ERGONOMIC STUDY ON CAR SEAT DESIGN TO IMPROVE THE COMFORT OF MALAYSIAN DRIVERS

MUGILAN A/L MURALITHARAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

School of Mechanical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

APRIL 2022

DEDICATION

To my beloved parents, to my caring and beloved partner, to all my friends and companions, to those who helped me, thanks for everything.

ACKNOWLEDGEMENT

Thank you to the one whom have blessed me this life for giving me courage and patience in finishing this research. I am motivated by the great deal of support initiating from Appa, Amma and Murvin as well motivation along my journey to prepare this thesis. I wish to express my sincere gratitude to my main supervisor, Assoc Professor Dr. Syed Ahmad Helmi bin Syed Hassan, for his guidance and encouragement in completing this thesis. Besides, I am also thankful to my co-supervisor Dr. Kamarulafizam bin Ismail who gave me various input and ideas to further my studies in master research.

Thank you to all NIOSH Ergonomic Department as well my respondents who are willing to sacrifice their time for the success of this study. Nevertheless, my wife to be, Tharishinny Raja Mogan as well my friends Logadhasan Suwedan, Duraisamy Ramachandar, Loganathan Krishnan, Vivekanathan Ganason, Seridran Gunaisegaran, Puvanesan Velayutham, Kuhilan Selvarajoo and Naavin Tamil Chelvam for the encouragement and made me believe that I can make it. I will never forget all the help. Looking forward for the best to be in return for all.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member

ABSTRACT

Apart from the aesthetic value of automobile design, being safe and providing comfort to the occupants are among the selling points of car manufacturers. However, poor pressure distribution with constrained posture in terms of long driving hours and cramping with limited space upon the vehicle packaging factor would lead to musculoskeletal disorders. The present work was aimed at changing the mainstream padding material for car seats to the concern on having greater pressure distribution as well considering Malaysian anthropometry measurement to reduce musculoskeletal disorders. First, the adequacy of driver seats from commonly used vehicles in Malaysia was measured and the dimensions were compared with the Malaysian anthropometric database. The result showed that the ergonomic aspects of the driver seats designed are in compliance with the standard based on the database. This finding was triangulated with previous studies that found that the dimensions for most commonly used cars in Malaysia do follow the Malaysian anthropometry data. Secondly, to scrutinize the finding, the common types of driving posture of Malaysian drivers from the previous studies were extracted and assessed by an ergonomic tool. The posture scores were analysed according to the Rapid Upper Limb Assessment (RULA). These posture scores indicated that they were in the medium risk range. Thus, the driver seat could be improved to make it more ergonomic and comfortable. Lastly, the ergonomic improvement and driving comfort were established through the modification of seat cushion foam. The designed seat was analysed through pressure distribution and subjective assessment over 30 respondents who sat on the modified car seat for at least 60 minutes. The differences in peak pressures recorded between the original and modified seats showed an average of 2 kPa pressure reduction for the 95th percentile, 4 kPa for the 5th percentile, and 3 kPa for the 50th percentile. The improvement in the comfort level was also proven when 23 of the 30 respondents commented on the comfortness over sitting on the modified seat for 60 minutes. It is ascertained that the new seat foam with the designed pressure distribution could be a niche for providing better ergonomic posture and increasing drivers' comfortness.

ABSTRAK

Selain dari nilai estetik pada reka bentuk kereta, aspek keselamatan dan keselesaan juga merupakan antara faktor yang menjadi daya tarikan oleh pengeluar kereta. Taburan tekanan yang lemah daripada kekangan postur akibat pemanduan jangka panjang, ditambah pula dengan ruang tempat duduk yang terhad berdasarkan reka bentuk sesebuah kereta boleh mengundang kepada gangguan muskuloskeletal. Penyelidikan ini adalah bertujuan untuk menukar bahan pelapik untuk kerusi kereta dengan menimbangkan data pengukuran antropometri Malaysia. Sebagai langkah pertama di dalam kajian ini, dimensi kesesuaian reka bentuk tempat duduk pemandu bagi model kereta yang biasa digunakan di Malaysia telah diukur berpandukan kepada sistem data antropometri Malaysia. Keputusan kajian mendapati bahawa aspek ergonomik reka bentuk tempat duduk pemandu kereta adalah memenuhi piawaian berdasarkan kepada data antropometri Malaysia. Keputusan ini juga telah ditriangulasikan dengan kajian-kajian yang lepas yang menunjukkan bahawa kebanyakan dimensi reka bentuk kereta di Malaysia mematuhi data antropometri Malaysia. Seterusnya, untuk meneliti hasil kajian beberapa jenis postur pemanduan biasa pemandu Malaysia daripada kajian terdahulu telah disaring dan dikaji dengan menggunakan alat ergonomik. Skor postur dianalisis berdasarkan *Rapid Upper Limb Assessment* (RULA). Hasil skor postur mendapati bahawa semua jenis postur berada dalam kategori sederhana. Oleh itu prestasi ini masih boleh ditingkatkan untuk mendapatkan postur pemanduan yang lebih ergonomik. Akhirnya, penambahbaikan dari segi reka bentuk kerusi yang lebih ergonomik dan menambah keselesaan pemanduan telah diusahakan melalui pengubahan pada kusyen tempat duduk pemandu. Kerusi yang telah direkabentuk telah dianalisa melalui taburan tekanan dan penilaian terhadap 30 responden yang menduduki kerusi kereta yang telah diubah suai untuk sekurang-kurangnya selama 60 minit. Perbezaan tekanan yang direkodkan antara kerusi asal dan kerusi yang diubah suai menunjukkan purata pengurangan tekanan sebanyak 2 kPa untuk persentil ke-95, 4 kPa untuk persentil ke-5, dan 3 kPa untuk persentil ke-50. Penambahbaikkan dalam paras keselesaan telah terbukti dengan 23 daripada 30 responden mengakui keselesaan apabila duduk selama 60 minit di kerusi yang telah diubah suai. Telah dipastikan bahawa kusyen tempat duduk baharu yang diubah suai mempunyai taburan tekanan yang lebih baik dan ini memberikan peluang untuk menghasilkan postur yang lebih ergonomik serta meningkatkan keselesaan pemandu.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ERA	-	Ergonomic Risk Assessment (ERA)
MSD	-	Musculoskeletal Disorder
RULA	-	Rapid Upper Limb Assessment
REBA	-	Rapid Entire Body Assessment
DHM	-	Digital Human Model
LBP	-	Lower Back Pain

