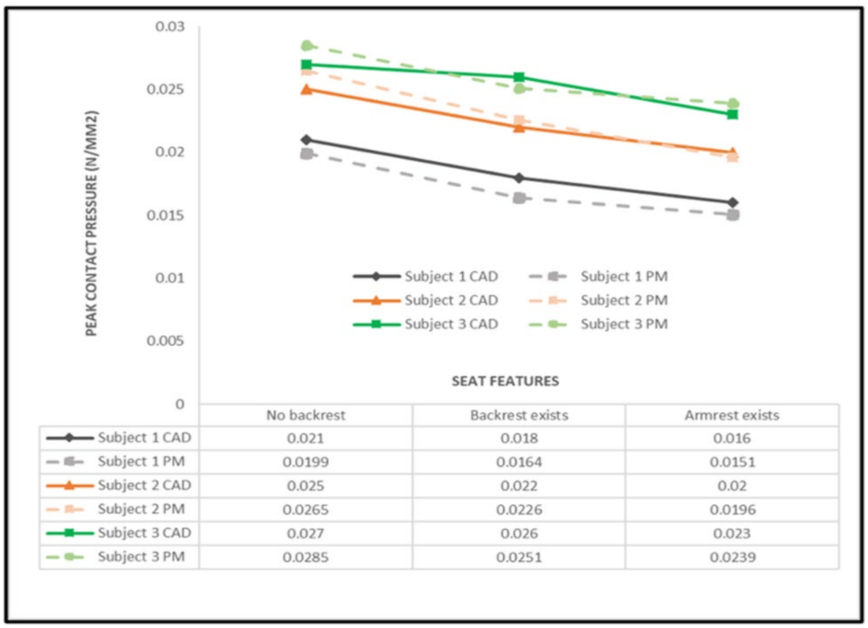
Results Obtained by Running Human Factors Simulation

As discussed in the literature review, sitting posture is a major factor that impacts seat comfort. Hence, measuring the comfort of the sitting position helps in understanding the level of comfort experienced when on the seat. Figures in Jack® were manipulated to represent the required sitting posture, and their comfort was assessed using Krist and Dreyfuss 2D comfort rating scales. Figure 8 represents, as an example, the output of the comfort scales for a male model with a 50th percentile anthropometric measure when sitting straight. This result was obtained by manually adjusting the angles of all the joints to visually mimic as closely as possible to the sitting posture portrayed in Figure 3a.

4.3 Validation of Human Factors Simulation using Motion Capture System

Even Jack® provides the user with the means to manually control the posture by adjusting the joint angle, it becomes difficult to duplicate the posture of an actual human completely. As a result, we employed two motion capture systems alongside Jack to increase the fidelity of the output. A markerless and an inertial motion capture sensors were used independently to track the human body and detect the joints to then transform them into an animated figure on Jack® software. Comfort assessment scales were then applied to the animated figure to detect the posture comfort of the seated human subject in real-time. Figure 9 and Figure 10 represent the output of the comfort scales for a male participant when sitting straight using a markerless and an inertial motion capture sensor, respectively.

When using the Krist comfort assessment scale to rate the comfort of different body parts seated in different postures, it was found that it can interpret the differences between the postures of the human and hence rated the comfort of each body part differently. In this case, it can be noted that the scores of almost all body parts when seated on an office chair, with the back leaning on the backrest and arms on armrests, were lower than when seated straight on an office chair most of the time, indicating more comfort. The comfort and fatigue indices were also in favor of the former sitting position. As for the Dreyfuss 2D comfort assessment scale, the comfort of body joints when sitting with the back leaning on the backrest was closer to the 'mode' and was within the comfort range than when sitting straight on an office chair. These results also emphasize how the motion capture system is a technique that can be used to study the posture comfort of the human on different types of seats. Weird or slouched sitting postures can also be tested in this tool to understand why some people prefer these sitting postures over balanced ones.



