Investigating the Effect of Seat Features and Cushion Material on Seat Comfort using Finite Element Analysis

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Abstract

The need for comfortable seats rises as individuals spend more time sitting to perform various activities. The design and material used for cushioning the chairs play an important part in the overall comfort experienced by the human. Traditional methods, like questionnaires, for evaluating seat comfort are not accurate since the interpretation of discomfort is subjective and varies from human to human. Thus, this study proposes a system that models humans of different anthropometry and seats of different designs and cushion materials using Computer Aided Design (CAD) and then evaluates seat comfort by testing the contact pressure between them using Finite Element Analysis (FEA) at early design stages without the need for physical prototyping.

Keywords
Seat comfort analysis, computer aided design, contact pressure, finite element analysis

Introduction
Importance of Seat Comfort
With the digital revolution automating manual work, human tasks are becoming less active as employees rely on computers for machine control and monitoring, which results in the employee being seated for a considerable amount of time during the day. The American Heart Association stated that sedentary jobs have increased by 83% since 1950, and a normal office worker sits for a shocking 15 hours in total every single day, while people with long commutes even more (Roberts 2019). This concludes the evident growth in people's need of having a comfortable seat that is well-designed to provide physical support and balanced posture.

Seats come in a variety of styles and designs. Nevertheless, there are basic features that must be present in a seat to ensure a minimum level of comfort to the person sitting, such as backrest, armrest, seat tilt, and cushion. Other features that are specific to flight seats include footrests, headrests, and seat pans. Another important factor that impacts the comfort of the seat is the material out of which it is made. Common seating materials include memory foam, rubber, neoprene, silicone, and plastic mesh. The cushion material can provide a range of flaccidity from soft air-filled cushions to hard surfaces. Properties of such materials play a major role in providing the required softness, elasticity, and robustness that affect the level of comfort.

Conventionally, seat comfort evaluation relies on the subjective assessment of individuals gathered using questionnaires, scales, or interviews to investigate their perception of the finished physical product. But due to the disparity of data that varies on a person's mood and the instability of a person's opinion, subjective assessments must be correlated with objective measures (Ulherr and Bengler 2017). As a result, objective evaluations are required to measure seat comfort and provide appropriate solutions to improve seat designs before production begins.

This paper proposes a system to assess seat comfort by running Finite Element Analysis (FEA) on Computer Aided Design (CAD) models of human mannequins and different seat designs and cushion materials to expedite the design process of new seats. The methodology considers the anthropometric dimensions of the sitters and studies the effect of seat features and seat cushion material on the overall seat comfort.

Problem Statement

Sitting for an extended period is a common act that people nowadays are experiencing daily whether while working, driving, riding trains, or attending short- and long-haul flights. Such a position contributes to back pain, physical aches, and other health complications, especially when wrong practices are followed, or incorrect types of equipment are used. Injuries resulting from such situations are serious and worrisome for occupational health and safety.

Hence, seat comfort analyses are important to ensure a healthy environment and the safety of individuals. Yet, most of the dependence on achieving such investigations steers toward the subjective output. Many issues arise when considering subjective information to instrument solutions, as subjective feedback does not guarantee effective remedies to the problem especially since the users do not necessarily understand the factors that cause discomfort. Making changes to the finished product is also a difficult task that is costly and requires significant consumption of resources (Amer and Onyebueke 2013).

Therefore, objective analyses are needed concurrently to assess seat comfort and propose correct solutions that improve seat designs and sitting postures. Proper solutions will be beneficial to multiple industries as this work aims to optimize the process of seat comfort evaluation for different seat features and cushion materials at early design stages without consuming resources such as manpower, time, material, factory space, etc.

Objectives

The main objective of this research is to propose a single system integrating CAD and FEA simulation to assess the comfort of various seat designs and different human body postures with feasible enhancement over traditional evaluation methods.

The proposed system allows the evaluation of seat comfort for human models of various anthropometric dimensions with respect to the diverse population, without the need to build multiple prototypes. Based on the experiment, designers and engineers will have a tool to help them determine the best seat configuration while taking into account multiple factors that affect seat comfort, such as seat features and cushion material, to ensure occupants' comfort and wellbeing while sitting.

The expected contributions of this study will enrich the comfort assessment process for new seats, and recommendations will be made on how to improve seat comfort assessment in the early design stages without the exploitation of resources.