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

It requires much patience and energy to drive a car than it does to be driven, therefore the driver's seat is the utmost importance in the manufacturing process so the driver will be alert and conscious to control their vehicle (Deros et al., 2015). It is the driver who gets more fatigue than the passenger which is a serious issue for drivers (Jhinkwan and Singh, 2014). Automotive seat design do challenge engineers in every way as increasing parameters are applied to design on every day basis (Shivakumar, Kamat and Prakash, 2016). Figure 1.1 shows an overview of the existing automobile seat market (Shivaji, 2013).

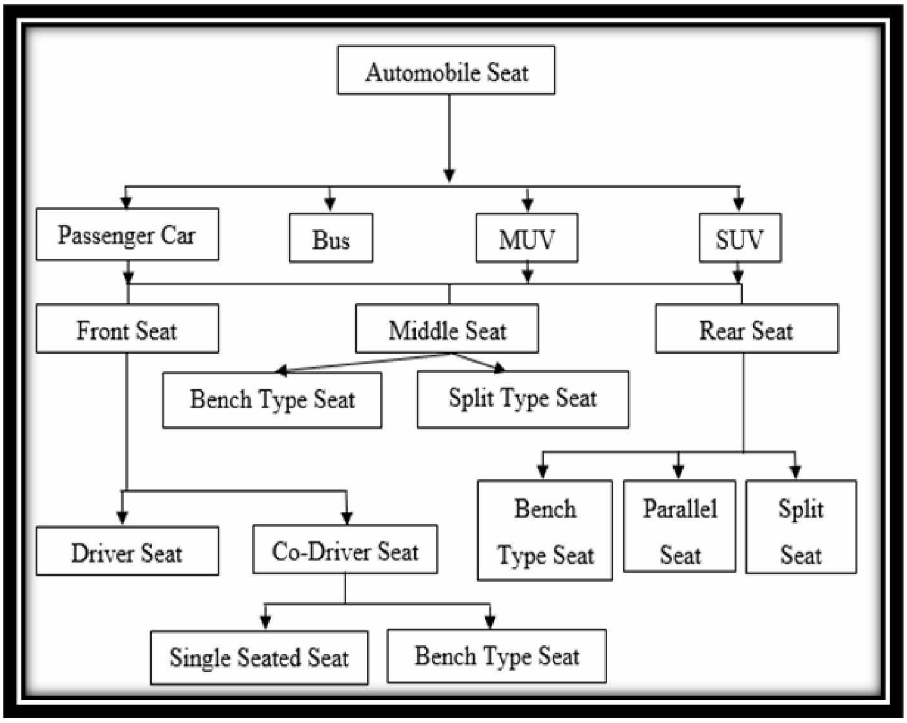

Figure 1.1 Flowchart of existing automobile seat in market (Shivaji, 2013).

Design parameters can be categorized into three main categories, fit parameter, feel parameter and support parameter (Rajeshkumar, 2008). Fit parameters are related to populations. Secondly, feel parameters are related to physical contact including pressure distribution. Finally, the contours of the seat and its adjustment affect the posture of the occupant. Driver body height influences anthropometric measurements and surrounding that are essential to safe car control. For instance, tall drivers than the averaged ones will feel cramped due to safety belts for a possibility of injury. The number of airbags is increased and possible head and spine injury can occur (Pdbiad, 2010). Some of the effects on driving posture are seat height, steering wheel position, and seat cushion angle which essentially independent of body composition and gender. (Reed et al. 2000).

Automotive car seat are seats that are built with major objectives in mind; they must be visually attractive, safe, supportive and pleasant (Mike Kolich, 2014). The primary function of a vehicles driver's seat is to allow the driver to safely and comfortably complete the driving job within reach of hand (Smith, Mansfield, and Gyi, 2015). The frame, cushioning, seat belt, height adjustment, fore and after modification, as well as seat pan, head restraints system, reclining system with lever trim (seat cover) and suspension., are all major components of the driver seat as depicted in Figure 1.2 (Kale and Dhamejani, 2015).

