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Lower Back & Comfortability Analysis of Driving Posture to Mitigate Musculoskeletal Disorders: An Ergonomics Study using Digital Human Modelling in JACK Software

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Abstract: In this paper, the crucial aspect of driver comfort was explored by investigating the prevailing driving postures among individuals, aiming to discern their ergonomic implications and ascertain whether the commonly adopted postures are conducive to musculoskeletal health or pose potential risks. From the last decade vehicle like cars have become one of the common modes of personal transport. Car has high relevance in day-to-day activities like commuting, economic activities and sports etc. The continuous driving of vehicle can lead the driver prone to musculoskeletal disorders such as back pain, spine injury and posture issues. This study is conducted to address the ergonomic aspects of posture of the driver to highlight the risk of Musculoskeletal disorders (MSDs) and to optimize the driving posture. Lower Back Analysis (LBA) and Comfortability Analysis is performed in JACK Software to analyze the driving posture. A DHM (Digital Human Model) is created in JACK Simulation Software according to the collected anthropometric data of an average Pakistani man. A virtual Environment is created in JACK Simulation Software. The posture of the subject is analyzed by taking measurements of the subject's angle of joints when they are sitting in a driving posture. For Ergonomic Analysis the Driving Posture is evaluated on JACK software to Mitigate Musculoskeletal Disorders. Results show that the subject is having low back compression force of 672 which is below the NIOSH Back Compression Action Limit of 3400N representing a nominal risk of low back injury.

Keywords: Anthropometric data collection, Comfortability analysis, JACK Software, Lower Back Analysis LBA

1. Introduction

From the last decade vehicle like cars have become one of the common modes of personal transport. The car has high relevance in day-to-day activities like commuting, economic activities, and sports etc. The most prevalent use of cars are for transportation and business. The ownership of private vehicles in Pakistan has experienced a significant surge in the past four years. The proportion of

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households owning cars has increased to over 9%, marking a notable rise from the 6% recorded in 2015.VeAccording to Pakistan Bureau of Statistics (PBS) 3,944,066 number of passenger cars have been registered till 2021 in Pakistan. Here passenger cars include Motor Cabs/Taxis Motor Cars, Jeeps & Station Wagons [1]. The increased use of cars is thus increasing the driving time, which in result rises the risk of Musculoskeletal Disorders, posture, and spine issues among drivers. Drivers facing musculoskeletal problems are a significant concern in many industries, especially those involving prolonged sitting or repetitive tasks. Musculoskeletal problems can affect the health, well-being, and productivity of drivers, and it is crucial to address these issues to ensure their safety and overall job satisfaction. The nature of driving, particularly during long journeys, often entails maintaining a fixed posture for extended periods. This static positioning can lead to strain on the muscles, ligaments, and joints of the back, potentially triggering discomfort, and pain. Factors such as inadequate lumbar support, improper seat adjustments, and limited movement while driving can exacerbate the problem. Furthermore, the repetitive motion of pressing pedals and holding the steering wheel can contribute to muscle fatigue and tension. Over time, these issues can accumulate, leading to chronic back pain or exacerbating pre-existing conditions. Addressing this challenge requires a combination of ergonomic car design, driver education on posture and stretching, and regular breaks during long trips to alleviate the stress on the spine and muscles.

1.1 Musculoskeletal Disorder (MSDs)

Musculoskeletal issues often involve persistent discomfort and limitations in mobility and manual abilities, impacting individuals' ability to do work and participate in day-to-day social interactions. The most common form of non-cancer-related pain arises from discomfort in musculoskeletal components. Musculoskeletal health pertains to the proper functioning of the locomotor system, encompassing well-functioning muscles, bones, joints, and the surrounding supportive tissues. According to the estimations of World Health Organization (WHO) around 1.71 billion individuals worldwide suffer from musculoskeletal problems. Low back pain is the top cause of disability in 160 different nations worldwide, and the main cause of disability are the musculoskeletal diseases. Musculoskeletal impairments, which are typified by deficiencies in the muscles, bones, joints, and adjacent connective tissues and result in temporary or permanent limitations in functioning and participation, can be brought on by more than 150 different diseases and ailments that have an impact on the body [2]. A cross-sectional study conducted in Faisalabad Pakistan focused on non-occupational drivers, enrolling 192 participants of both genders aged between 18 and 60 years. The Nordic Musculoskeletal Questionnaire was employed to assess pain in different body areas among these drivers. The findings revealed that backache was the most prevalent issue, with 41% reporting lower back pain in the last twelve months and 38% in the last seven days. The occurrence of low back pain was notably higher compared to other body areas during both the past 12 months and the preceding week [3].