Literature Review

The topic of seat comfort is widely discussed in multiple industries such as automation, biomechanical and aviation, and it has been found that there are several mediating factors that directly influence the comfort of the seat.

Effect of Seat Features and Contact Pressure on Seat Comfort

Measuring the contact pressure between the human and the seat has been widely used a way of evaluating the level of comfort provided, and according to many researchers, the relation between them is contrary to each other such that reducing the contact pressure induces better comfort (de Looze et al. 2003). Correspondingly, attaching features on the seat are found to increase the contact area between the human and the seat, and hence brings about more comfort (Hix et al. 2000). For instance, Carcone and Keir (2007) indicated that the seat pan comfort ranking was higher when the contact area was large, and Noro and Fujimaki (2005) discovered that lower average pressure results in less discomfort.

Effect of Anthropometry on Seat Comfort

It is important to point out that the seat does not solely affect the comfort of the person sitting, but the anthropometry of the person plays a major role as well. Branton and Grayson (1967) observed train passengers and found 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, Teraoka, et al. (2004) performed a study on home furniture and came to find that short people were more likely to have less foot contact with the floor or with the backrest in combination with a slumped posture compared to taller people.

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Seat Comfort Analyses

The evaluation process itself is divided into two approaches: subjective and objective. Firstly, the subjective assessment is done by conducting questionnaires, scales, and interviews to study the perception and point of view of individuals and then used to develop objective assessment methods. The objective assessment usually includes physical prototyping, physical measurement, or the involvement of humans to evaluate seat comfort and propose correct solutions that improve seat designs, sitting postures, and proper sitting practices.

Menegon et al. (2017) proposed a scale to measure the comfort of aircraft seats using item response theory. The sample consisted of 1500 questionnaires filled by passengers at a Brazilian airport. The scale generated covers all levels of comfort from 'no comfort' to 'maximum comfort, allows comparison of passenger's comfort from different populations or passengers from the same population in different situations. Park et al. (2015) found during their study about the comfortable driving posture of Koreans using 3D scanning technique that despite the satisfaction of the participants with the overall seat comfort, their pressure distribution showed the opposite, emphasizing that manufacturers need to consider the pressure distribution besides the preferred driving postures when designing a new automobile seat. Amer and Onyebueke (2013) introduced a technique with the use of Quality Function Deployment (QDF) and CAD to translate customer requirements into design parameters to establish a seat comfort level based on design analysis before production. Ciaccia and Sznelwar (2012) analyzed pressure maps to study the comfort of an aircraft seat in a simulator that represented the interior of a commercial aircraft for two different activities, which are reading and resting. They also adopted postures during the experiment as well as the participant's discourse after the experiment. Results showed that participants adopted similar postures despite the difference in their anthropometry. The method also identified strategies used by participants to reduce the state of discomfort, and their perception after the experiment was crucial to interpreting the postural changes and helped identify areas of improvement in the design of the seat.

Based on the literature surveys, it is evident that the topic of seat comfort remains to be a matter of great debate. This research focuses on reducing the consumption of resources and allowing the designers to test multiple seat configurations for various anthropometries at once to avoid wasting time on testing physical prototypes in real life.

Methodology

The primary methodology used in this study uses SolidWorks® for modeling the human mannequins and seats using CAD. To fabricate the human models in the CAD system, the anthropometric dimensions of the Asian-Indian population were considered as they represent most of the population in the UAE. These models were also simulated with the proper quasi-linear viscoelastic material properties that allow its interaction with external loading to behave like human flesh and bone (Tang and Tsui 2006). Finite Element Analysis (FEA) was then applied to study the contact pressure between the human models and seats as an indication of the comfort level.

Results and Discussion

Graphical and Numerical Results

The five different seat designs studied can be seen in Figure 1 below.