The adjustability capacity of the seat with steering wheel is closely dependent to two extreme human sizes; 5^{th} percentile woman and 95^{th} percentile man (Mircheski, Kandikjan, and Sidorenko, 2014). Adjustable backrest, adjustable seat top and bottom are recommended. This is to ensure drivers with shorter stature can reach accelerator and brake pedals while the seat back is adjustable for shorter and taller person (Rifano et al., 2018).

Figure 1.2 Cut section of driver seat components and systems (Kale and Dhamejani, 2015)

Part of automobile seat which has been illustrated in Figure 1.3, whereby vehicle package is a primary determinant defined by roominess, headroom, leg room, shoulder room and hip room (Rajeshkumar U. More, 2008). Thighs, buttocks, lower and upper back, and head support are all supported by a conventional vehicle seat. When it comes to creating a vehicle seat, it's critical to fulfil a number of OEM criteria (Shivakumar et al., 2016). Several measurements, such as eyellipse, H-point and others are used to describe driver's position. The H-point is defined by the eyellipse which represents the field of vision. The H-point, also known as hip point, is the junction of the torso and thigh lines (Shivakumar et al., 2016).

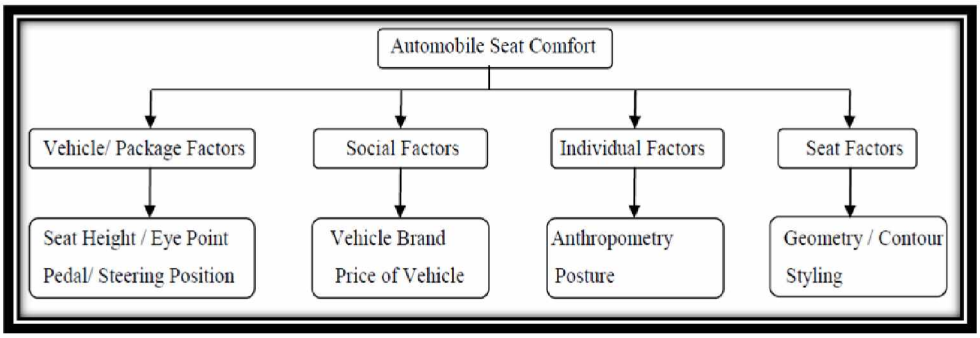

Figure 1.3 Factors affecting automobile seat comfort (Rajeshkumar U. More, 2008).

Existing seats are mostly composed to fit driver with comfort. Open cell polyurethane (PUR) has become the ideal material for automotive seat cushion manufacturing as compared to traditional steel spring support structures since it has a much lower weight/performance ratio (Patten, Sha, and Mo, 1998). Discomfort is more related to experience, emotion, unexpected features and luxury (Kamp, 2012). Comfort has always been a major concern, especially for those who work in the transportation industry. Seats with firm cushions, especially those with significant side lumbar support, may be considered "sporty," whilst seats with softer cushions may be considered "luxurious" (Beard and Griffin 2016). Therefore, foam manufacturers must figure out the most suitable foam for comfort as well keeping in mind support and safety of the driver.

Many aspects should be considered while optimising the design of a seat, including the form, breadth, and height of the seat pan and backrest, as well as seat cushioning, all of which have the ability to affect both the static and vibration discomfort of seat passengers (Beard and Griffin, 2016). Electromyography, disc pressure measurement, vibration transmissibility, pressure distribution at the occupant-seat interface, and microclimate at the occupant-seat interface have historically been used to quantify physiological variables that deal with muscles, spinal discs, joints, and skin (Fazlollahtabar, 2010). The seat or bed must provide enough body support while also contouring to provide an equal distribution of contact pressure on the body (Hänel, Dartman, and Shishoo, 1997). Skin intolerance to pressure sensitivity could lead to less discomfort.

Figure 1.4 shows the element of importance of driving seat. First is the driver's seat should provide clear vision and ability to reach all vehicle control. Secondly, provide proper back support, head rest, and thigh support, but there should be no limitation during arm or leg movement. Thirdly, the driver's seat should provide adequate back support, head rest, and thigh support, and there should be freedom during arm or leg movement and fit the drivers' body composition. Fourthly, it should become comfortable with time. Lastly, provide safety zone for the driver in the event of an accident (Mandal, Maity, and Prasad, 2015).

Figure 1.4 The model of criteria to be considered for driver to fit driver's seat ergonomically (Marek and Siebertz, 2014).

Measurement for seat width, pan length and backrest height to design an automotive car seat would be influenced by anthropometry data such as the shoulder height, hip breadth, and popliteal height. A number of limitations are strictly geometrical, resulting from the dimensions of the human body, which is a separate study known as "Anthropometry." (Wilson 2014)(Wilson, 2014). Although both seat dimension and anthropometry measurement have been considered in Table 1.1 and Figure 1.5 to design a seat, the seats could not provide comfort as well remedy for backache.