	No backrest	Backrest exists	Armrest exists
Subject 1 CAD	0.021	0.018	0.016
Subject 1 PM	0.0199	0.0164	0.0151
Subject 2 CAD	0.025	0.022	0.02
Subject 2 PM	0.0265	0.0226	0.0196
Subject 3 CAD	0.027	0.026	0.023
Subject 3 PM	0.0285	0.0251	0.0239

Figure 7. CAD versus PMS pressure maps for different subjects

The results obtained using the markerless and the inertial motion capture systems had a variation. This difference in values arose due to the inherent shortcomings of both of the systems. In the case of a markerless motion capture system, the noise in the form of surrounding light influenced the performance of the system significantly, and in the case of an inertial sensor-based motion capture system, the magnetic interference from the surrounding affected the data being registered by the inertial sensors and accelerometers. In our enquiry it was found that the results obtained using the inertial motion capture system was more accurate since the markerless systems was even prone to the light present in the testing area and thus the comfort rating obtained by utilizing the inertial motion capture system was considered for this work.

A. Integration of Contact Pressure, Posture Analysis, and Joint Analysis Using AHP Methodology

- Posture 1: Sitting straight
  Overall Seat Comfort= 0.5×5.0+0.3×4.9+0.2×7.4=5.4
- Posture 2: Sitting with backrest
  Overall Seat Comfort= 0.5×5.6+0.3×3.7+0.2×5.0=4.9

- Posture 3: Sitting with backrest and armrests
  Overall Seat Comfort= 0.5×6.0+0.3×3.8+0.2× 6.5=5.5

The study on seat comfort and posture analysis using human factors simulation faced several limitations, such as the challenge of accurately replicating real-life hu- man movements in Jack® software and the influence of external interferences on motion capture systems. Comfort assessment scales like Krist and Dreyfuss 2D are subjective and may not adequately capture dynamic comfort aspects. Moreover, the controlled environment of the experiments does not fully represent real-world conditions, including prolonged sitting and environmental variations. Future research should aim to improve simulation accuracy, refine motion capture techniques, expand comfort assessment tools, validate results in real- world settings, and customize AHP weights based on user feedback.

5. Conclusion

This study presents validated methods to assess and integrate three different factors, contact pressure, posture analysis, and joint angle analysis, for seat comfort assessment. The effect of combining different features, such as backrests and armrests, on total seat comfort was evaluated by studying their effect on contact pressure in the virtual environment using FEA methodology. The results were then validated against the values obtained using Tekscan™ pressure mapping system. The posture and joint angle analysis were performed using the comfort assessment tool available within Jack®. The comfort experienced by the virtual human model due to the posture was evaluated using the Krist scale and the bending at different joints was assessed using Dreyfuss 2D scale. The results obtained here were validated using both marker-less and inertial motion sensor-based motion capture systems. The contact pressure and the rating obtained from the comfort assessment scales had different units, so the obtained results from each method were normalized on a scale from 0 to 10 and were then integrated, wherein the weight of each of the factors was calculated using the AHP method. Using the proposed hybrid system, designers can simply test a variety