Preventing MSDs involves creating ergonomic work environments, promoting proper posture, providing training on safe lifting techniques, encouraging regular breaks, and implementing tools and equipment that reduce the physical strain on the body. Early intervention, ergonomic adjustments, and proper awareness can significantly reduce the risk of developing MSDs and improve overall well-being, especially for those whose work involves prolonged physical activity or repetitive motions.

1.2 Lower Back Disorder

Almost everyone has endured lower back discomfort at some point in their lives. According to Global Burden of Disease research, low back pain (LBP) is defined as discomfort that lasts for at least one day and is located on the posterior portion of the body between the lower boundary of the twelfth ribs and the lower gluteal folds. Around the world, low back discomfort is a widespread issue. Around

7.5% of the world's population, or 577.0 million people, were predicted to experience low back discomfort in 2017 [4]. Between the years of 1990 and 2019, disability caused by Lower Back Pain rose across all age groups, and the highest levels of disability were seen in the age group of 50-54 in 2019. About 70% of the years lost to disability were experienced by those who were working (ages 20 to 65) [5]. As the world's population continues to age and the prevalence of sedentary lifestyles increases, the challenge of addressing low back pain remains ongoing. Collaborative efforts between healthcare providers, policymakers, and individuals are crucial to mitigate the impact of LBP on people's lives and societies. By fostering a culture of proactive self-care and informed decision-making, we can work towards a future with fewer instances of low back discomfort and improved overall well-being.

1.3 Lower Back Analysis Test

The five vertebrae in the lower back, also known as the lumbar spine, are labelled L1 to L5. The two lowest vertebrae, L4 and L5, are positioned above the sacrum and are supported by the lumbar disc, which is made up of nerves, joints, and tissues. These vertebrae support the upper body and enable motion in multiple directions, including backward and for-ward bending, and twisting. However, due to the heavy weight they bear, the L4 and L5 vertebrae are prone to injuries. These injuries can be caused by carrying heavy loads, improper lifting technique, obesity, or abnormal body movements. These can lead to issues such as a herniated L4-L5 disc, L4 vertebra slipping over the L5 vertebra and impinging the nerve root, and L4 nerve root irritation from inflammatory proteins or external pressure. Some common diseases related to carrying excess weight include L4-L5 disc herniation, degenerative disc disease, and spondylolisthesis [6]. Musculoskeletal diseases are more likely to develop when poor posture and chronic lower back pain are present. To determine the possible risk of MSDs, ergonomic evaluations like LBA are helpful. The JACK software is designed to simulate and analyze human interactions with products, tasks, and environments to assess ergonomic factors and human factors engineering. When it comes to lower back analysis, the software follows a systematic process to evaluate how various tasks or activities can impact the biomechanics and comfort of the lower back region.

1.4 Jack Simulation Software

The Jack human modelling tool was created in the 1980s at the University of Pennsylvania's Centre for Human Modelling and Simulation, under the leadership of Dr. Norman Badler. Its primary purpose was to aid in the design and optimization of human-machine interfaces in workspaces. Funding for Jack's development came from various sources, including NASA and the US Army, and it is now used in a variety of industries by companies such as John Deere, BAe Systems, NASA, and the US Army [7]. Designing effective interiors for vehicles such as cars, trucks, airplanes, and construction equipment can be difficult. The Occupant Packaging Toolkit (OPT) is an add-on for the Jack software program that aims to simplify this process by providing analytical tools to design vehicle interiors that promote optimal performance and comfort for occupants, as well as minimizing the need for costly physical prototypes. OPT is an extension of the popular Jack software, which is used for human simulation and ergonomics analysis. The OPT module offers a specialized set of tools for analyzing various aspects of your vehicle design. These tools allow you to compare your design to other vehicles or design options using the comprehensive SAE J-Standards tools. You can also use OPT to predict how a person might position themselves in the vehicle and assess their comfort level, as well as analyze their visibility and reach [8].