Table 1.1 Seat dimensions and related anthropometric measurements (Reed, 2000)

Seat Dimension	Anthropometric Measurement
Cushion Width (A)	Seated Hip Breadth (A)
Cushion Length (B)	Buttock-to-Popliteal Length (B)
Seat Height (C)	Popliteal Height (C)
Backrest Width (D)	Chest Breadth (D) Interscye Distance*
Backrest Height (E)	Shoulder Height (E)

*Distance across back between the armholes of a garment

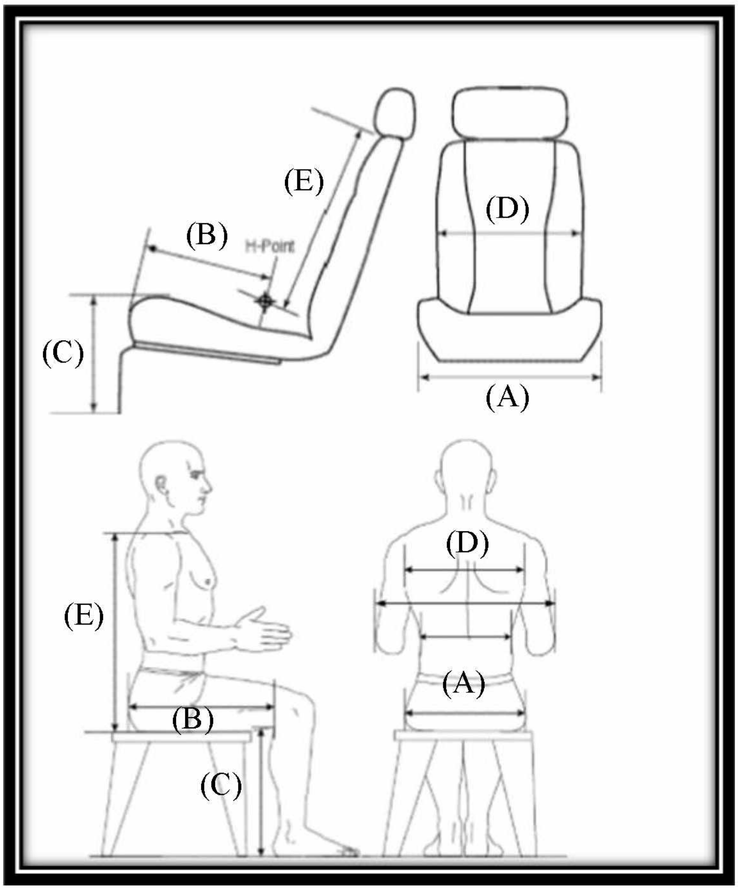

Figure 1.5 Related anthropometric dimension (Reed, 2000)

1.2 Problem Statement

Sitting can be main posture for many individuals, whom involve in office works, trucks and taxi drivers as well wheelchair users (Al-Dirini, Reed, and Thewlis, 2015). It is well recognized that constrained posture for a long-term exposure can risk health and lead discomfort (e.g., back, neck, and shoulder pain). This has a high societal cost in terms of lost work and lower job effectiveness/productivity, independent of the task or vibration exposure (Sammonds, Fray, and Mansfield, 2017) (Grujicic et al., 2009). According to the findings of a prior exploratory study, most drivers experience low back pain after driving (Rhimi, 2017). Adjustability factor, cushion material, headrest and cushion length are factors influencing comfort (Deros et al., 2015). Also, the presence of vibration induces a faster start of discomfort.

Material used to design a seat should not be neglected. Rigidity, pressure difference, and shape, as well as dynamic factors, are all important considerations produced by the seat's immediate environment (vibration). All has been taken into account while installing foam in the seat (Sammonds, Fray, and Mansfield, 2017). Comfort has been defined as a prevailing opinion concept with a static and dynamic component that can be objectively manifested in the context of automotive seating. A significant number of delegate people (aligned to the target customer/market in terms of diversity, anthropometry, and values) interpret the seat in the same way. Consistently quantifiable in support of his own experimental research (Mike Kolich, 2014).

According to a study, there is a link between low back pain and discomfort generated by sitting posture, which is explained by the fact that the intradiscal pressure imposed in this position is higher than the pressure created by standing (Rhimi, 2017).There are two technical paradigms of posture that may relate to musculoskeletal disorders (MSDs) including low back pain which is static posture involving maintaining the same posture for relatively long periods of time and awkward posture deviated from neutral position in search of comfort (Fadhli, 2016).

The combination between appointment carrying mode and vehicle seat design might be one source of pain (Filtness, Mitsopoulos-Rubens, and Rudin-Brown, 2014).

Even though the designed seat is examined to provide comfort and ergonomically fit humans, repetitive exposure to the vibration from the road does lead to some backache diseases. Many studies have found that whole-body vibration, as well as postural stress from uncomfortable and sedentary postures, may increase the risk of low back discomfort (Yokoyama et al., 2007).A good car seat design can increase driver comfort, performance, well-being, and safety by reducing musculoskeletal fatigue (Varela et al., 2019). The amount of knowledge of driver's seat design was compared, and virtually all participants (85%) reported to being aware on the level of comfort due to the seat design (Deros et al., 2015).

Occupational factors such as whole-body vibration, long working hours, limited driving space, total mileage, long distance driving, monotonous driving, time employed as a taxi driver, job dissatisfaction, and job stress may contribute injuries on low back pain and also related to MSD generally (Irwan Syah et al., 2020). Table 1.3 shows that the most prevalent musculoskeletal disorders during the past year were in the neck and waist for bus drivers and in the lower back, knee and shoulder areas for 275 bus drivers and 272 truck drivers based on the number of cases reported in a study at Ishafan, Iran. (Sadri, 2017). Numerous complaints obtained from past researchers among taxi drivers related to MSD especially on low back pain (Irwan Syah et al., 2020). Most of the MSD complaints received from both heavy vehicle drivers and taxi drivers are mostly on the lower back pain issue.