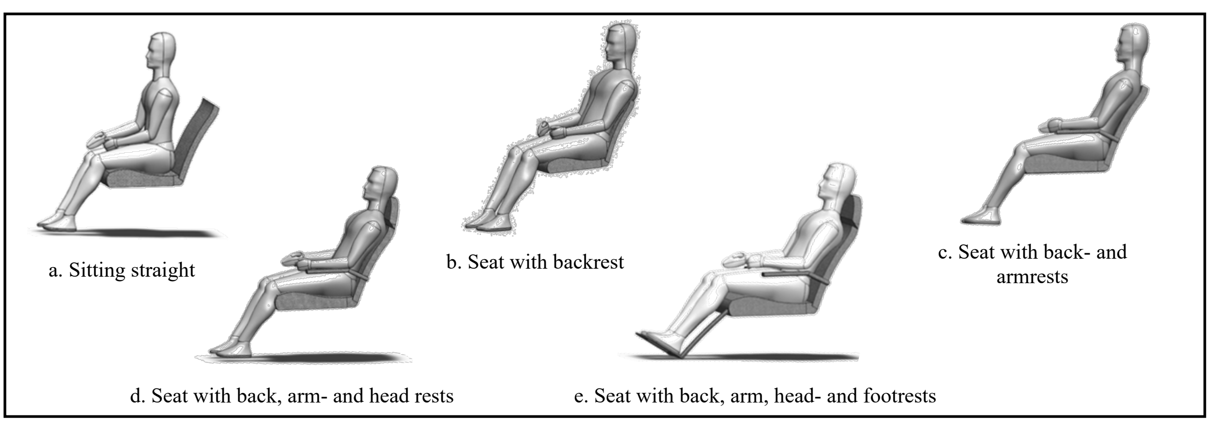

Figure 1. Different seat designs and postures

The initial model consisted of the human mannequin seated in an erect position with no back support. The contact between the human and the seat was mainly distributed over the seat pan only. Then, the mannequin rested on the backrest with 110° back inclination. Following this, the armrest, headrest, and footrest were also added. The effect of different seat features on seat comfort was studied first by running FEA on different seat designs. A sample of the FEA output for a male model in the 50th percentile can be seen in Figure 2 below.

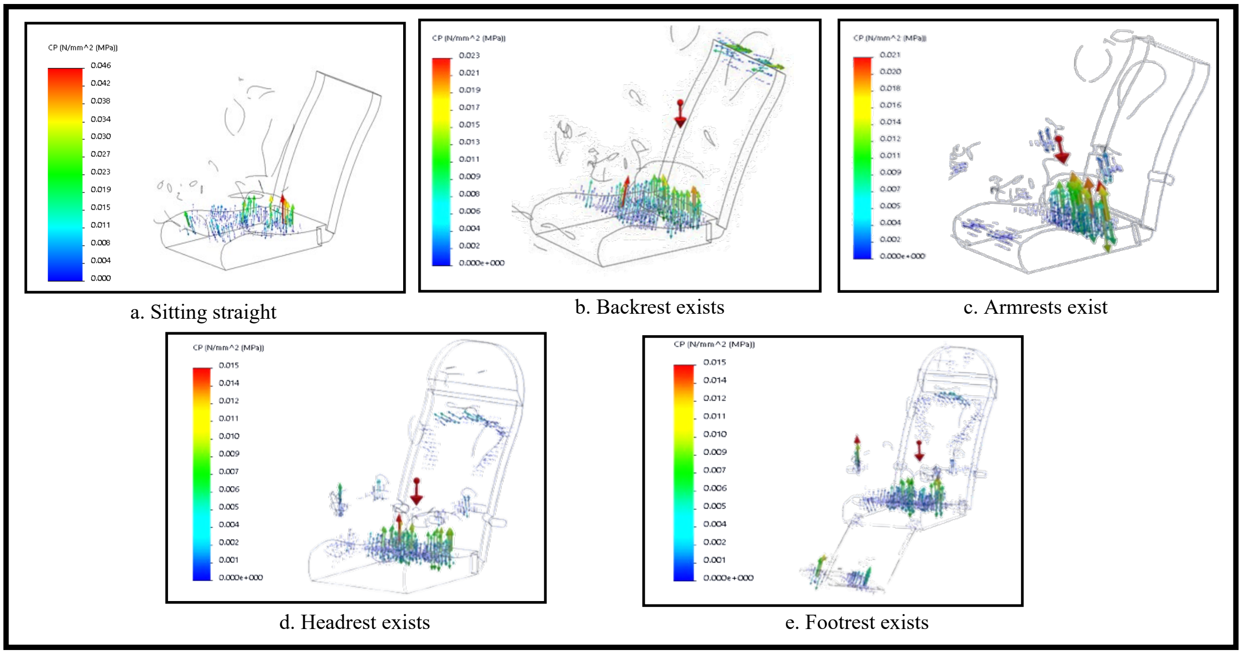

Figure 2. FEA output for a male model in the 50th percentile

The second set of results illustrates the effect of cushion material on the peak contact pressure detected between different seat designs and human models.