1.5 Digital Human Model (DHM)

DHMs are virtual 3D models of people used in computer-aided design and related software. Ergonomists, industrial engineers, and other experts are increasingly using DHMs to create tools, workspaces, and products that are suitable for human operators. Design engineers can place and manipulate virtual operators with varied anthropometric features within a simulated work environment using DHM software, such as JACK, and do numerous assessments, including those of work posture, lower back fatigue, and metabolic energy expenditure. JACK is a program for modelling and simulating humans that offers design tools for ergonomically analyzing virtual goods and work situations. It can be used to analyze human performance while doing jobs, improve industrial operations and product designs from an ergonomics standpoint [6].

1.6 Comfortability Test

The OPT module includes a range of tools for analyzing various aspects of your vehicle design. These tools allow you to compare your design to other vehicles or design options using the comprehensive SAE J-Standards tools. You can also use OPT to predict how a person might position themselves in the vehicle and assess their comfort level, as well as analyze their visibility and reach [8]. The continuous driving of vehicle can lead the driver prone to musculoskeletal disorders such as back pain, spine injury and posture issues. The driver stays in a particular posture while driving, these awkward postures may lead to the risk of MSDs. Mainly the driver's upper extremity and lower back are affected by MSDs, which results in back pain, and fatigue. DMSD, or driving-related musculoskeletal disorders, are brought on by poor posture, stress, and repetitive motions made when driving. This research study is aimed to identify the comfortability of driver's preferred posture while driving the car and to analyze the lower back of driver in that posture. This study is focused on creating a Manikin that reflects the anthropometric dimensions of the population and to analyze the driving posture of the population in terms of ergonomics.

2. Research Methodology

This section presents a comprehensive description of the methodology that we have employed in this study, to identify the most preferred posture for driving among individuals and to conduct a Comfortability Analysis & Lower Back Analysis (LBA) Test aiming to recognize the significance of driver comfort in ensuring safe and enjoyable driving experiences. Fig. 1 displays the process flow chart for the research methodology used in this work, which includes the research design, collection of data procedures, and data analysis approaches. By understanding the posture preferences of drivers, valuable insights can be gained to enhance ergonomic designs and promote a more comfortable driving experience. The following subsections explain in detail the steps of research methodology employed in this study. Through outlining the specific steps taken to address the research objectives, this section provides a transparent account of the study's execution and ensures the reliability and validity of the findings.

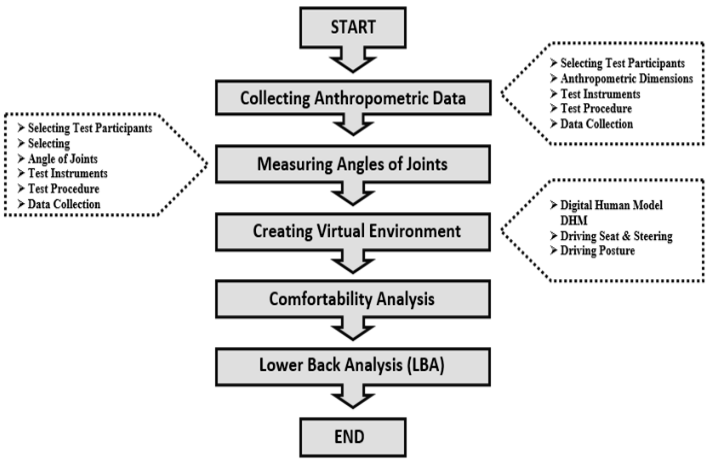


Fig. 1 - Methodology for ergonomic analysis of driving posture using JACK Software