Despite the pressure distribution, posture analysis was also reviewed which may also lead to musculoskeletal disorder. MSDs increase significantly, possibly because longer work hours results in a longer period of maintaining a poor posture, increased exposure to high-pressure forces and more repetition (Dong et al., 2019).

Table 1.2 The prevalence of musculoskeletal disorders in different areas of the body among bus drivers and truck drivers (Sadri, 2017)

BODY PARTS	NO OF CASES REPORTED	PREVALENCE (%)
NECK	143	14.8
SHOULDER	134	13.92
ELBOW	38	3.95
HAND/WRIST	38	3.95
UPPER BACK	78	8.11
LOWER BACK	162	16.84
HIP AND THIGH	31	3.22
KNEE	134	13.93
LEG AND ANKLE	61	6.34

Therefore, this research will be an attempt to reduce problem faced by drivers upon pressure distribution. As well, this study also investigates the existing seat measurement with anthropometry measurement as the difference could also lead to discomfort for a prolonged duration.

1.3 Research Questions

The research was carried based on the research questions below:

(a) Does Malaysian anthropometry data of common car seat design is adequate for proper driving comfort level?

(b) What are the typical driving postures of Malaysian drivers?

(c) Does use of expanded polystyrene as car seat material improves driving comfort experience through subjective assessment and pressure distribution analysis?

1.4 Objective of Research

Manufacturers of car seats are concerned with the hardness of their seat cushions, mostly for user comfort. Moulding techniques developed for low density flexible foams have changed seat foam. The materials used in existing seat are polymers expanded by isocyanates. This foam has a latex/rubber-like feel, improved inherent flammability resistance, higher support factor, and most importantly maintains its resilience over the long term as well lower production temperature concluding less energy consumption. Isocyanate components do influence the hardness of foam.

This research will be an improvement method in changing the material to a much softer material which is Expanded Polystyrene (EPS) for the similar concern of each car manufacturers regarding comfort. This research is to change the mainstream padding material for car seats. To the concern of considering Malaysian Anthropometry measurement, the objectives of the study below will be achieved.

(a) To determine the adequacy of common car seat designs based on the anthropometry of Malaysian drivers for proper driving comfort level.
(b) To assess the typical driving postures of Malaysian drivers using RULA ergonomic analysis tool.
(c) To investigate the driving comfort improvement from the use of expanded polystyrene as the car seat material through experimental subjective assessment and pressure distribution analysis.

1.5 Research Scopes and Limitations

The scopes of work are as follows:

(a) The most driven car on Malaysian road is identified and the design principles are used to manipulate the foams.

(b) The driver seat changed with foams is later compared with over the pressure distribution where:

- The seated hip breadth will be compared with the cushion width.
- The buttock-to-popliteal length as well popliteal height will indicate the cushion length and seat height. The popliteal is the point of intersection between the knee and the back of the leg.
- Backrest width and backrest height seat dimensions are compared with chest breadth and shoulder height.
- The head rest angle as well knee angle was not considered in this study.

(c) Malaysian Anthropometry measurement is used as guideline to be compared on its suitability of other existing seats of commercial vehicle.

(d) The posture analysis was conducted based on ergonomic tools analysis.

(e) The seat of a commonly driven automobile has been modified and tested with respondents.

1.6 Summary

This chapter have explained the problem statement and the objective of this research. The details were then referred with some of previous studies which were mostly explained in next chapter. This research of finding an alternative foam that would replace existing foams could probably be an option to reduce MSD reported.

REFERENCES

Mike Kolich Ã, Essenmacher Steven D, and Mcevoy James T. 2005. "ARTICLE IN PRESS Automotive Seating : The Effect of Foam Physical Properties on Occupied Vertical Vibration Transmissibility" 281: 409–16. https://doi.org/10.1016/j.jsv.2004.03.058.

Al-Dirini, Rami M.A., Matthew P. Reed, and Dominic Thewlis. 2015. "Deformation of the Gluteal Soft Tissues during Sitting." *Clinical Biomechanics* 30 (7): 662–68. https://doi.org/10.1016/j.clinbiomech.2015.05.008.

Andreoni, Giuseppe, Giorgio C. Santambrogio, Marco Rabuffetti, and Antonio Pedotti. 2002. "Method for the Analysis of Posture and Interface Pressure of Car Drivers." *Applied Ergonomics* 33 (6): 511–22. https://doi.org/10.1016/S0003-6870(02)00069-8.

Azman Abdullah, Mohd, Abd Rahman Dullah, S Mat, Ma Abdullah, Ar Dullah, Sa Shamsudin, and MF Hussin. 2017. "Car Seat Design Using RULA Analysis," no. May: 1–2. https://www.researchgate.net/publication/322784146.

Beard, George F., and Michael J. Griffin. 2016. "Discomfort of Seated Persons Exposed to Low Frequency Lateral and Roll Oscillation: Effect of Backrest Height." *Applied Ergonomics* 54: 51–61. https://doi.org/10.1016/j.apergo.2015.11.010.