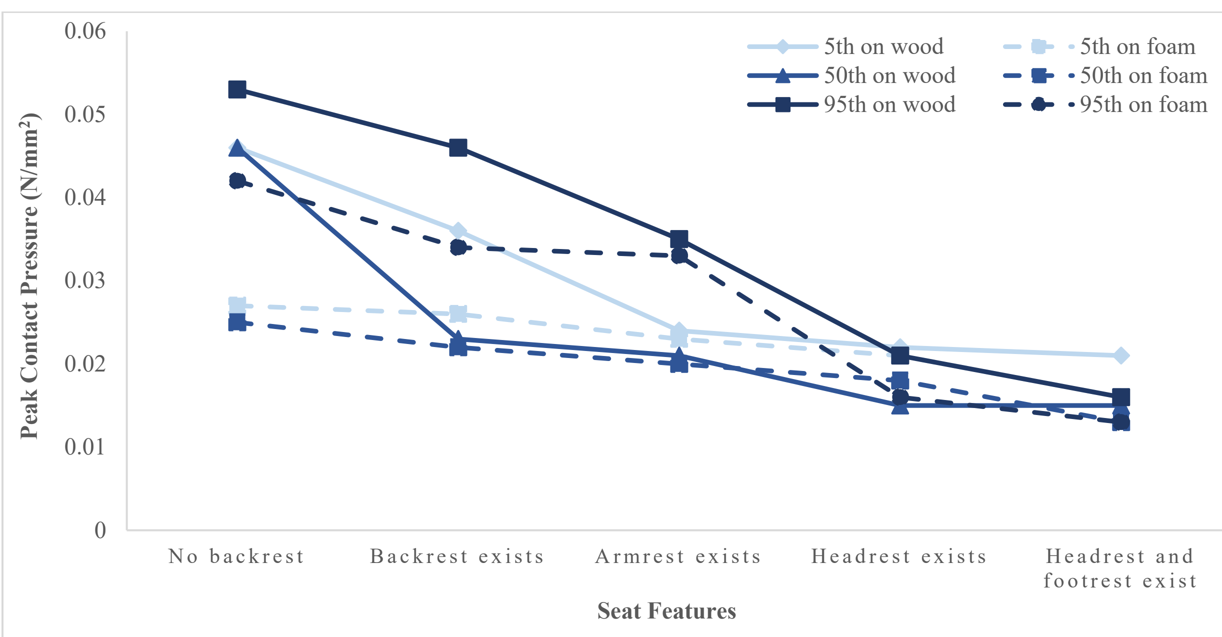

Figure 3. Effect of cushion material on peak contact pressure in males

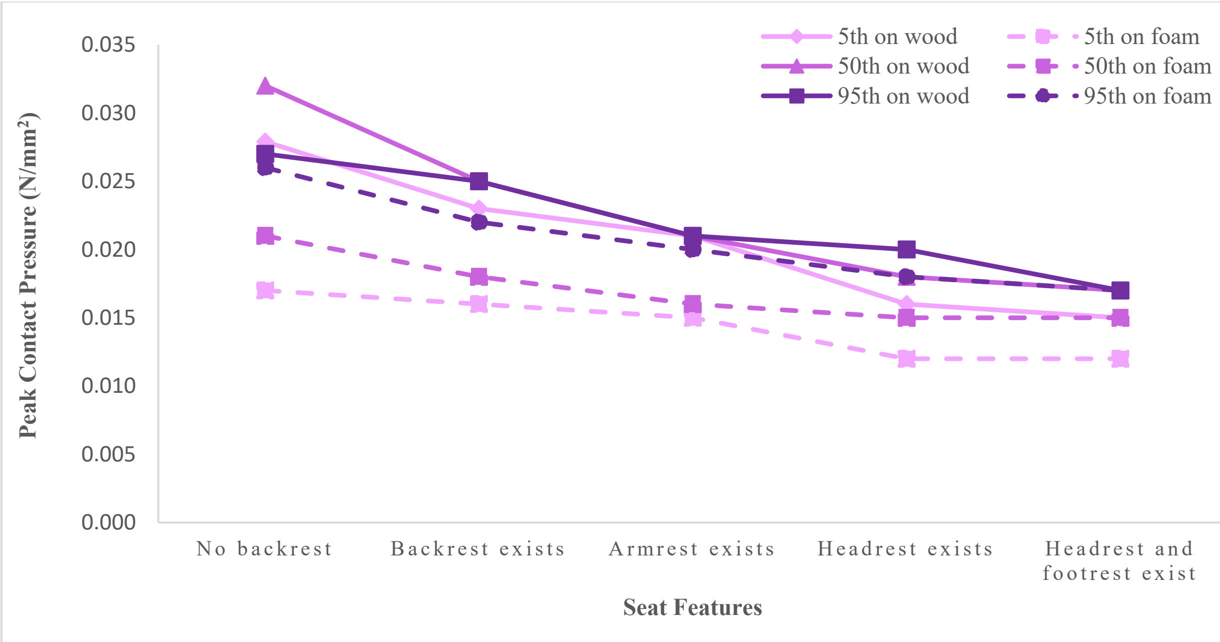

Figure 4. Effect of cushion material on peak contact pressure in females

Figure 3 and Figure 4 showcase the different values of peak contact pressure detected for each of the male and female human models, respectively, on different cushion materials. Sitting on memory foam induced better comfort for the same design of the seat, and the peak contact pressure was further reduced as more features were attached to the seat. For example, a male model in the 50th percentile sitting straight on a wooden surface without leaning on the backrest illustrated a peak contact pressure equal to 0.046 N/mm², which was about two times higher than the peak contact pressure detected when seated on the same seat design but with a cushion made of memory foam. In parallel, a female model representing the 50th percentile sitting on a memory foam cushion when leaning on the backrest and placing arms on the armrest was almost lower by 24% than the peak contact pressure detected when sitting on a hard cushion surface. In conclusion, results indicate that as the seat is provided with more features and a softer surface, the maximum contact pressure detected is reduced, indicating more comfort being provided to the object sitting as the contact pressure between the human and the seat gets distributed over the seat features.

When comparing the results to the literature, they are on par with the findings of Mohanty and Mahapatra (2014), who proposed a finite element approach to investigate the behavior of various types of cushion materials and thicknesses without incurring costly experimental costs to help practitioners in determining the type of cushion to use to lessen the risk of developing a pressure ulcer while sitting for lengthy periods. Although they considered the time of sitting as a factor affecting the stress level, their results also showed that less stress was developed on the ischial tuberosity when seated on a cushion made of polyurethane foam than on a rigid surface and that the tissue muscles take relatively longer time to become stiffened when interacted with soft cushion than that of the rigid seat. In addition, Yadav et al. (2021) employed an FE biomechanical model to aid seat comfort design along with cushion material selection, and their results indicated that a seat cushion design with a single type of foam might lead to essentially different biomechanical responses of the human body while sitting.

Validation

The CAD technique was validated using the Tekscan™ pressure mapping system. The human subjects who participated in the experiments represented the Asian-Indian population and hence the human mannequins modeled in the CAD environment. Figure 5 shows a sample of the CAD versus PMS output for a male subject representing the 50th percentile when sitting on an aircraft seat having back, arm- and headrests.