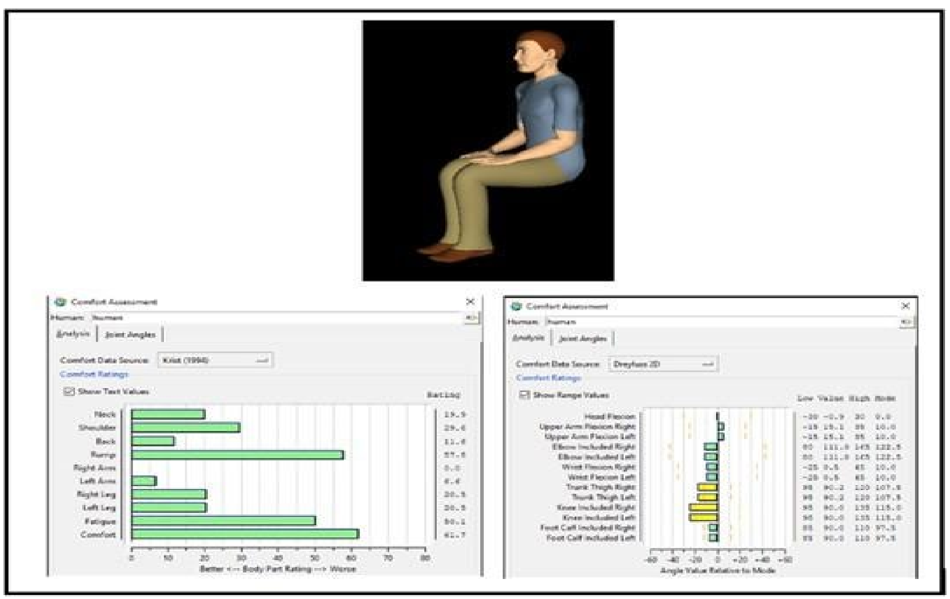


Figure 8. Comfort assessment using Jack® figure when sitting straight

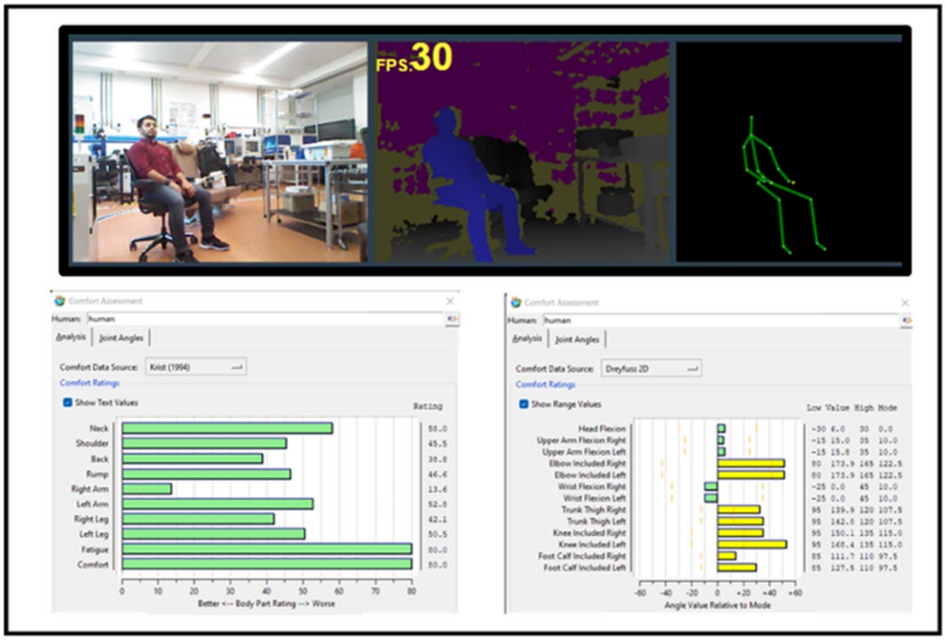


Figure 9. Comfort assessment output for subject 1 when sitting straight using a markerless motion capture system

of seat configurations virtually to find the best option for the diverse population of occupants they aim to satisfy in different industries without the need to build numerous prototypes. The integrated system can detect different postures of the human body when sitting and assess the level of comfort of body parts and/ or joints using human factors simulation software.