Bergs, Janis, and Daina Kanaska. 2012. "Motor Vehicle Seats and Their Defect Classification," 314–17.

Carvalho, Diana E De, and Jack P Callaghan. 2012. "In Fl Uence of Automobile Seat Lumbar Support Prominence on Spine and Pelvic Postures : A Radiological Investigation." *Applied Ergonomics* 43 (5): 876–82. https://doi.org/10.1016/j.apergo.2011.12.007.

Cascioli, Vincenzo, Zhuofu Liu, Andrew Heusch, and Peter W Mccarthy. 2016. "A Methodology Using In-Chair Movements as an Objective Measure of Discomfort for the Purpose of Statistically Distinguishing between Similar Seat Surfaces." *Applied Ergonomics* 54: 100–109. https://doi.org/10.1016/j.apergo.2015.11.019.

Cho, Jae Ung. 2016. "A Study on Safety Design through Static Analysis at Car Seat Frame" 130: 34–38.

Deros, Baba Md, Mohd Yusuff, Rosnah, Mohamad, Darliana, Yusoff, Ahmed Rithauddeen. 2013. *ANTHROPOMETRIC RESEARCH IN MALAYSIA*. Selangor: National Institute of Occupational Safety and Health (NIOSH), Malaysia.

Deros, Baba Md, Nor Hassanil Hanief Hassan, Dian Darina Indah Daruis, and Shamsul Bahri Mohd Tamrin. 2015. "Incorporating Malaysian's Population Anthropometry Data in the Design of an Ergonomic Driver's Seat." *Procedia - Social and Behavioral Sciences* 195: 2753–60. https://doi.org/10.1016/j.sbspro.2015.06.388.

Dong, Hongyun, Qiong Zhang, Guangzeng Liu, Tingguo Shao, and Yingzhi Xu. 2019. "Prevalence and Associated Factors of Musculoskeletal Disorders among Chinese Healthcare Professionals Working in Tertiary Hospitals: A Cross-Sectional Study." *BMC Musculoskeletal Disorders* 20 (1): 1–7. https://doi.org/10.1186/s12891-019-2557-5.

Fai, T C, F Delbressine, M Rauterberg, Universiti Teknikal, and Ayer Keroh. 2007. "[Mae] 008 VEHICLE SEAT DESIGN: STATE OF THE ART AND RECENT DEVELOPMENT 1" 2007: 51–61.

Fazlollahtabar, Hamed. 2010. "A Subjective Framework for Seat Comfort Based on a Heuristic Multi Criteria Decision Making Technique and Anthropometry." *Applied Ergonomics* 42 (1): 16–28. https://doi.org/10.1016/j.apergo.2010.04.004.

Filtness, A. J., E. Mitsopoulos-Rubens, and C. M. Rudin-Brown. 2014. "Police Officer In-Vehicle Discomfort: Appointments Carriage Method and Vehicle Seat Features." *Applied Ergonomics* 45 (4): 1247–56. https://doi.org/10.1016/j.apergo.2014.03.002.

Ghazalli, Zakri, Rizalman Mamat, Kumaran Kadirgama, and Shahrir Sani. 2016. "The Enhancement of Driver Seat Comfort for Small Size Car : A Preliminary Study ORIGINAL ARTICLE THE ENHANCEMENT OF DRIVER SEAT COMFORT FOR SMALL SIZE CAR : A," no. January 2017.

Grujicic, M., B. Pandurangan, G. Arakere, W. C. Bell, T. He, and X. Xie. 2009. "Seat-Cushion and Soft-Tissue Material Modeling and a Finite Element Investigation of the Seating Comfort for Passenger-Vehicle Occupants."

Materials and Design 30 (10): 4273–85. https://doi.org/10.1016/j.matdes.2009.04.028.

Hänel, Sven Erik, Torbjörn Dartman, and Roshan Shishoo. 1997. "Measuring Methods for Comfort Rating of Seats and Beds." *International Journal of Industrial Ergonomics* 20 (2): 163–72. https://doi.org/10.1016/S0169-8141(96)00049-2.

Hearon, Keith, and Pooja Singhal. 2013. "Porous Shape-Memory Polymers," no. May 2015. https://doi.org/10.1080/15583724.2012.751399.

Irwan Syah, M. Y., S. Ruhaizin, M. H. Ismail, and A. M. Ahmad Zuhairi. 2020. "Accessing Driving Posture among Elderly Taxi Drivers in Malaysian Using Rula and QEC Approach." *Malaysian Journal of Public Health Medicine* 20 (Specialissue1): 116–23. https://doi.org/10.37268/MJPHM/VOL.20/NO.SPECIAL1/ART.671.

Jhinkwan, Ankit, and Jaswinder Singh. 2014. "Design Specifications and Ergonomic Evaluation of Car Seat (A Review)." *International Journal of Engineering Research & Technology (IJERT)* 3 (5): 611–13.

Jie, Chen. 2015. "Ergonomics Analysis of Automobile Seat" 16 (March): 412–15. https://doi.org/10.19554/j.cnki.1001-3563.2015.22.036.

Kale, Hanumant N, and C L Dhamejani. 2015. "Design Parameters of Driver Seat in an Automobile." *International Journal of Research in Engineering and Technology* 4 (6): 448–52.