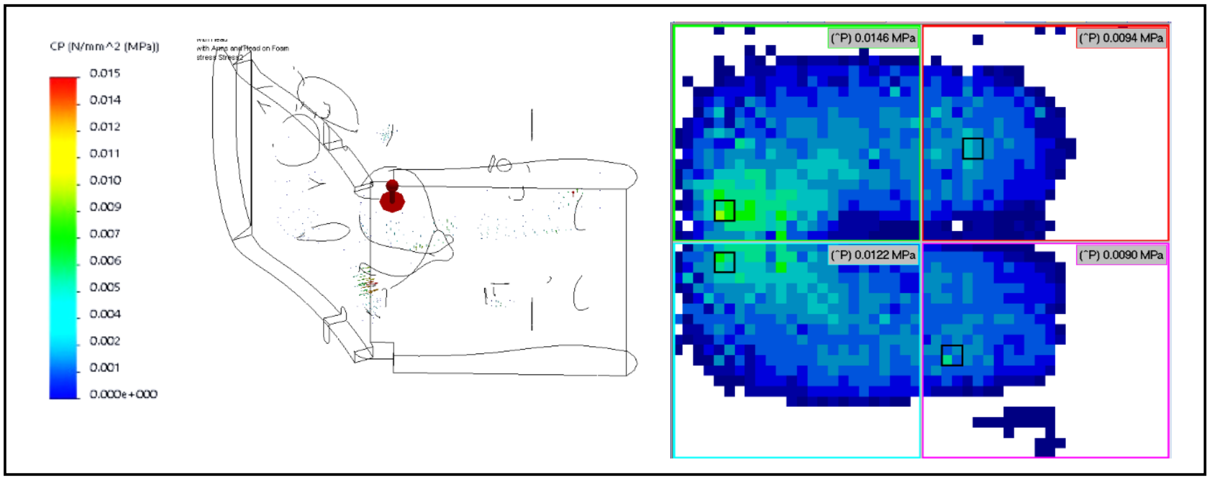

Figure 5. CAD versus pressure mapping system

The difference in contact pressure between both techniques was studied to indicate if there was any significant difference between them, and so a paired T-test was performed.

Table 1. Differences between CAD and pressure mapping system values

CAD (N/mm^2)	PM (N/mm^2)	Error (N/mm^2)
0.021	0.0199	0.0011
0.018	0.0164	0.0016
0.016	0.0151	0.0009
0.015	0.0146	0.0004
0.025	0.0265	-0.0015
0.022	0.0226	-0.0006
0.02	0.0196	0.0004
0.018	0.018	0.000
0.027	0.0285	-0.0015
0.026	0.0251	0.0009
0.023	0.0239	-0.0009
0.021	0.022	-0.001

The ***null hypothesis*** is that the difference in means is equal to zero:

$$\mathbf{H_o}: \mu_1 - \mu_2 = 0$$

The ***alternative hypothesis*** is that the difference in means is not equal:

$$\mathbf{H_1}: \mu_1 - \mu_2 \neq 0$$

were μ_1 is the mean of CAD and μ_2 is the mean of PMS.

For a two-tailed test with significance level of 95%, the p-value (0.958) was higher than 0.05, hence we fail to reject the null hypothesis concluding that there was no significant difference between CAD and PMS indicating an insignificant effect on the comfort assessment process.

Conclusion

Cushions, seat backs, armrests, headrests, and footrests are major parts of many seat designs that aim to provide more comfort to humans, but due to the frequent physical prototypes required to satisfy all customer needs the process of developing a new seat or modifying an existing one is an intricate, costly, and time-consuming task. In addition, measuring and evaluating comfort, particularly in the subjective area, is a difficult task for designers.

This research proposes a system of seat comfort assessment that can replace the costly conventional comfort evaluation methods and expedite the design process with minimum consumption of resources by using CAD to model seats and human bodies with various anthropometric dimensions in different sitting postures and then detect the contact pressure using FEA, followed by a simple validation in the real-world utilizing pressure mapping. By varying the seat features and material of the cushion through built-in libraries in CAD, the system can explore different seat designs and propose the optimum combination for the best sitting comfort.

Validations reveal a 98% correlation between the numerical and experimental techniques, broadening the comfort evaluation metrics and enhancing the efficiency of the design process. Using the proposed system, designers can simply test a variety 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 and waste resources.

This presented study was limited to the Asian-Indian population and analyzed seat comfort for two different cushion materials only. Future development of this work will consider a wider selection of cushion materials and study the influence of changing the parameters of seat features. The study shall also integrate human factors simulation to study the comfort of different human postures with respect to various seat designs. A motion capture system is to be used to validate the virtual environment by detecting the human body joints in diverse sitting postures and then assessing their posture comfort using a comfort assessment tool. This will pave the way for research on human factors simulation for assessing comfort of human body posture.

References

Amer, S., & Onyebueke, L. The Integration of Quality Function Deployment and Computer Aided Design in Seat Comfort Design and Analyses. *In ASME International Mechanical Engineering Congress and Exposition*, Vol. 56413, p. V012T13A011, 2013.