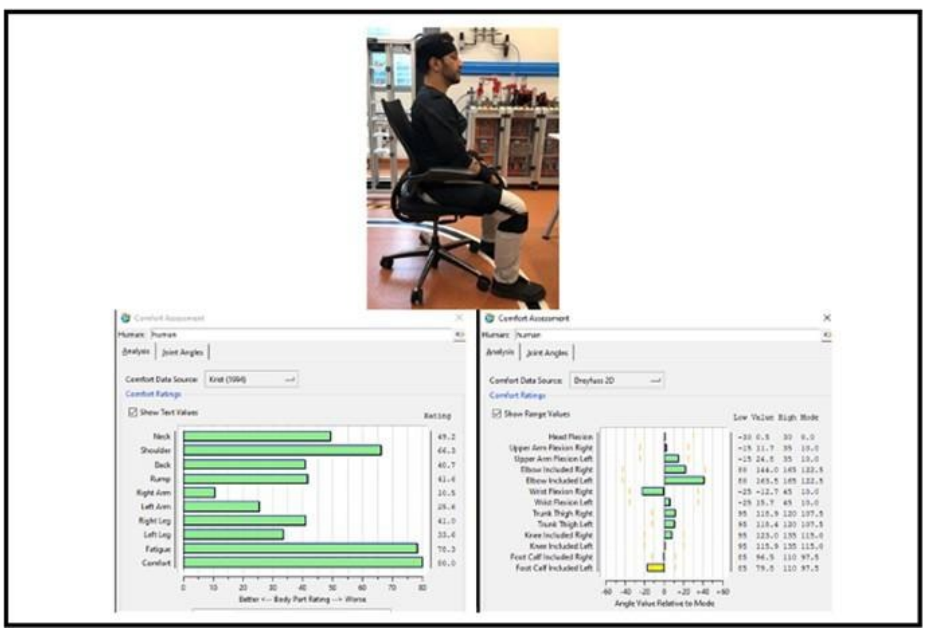


Figure 10 . Comfort assessment output for subject 1 when sitting straight using inertial motion sensors

By varying seat features, the system can explore different seat designs and propose the optimum combination for the best sitting comfort. This study was limited to analyzing different seat designs and sitting postures. Future development of this work will consider the influence of changing the parameters of seat features and studying the effect of sitting time to consider additional vital aspects affecting the comfort level.

REFERENCES

Amer, S., & Onyebueke, L.. The integration of quality function deployment and computer aided design in seat comfort design and analyses. ASME Interna- tional Mechanical Engineering Congress and Expo- sition, 56413, V012T13A011, 2013

Amer, S. T., & Onyebueke, L.. Experimental validation of the computer aided design technique for seat com- fort design and evaluation (tech. rep.). SAE Technical Paper, 2013.

Amer, S. T., Onyebueke, L., & Rababaah, A. R.. Intelligent system for integrating customer's voice with cad for seat comfort. In Applications of math- ematical modeling, machine learning, and intelligent computing for industrial development (pp. 259–286). CRC Press, 2023.

Arrowsmith, M.. The design and development of the xj40 seating system. Proceedings of the Institution of Mechanical Engineers, Part D: Transport Engineer- ing, 200(5), s79–s85, 1986.

Bermamet, H., Syed, S., & Amer, S.. Investigating the effect of seat features and cushion material on seat comfort using finite element analysis. Proceedings of the 5th European International Conference on Industrial Engineering and Operations Management Rome, Italy, July 26-28, 2022

Branton, P., & Grayson, G.. An evaluation of train seats by observation of sitting behaviour. Ergonomics, 10(1), 35–51, 1967.

Brogioli, M., Gobbi, M., Mastinu, G., & Pennati, M.. Parameter sensitivity analysis of a passenger/seat model for ride comfort assessment. Experimental mechanics, 51, 1237–1249, 2011.

Cappetti, N., & Manso, E. D.. Study of the relation- ships between articular moments, comfort and human posture on a chair. Work, 68(s1), S59–S68, 2021.

Carcone, S. M., & Keir, P. J.. Effects of backrest design on biomechanics and comfort during seated work. Applied Ergonomics, 38(6), 755–764, 2007.

Chaffin, D. B., Andersson, G. B., & Martin, B. J.. Occupational biomechanics. John wiley & sons, 2006.

Chakrabarti, D.. Indian anthropometric dimensions for ergonomic design practice. National institute of design, 1997.

Choi, S., Kim, H., Kim, H., & Yang, W.. A develop- ment of the self shape adjustment cushion mechanism for improving sitting comfort. Sensors, 21(23), 7959, 2021.

De Looze, M. P., Kuijt-Evers, L. F., & Van Dieen, J.. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics, 46(10), 985–
997, 2003.

Fasulo, L., Naddeo, A., & Cappetti, N.. A study of classroom seat (dis) comfort: Relationships between body movements, center of pressure on the seat, and lower limbs' sensations. Applied ergonomics, 74, 233–240, 2019.