Kamp, Irene. 2012. "The Influence of Car-Seat Design on Its Character Experience." *Applied Ergonomics* 43 (2): 329–35. https://doi.org/10.1016/j.apergo.2011.06.008.

Kim, Dae Young, Jun Ho Bang, Chung An Lee, Heon Young Kim, Kwon Yong Choi, and Byung Guk Lim. 2018. "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: 178–87. https://doi.org/10.1016/j.ergon.2016.08.010.

Kolich, M. 2004. "Predicting Automobile Seat Comfort Using a Neural Network." *International Journal of Industrial Ergonomics* 33 (4): 285–93. https://doi.org/10.1016/j.ergon.2003.10.004.

Kolich, Mike. 2014. "Using Failure Mode and Effects Analysis to Design a Comfortable Automotive Driver Seat." *Applied Ergonomics* 45 (4): 1087–96.

https://doi.org/10.1016/j.apergo.2014.01.007.

Le, Peter, Joseph Rose, Gregory Knapik, and William S. Marras. 2014. "Objective Classification of Vehicle Seat Discomfort." *Ergonomics* 57 (4): 536–44. https://doi.org/10.1080/00140139.2014.887787.

Li, Wenhua, Suihuai Yu, Haicheng Yang, Huining Pei, and Chuan Zhao. 2017. "Effects of Long-Duration Sitting with Limited Space on Discomfort, Body Flexibility, and Surface Pressure." *International Journal of Industrial Ergonomics* 58: 12–24. https://doi.org/10.1016/j.ergon.2017.01.002.

Ligia, Silvana, Vincenzi Bortolotti, Izabel Carolina, and Martins Campos. 2012. "Comfort Model for Automobile Seat" 41: 295–302. https://doi.org/10.3233/WOR-2012-0172.

Mandal, Subrata Kr, A Maity, and Ashok Prasad. 2015. "AUTOMOTIVE SEAT DESIGN : BASIC ASPECTS," 62–68.

Marek, Clemens, Ford Werke Köln, Karl Siebertz, and Ford Forschungszentrum Aachen. 2016. *Ergonomics for Passenger Cars*. https://doi.org/10.1002/9781118354179.auto247.

Marek, Clemens, and Karl Siebertz. 2014. *Ergonomics for Passenger Cars*. *Encyclopedia of Automotive Engineering*. https://doi.org/10.1002/9781118354179.auto247.

Mehta, C. R., L. P. Gite, S. C. Pharade, J. Majumder, and M. M. Pandey. 2008. "Review of Anthropometric Considerations for Tractor Seat Design." *International Journal of Industrial Ergonomics* 38 (5–6): 546–54. https://doi.org/10.1016/j.ergon.2007.08.019.

Mircheski, Ile, Tatjana Kandikjan, and Sofija Sidorenko. 2014. "COMFORT ANALYSIS OF VEHICLE DRIVER ' S SEAT THROUGH SIMULATION OF THE SITTING PROCESS" 3651: 291–98.

Mohamed, Zamri, and Rosnah Mohd Yusuff. 2007. "Automotive Ergonomics: Passenger Cars Interior Dimension Parameters and Comfort," 3–6.

MZK, Fadhli (Universiti Kuala Lumpur, Institute of Medical Science Technology). 2016. "Ergonomic Risk Factors and Prevalence of Low Back Pain among Bus Drivers" 3 (1): 1–3.

Naseri, Arash. 2011. "INTERFACE PRESSURE AND VIBRATION COMFORT EVALUATIONS," no. September.

National Occupational Health and Safety Commission. 1991. "Ergonomic Principles and Checklists for the Selection of Office Furniture and Equipment," no. November: 1–45.

Patten, W. N., S. Sha, and C. Mo. 1998. "A Vibration Model of Open Celled Polyurethane Foam Automotive Seat Cushions." *Journal of Sound and Vibration* 217 (1): 145–61. https://doi.org/10.1006/jsvi.1998.1760.

Paul, Gunther, and Jason Miller. 2013. "G Paul FEM of Seat Cushion Indentation A Finite Element Model of Seat Cushion Indentation with a Soft Tissue Human Occupant Model," no. June 2014.

Pdbiad, Codenfile:///C:/Users/Acer2/Desktop/MASTERS/Journals/completed/Reed_2000.pdf. 2010. "Impact of Anthropometric Measurements on Ergonomic Driver Posture and Safety" 112 (1): 51–54.

Poirson, Emilie, and Matthew Parkinson. 2014. "Estimated Anthropometry for Male Commercial Pilots in Europe and an Approach to Its Use in Seat Design." *International Journal of Industrial Ergonomics* 44 (5): 769–76. https://doi.org/10.1016/j.ergon.2014.05.003.

Rajeshkumar U. More, Dr. R. S. Bindu. 2008. "Comfort Analysis of Passenger Car Vehicle Seat." *Certified International Journal of Engineering Science and Innovative Technology* 9001 (4): 2319–5967.

Reed, Matthew P. 2000. "Survey of Auto Seat Design Recommendations for Improved Comfort," no. April.

Reed, Matthew P, Lawrence W Schneider, and Leda L Ricci. 1994. "Survey of Auto Seat Design Recommendations for Improved Comfort," no. April: 1–96.