Amer S, Onyebueke L., Experimental validation of the computer aided design technique for seat comfort design and evaluation, *SAE Technical Papers*, vol. 2, SAE International; 2013.

Branton, P., & Grayson, G. An evaluation of train seats by observation of sitting behaviour. *Ergonomics*, 10, 1, pp 35-51, 1967.

Carcone SM, Keir PJ., Effects of backrest design on biomechanics and comfort during seated work, Applied Ergonomics 2007;38:755–64.

Ciaccia, F. R. D. A. S., & Sznelwar, L. I. An approach to aircraft seat comfort using interface pressure mapping. *Work*, 41, 1, pp 240-245, 2012.

Hix K, Ziemba S, Shoof L., Truck Seat Modeling- A Methods Development Approach. *International ADAMS User Conference,* 2000.

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

da Silva Menegon, L., Vincenzi, S. L., de Andrade, D. F., Barbetta, P. A., Merino, E. A. D., & Vink, P. Design and validation of an aircraft seat comfort scale using item response theory. *Applied Ergonomics*, 62, 216-226, 2017.

Mohanty, P. P., & Mahapatra, S. S. A finite element approach for analyzing the effect of cushion type and thickness on pressure ulcer. *International Journal of Industrial Ergonomics*, 44, 4, pp 499-509, 2014.

Noro, K., Fujimaki, G., & Kishi, S. A theory on pressure distribution and seat discomfort. Comfort and Design, pp 33-39, 2005.

Park SJ, Min SN, Subramaniyam M, Lee H, Shin YK, Jang CH, et al., Driving Posture Measurement using 3D Scanning Measuring Technique. *SAE International Journal of Passenger Cars - Mechanical Systems*, 8, pp 600–605, 2015.

Roberts N. Americans Sit More Than Anytime In History And It's Literally Killing Us., Forbes 2019. https://www.forbes.com/sites/nicolefisher/2019/03/06/americans- sit-more-than-anytime-in-history-and-its-literally-killing-us/?sh=5b26114b779d (accessed April 5, 2021).

Tang CY, Tsui CP., Method of modeling muscular tissue with active finite elements 2006.

Teraoka, T., Mitsuya, R., & Noro, K., Comfort in furniture at home. *Comfort and Design*, pp. 155-164, 2004.

Ulherr, A., & Bengler, K., Seat assessment–a discussion of comfort and discomfort models and evaluation methods. *1st international comfort congress ICC*, 2017.

Yadav, S. K., Huang, C., Mo, F., Li, J., Chen, J., & Xiao, Z., Analysis of seat cushion comfort by employing a finite element buttock model as a supplement to pressure measurement., *International Journal of Industrial Ergonomics*, 86, 103211, 2021.

Biographies

Hala Bermamet holds a master's degree in Engineering Systems and Management from Khalifa University, UAE. She earned B.S. in Industrial Engineering from the German Jordanian University, Jordan. She has experience working as a procurement intern for surface treatments of automotive parts at Robert Bosch GmbH, Germany, and then as a full-time market research analyst in the customer experience and channel performance department at Ipsos, Jordan. Her research interests include supply chain optimization, data analytics, as well as studying the integration between seat comfort analyses and human factors simulation.

Shayaan Syed is currently pursuing his master's in Engineering Systems and Management from Khalifa University, UAE. He is enrolled with a full scholarship and is on a combined track for Master's in science and Doctor of Philosophy. He has a Btech in Mechanical Engineering from Mumbai University, India and has experience working as a process designer for Tebodin Bilfinger pvt ltd. His research interests, at present, concerns with warehouse operations and their impact on human body as well as comparative analysis of waste management systems.

Saed Amer is an Assistant Professor at Khalifa University. His research focuses on computer integrated manufacturing and robot-controlled nondestructive testing. He also worked on sustainability metrics research and systematic measures to enforce engineering sustainability education. His previous work included seat comfort analyses for Boeing aircrafts and robotics solutions for Unexploded Ordnance (UXO) remediation. Finally, Dr. Amer worked on simulation solutions for hybrid renewable energy research. Further, he earned his Doctor of Philosophy in Computer and Information Systems Engineering with a concentration on Computer Integrated Manufacturing Systems in August 2012 from Tennessee State University, USA.