Goonetilleke, R. S., & Feizhou, S.. A methodology to determine the optimum seat depth. International Journal of Industrial Ergonomics, 27(4), 207–217, 2001.

Gowtham, S., Ramnaath, M., Sudharsan, S., Kumar, B. L., Pra- neeth, V., Dinesh, S., & Subramaniyam, M.. Seating comfort analysis: A virtual ergonomics study of bus drivers in private transportation. IOP Con- ference Series: Materials Science and Engineering, 912(2), 022018, 2020.

Groenesteijn, L., Hiemstra-van Mastrigt, S., Gallais, C., Blok, M., Kuijt-Evers, L., & Vink, P.. Activities, postures and comfort perception of train passengers as input for train seat design. Ergonomics, 57(8), 1154–1165, 2014.

Gross, C. M., Banaag, J., Goonetilleke, R., & Nair, C.. Feedback system for load bearing surface [US Patent 5,170,364], 1992.

Gross, C. M., Goonetilleke, R. S., Menon, K. K., Banaag, J. C. N., & Nair, C. M.. The biomechanical assessment and prediction of seat comfort. In Hard facts about soft machines: (pp. 231–253). CRC Press, 2020.

Grujicic, M., Pandurangan, B., Arakere, G., Bell, W., He, T., & Xie, X.. Seat-cushion and soft-tissue ma- terial modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants. Materials & Design, 30(10), 4273–4285, 2009.

Habibillah, N. H. A., Ismail, N. H., & Romli, F. I.. Influence of seat pitch and body anthropometry parameters on aircraft passengers' seating comfort. Journal of Aeronautics, Astronautics and Aviation, 54(3), 241–250, 2022.

Helander, M. G.. Forget about ergonomics in chair design? focus on aesthetics and comfort! Ergonomics, 46(13-14),