Reed, Matthew R, Miriam A Manary, Carol A C Flannagan, and W Lawrence. 2000. "Effects of Vehicle Interior Geometry and Anthropometric Variables on Automobile Driving Posture" 42 (4): 541–52.

Rhimi, Abdelkerim. 2017. "Concepts for the Reduction of the Discomfort Generated by the Prolonged Static Posture during the Driving Task, Part II: Experiments and Validations." *International Journal of Industrial Ergonomics* 57: 55–62. https://doi.org/10.1016/j.ergon.2016.11.006.

Rifano, R., M. A. Ivananda, R. Ismail, H. Prastawa, and A. P. Bayuseno. 2018. "Ergonomic Analysis on Driver Seat of Electric Car and Its Comparison with Lcgc Car Seat." *AIP Conference Proceedings* 1977. https://doi.org/10.1063/1.5042860.

Sadri, Gholam Hossain. 2017. "Risk Factors of Musculoskeletal Disorders in Bus Drivers." *Archives of Iranian Medicine* 6 (3): 214–15.

Sammonds, George M., Mike Fray, and Neil J. Mansfield. 2017. "Effect of Long Term Driving on Driver Discomfort and Its Relationship with Seat Fidgets and Movements (SFMs)." *Applied Ergonomics* 58: 119–27. https://doi.org/10.1016/j.apergo.2016.05.009.

Schrodt, M, and G Benderoth. 2005. "Hyperelastic Description of Polymer Soft Foams at Finite Deformations," 162–73.

Scott Openshaw, Allsteel, and Allsteel Erin Taylor. 2006. "Ergonomics and Design A Reference Guide." *Allsteel Design to Work Build to Last*, 1–2.

Shivaji, Shri, and Shri Shivaji. 2013. "Reviwe of Design Aspects of Major Components of Automotive Seat QR Code for Mobile Users" 01 (01): 33–38.

Shivakumar, M R, Ashwat Kamat, and G S Prakash. 2016. "Comfort Design and Analysis of Driver Car Seat Using Finite Element Analysis," 974–78.

Smith, Dannion R, David M Andrews, and Peter T Wawrow. 2006. "Development and Evaluation of the Automotive Seating Discomfort Questionnaire (ASDQ)" 36: 141–49. https://doi.org/10.1016/j.ergon.2005.09.005.

Smith, Jordan, Neil Mansfield, and Diane Gyi. 2015. "Long-Term Discomfort Evaluation : Comparison of Reported Discomfort between a Concept Elevated Driving Posture and a Conventional Driving Posture." *Procedia Manufacturing* 3 (Ahfe): 2387–94. https://doi.org/10.1016/j.promfg.2015.07.387.

Tang, Chak Yin, Wai Chan, and Chi Pont Tsui. 2010. "Finite Element Analysis of Contact Pressures between Seat Cushion and Human Buttock-Thigh Tissue" 2010 (September): 720–26. https://doi.org/10.4236/eng.2010.29093.

Thakurta, Kuntal, Daniel Koester, Neil Bush, and Susan Bachle. 1995. "Evaluating Short and Long Term Seating Comfort." *SAE Technical Papers*, no. 412. https://doi.org/10.4271/950144.

Varela, Maria, Diane Gyi, Neil Mansfield, Richard Picton, Akinari Hirao, and Tomokazu Furuya. 2019. "Engineering Movement into Automotive Seating: Does the Driver Feel More Comfortable and Refreshed?" *Applied Ergonomics* 74 (November 2017): 214–20. https://doi.org/10.1016/j.apergo.2018.08.024.

Vaz, Caroline Rodrigues, Tania Regina Shoeninger Rauen, and álvaro Guillermo Rojas Lezana. 2017. "Sustainability and Innovation in the Automotive Sector: A Structured Content Analysis." *Sustainability (Switzerland)* 9 (6).

https://doi.org/10.3390/su9060880.

Vink, Peter, and Daan Lips. 2017. "Sensitivity of the Human Back and Buttocks: The Missing Link in Comfort Seat Design." *Applied Ergonomics* 58: 287–92. https://doi.org/10.1016/j.apergo.2016.07.004.

Wilson, John R. 2014. "Fundamentals of Systems Ergonomics/Human Factors." *Applied Ergonomics* 45 (1): 5–13. https://doi.org/10.1016/j.apergo.2013.03.021.

Wu, X, S Rakheja, and D Boileau. 1999. "Distribution of Human } Seat Interface Pressure on a Soft Automotive Seat under Vertical Vibration" 24: 545–57.

Yokoyama, Kazuhito, Juliana Jalaludin, Rusli Nordin, Source Apportionment, Safety Behaviour, and Safety Climate. 2007. "The Association between Risk Factors and Low Back Pain among Commercial Vehicle Drivers in Peninsular Malaysia : A Preliminary Result," no. June 2014. https://doi.org/10.2486/indhealth.45.268.

Zhang, Xiaolu, Yi Qiu, and Michael J. Griffin. 2015. "Transmission of Vertical Vibration through a Seat: Effect of Thickness of Foam Cushions at the Seat Pan and the Backrest." *International Journal of Industrial Ergonomics* 48: 36–45. https://doi.org/10.1016/j.ergon.2015.03.006.