1306–1319, 2003.
Helander, M. G., & Zhang, L.. Field studies of comfort and discomfort in sitting. Ergonomics, 40(9), 895– 915, 1997.
Hiemstra-van Mastrigt, S., Brauer, K., & Vink, P.. Influence of passengers' anthropometry and tasks on posture and discomfort in an aircraft seat. 1st International Comfort Congress, 1–8, 2017.
Hiemstra-van Mastrigt, S., Groenesteijn, L., Vink, P., & Kuijt- Evers, L. F.. Predicting passenger seat comfort and discomfort on the basis of human, context and seat characteristics: A literature review. Ergonomics, 60(7), 889–911, 2017.
Hix, K., Ziemba, S., & Shoof, L.. Truck seat modeling-a methods development approach. Interna- tional ADAMS User Conference, 2000.
Hostens, I., Papaioannou, G., Spaepen, A., & Ramon, H.. Buttock and back pressure distribution tests on seats of mobile agricultural machinery. Applied Ergonomics, 32(4), 347–355, 2001.
Huang, S., Zhang, Z., Xu, Z., & He, Y.. Modeling of human model for static pressure distribution predic- tion. International Journal of Industrial Ergonomics, 50, 186–195, 2015.
Khamis, N. K., Tee, N. C., Tahir, M. F. M., & Sabri, N.. Pattern of pressure distribution on the car seat under static condition and its relationship with driving posture. Int J Innov Technol Explor Eng, 8(12), 4189–94, 2019.
Kim, D. Y., Bang, J. H., Lee, C. A., Kim, H. Y., Choi,
K. Y., & Lim, B. G.. Numerical evaluation of time-dependent sagging for low density polyurethane foams to apply the long-term driving comfort on the seat cushion design. International Journal of Industrial Ergonomics, 64, 178–18, 2018.
Kim, D., Lee, D.-K., & Cho, H. K.. A study on the vdt workstations usage for office workers. Journal of the Ergonomics Society of Korea, 34(2), 179–190, 2015.
Kolich, M.. A conceptual framework proposed to formalize the scientific investigation of automobile seat comfort. Applied Ergonomics, 39(1), 15–27, 2008.
Kyung, G., & Nussbaum, M. A.. Driver sitting comfort and discomfort (part ii): Relationships with and pre- diction from interface pressure. International Journal of Industrial Ergonomics, 38(5-6), 526–538, 2008.
Lueder, R., & Noro, K.. Hard facts about soft ma- chines: The ergonomics of seating. CRC Press, 1994.
Lueder, R. K.. Seat comfort: A review of the construct in the office environment. Human factors, 25(6), 701– 711, 1983.
Moon, J., Sinha, T. K., Kwak, S. B., Ha, J. U., & Oh, J. S.
. Study on seating comfort of polyurethane multilayer seat cushions. International Journal of Automotive Technology, 21, 1089–1095, 2020.
Noro, K., Fujimaki, G., & Kishi, S.. A theory on pressure distribution and seat discomfort. Comfort and Design, 33–39, 2005.
Park, S. J., Min, S. N., Subramaniyam, M., Lee, H., Shin, Y. K., Jang, C. H., & Hwang, S. H..Driving posture measurement using 3d scanning measuring technique. SAE International Journal of Passenger Cars-Mechanical Systems, 8(2015-01-1392), 600–605, 2015.
Pileicikiene, G., Surna, A., Barauskas, R., Surna, R., & Base- vicius, A.. Finite element analysis of stresses in the maxillary and mandibular dental arches and tmj articular discs during clenching into maximum inter-cuspation, anterior and unilateral posterior occlusion. Stomatologija, 9(4), 121–128, 2007.
Qing, T., Jinsheng, K., Wen-lei, S., Shou-dong, W., & Zhao- bo, L.. Analysis of the sitting posture comfort based on motion capture system and jack software. *2017 23rd International Conference on Automation and Computing (ICAC)*, 1–7. https : / / doi . org / 10 . 23919/IConAC.2017.8081987, 2017.
Quattelbaum, B., Stylidis, K., Braun, A., & So¨derberg, R.. Preliminary study on perceived comfort of car seats: A quantitative approach to visual cues. Procedia CIRP, 104, 116–121, 2021.
Romli, F. I., & Aminian, N. O.. Ergonomic analysis of aircraft passenger seat: A malaysian case study. International Journal of Pure and Applied Mathematics, 119(15), 3749–3754, 2018.
Song, Y., Mao, F., & Liu, Q.. Human comfort in indoor environment: A review on assessment criteria, data collection and data analysis methods. IEEE Access, PP, 1–1. https : / / doi . org/ 10 . 1109 / ACCESS. 2019 . 2937320, 2019.
Tack, D. W., McKee, K. W., & Linda Bossi, C.. Warfighter integrated physical ergonomics tool devel- opment, 2011.
Tang, C. Y., & Tsui, C. P.. Method of modeling muscular tissue with active finite elements [US Patent 7,096,166], 2006.
Teraoka, T., Mitsuya, R., & Noro, K.. Comfort in fur- niture at home. In Comfort and design (pp. 155–164). CRC Press, 2004.

Van Rosmalen, D. M., Groenesteijn, L., Boess, S., & Vink, P.. Using both qualitative and quantitative types of research to design a comfortable television chair. Journal of Design Research, 8(1), 87–100, 2009.

Van Veen, S., Hiemstra-van Mastrigt, S., Kamp, I., & Vink,
P.. Improving car passengers' comfort and experience by supporting the use of handheld devices. Work, 49(2), 215–223, 2014.

Verver, M., Van Hoof, J., Oomens, C., Wismans, J., & Baai- jens, F.. A finite element model of the human buttocks for prediction of seat pressure distributions. Computer methods in biomechanics and biomedical engineering, 7(4), 193–203, 2004.

Verver, M. M., De Lange, R., van Hoof, J., & Wismans, J. S.. Aspects of seat modelling for seating comfort analysis. Applied Ergonomics, 36(1), 33–42, 2005.

Volpe, Y., Governi, L., & Furferi, R.. A computational model for early assessment of padded furniture com- fort performance. Human Factors and Ergonomics in Manufacturing & Service Industries, 25(1), 90–105, 2015.

Zemp, R., Taylor, W., & Lorenzetti, S.. Are pressure measurements effective in the assessment of office chair comfort/discomfort. A review, 48, 2015.