2.1 Collecting of Anthropometric Data

2.1.1 Selecting Test Participants (Subjects)

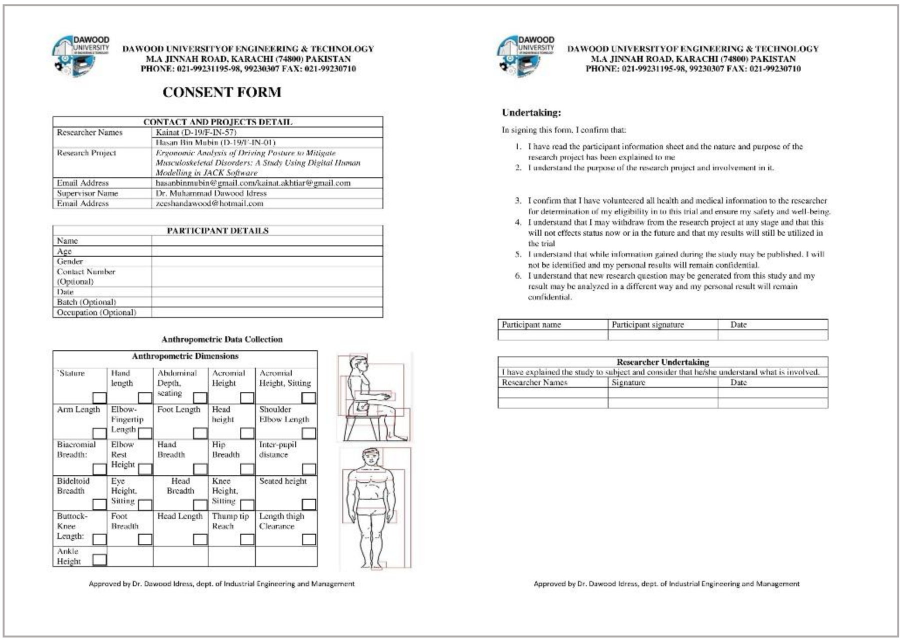
50 male subjects between the ages of 18-30 volunteered to participate in the experiment. The selected subjects had no history of musculoskeletal disorder. The detailed description of the experiment procedure was explained to all test participants before initiating the experiment. A consent form was given to the all test participants in order to get their consent on the mentioned undertakings as shown in Fig. 2 [9, 10]. To assure the anonymity and privacy of the Test participants, personal information like name, contact number was kept confidential and was not included in any sort of public data base or printed results. Photographs of the test participant were used in this study by the approval and consent of that participant.

2.1.2 Anthropometric Dimensions

Designing a custom digital human model for ergonomic evaluations and comfortability tests using JACK simulation software is a crucial step in this research study. The anthropometric dimensions, as depicted in Fig. 4, serve as the foundation for creating an accurate and representative virtual human that can mimic real-world interactions and movements. The use of JACK simulation software not only enhances the precision of these evaluations but also provides a cost-effective and efficient means of testing ergonomic factors. Engineers, designers, and researchers can simulate various scenarios and assess how different design choices impact the user's comfort and safety. This approach contributes to the creation of products and spaces that are better tailored to human needs, ultimately reducing the risk of musculoskeletal disorders, and improving overall user satisfaction. To do ergonomic evaluations like Lower Back Analysis (LBA) and comfortability tests, we need to create a custom Human in JACK simulation software. So, in order to create a DHM, we have to collect anthropometric data of subjects that represent the Pakistani Population. The software's required anthropometric dimensions to create digital Human model are shown in Fig. 4.

2.1.3 Test Instruments

In order to find the authentic and correct instrument for mentioned dimensions of the human body, literature review of several books and research papers was done. The anthropometric consent form and instruments used in this study are shown in Fig. 2 and Fig. 3 respectively.



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CONSENT FORM

CONTACT AND PROJECTS DETAIL	
Researcher Names	Kainat (D-19/F-IN-57)
	Hasan Bin Mubin (D-19/F-IN-01)
Research Project	*Ergonomic Analysis of Driving Posture to Mitigate Musculoskeletal Disorders: A Study Using Digital Human Modelling in JACK Software*
Email Address	hasanbinmubin@gmail.com/kainat.akhtiar@gmail.com
Supervisor Name	Dr. Muhammad Dawood Idress
Email Address	zeeshandawood@hotmail.com

PARTICIPANT DETAILS	
Name	
Age	
Gender	
Contact Number (Optional)	
Date	
Batch (Optional)	
Occupation (Optional)	

Anthropometric Data Collection

Anthropometric Dimensions				
`Stature	Hand length	Abdominal Depth, seating	Acromial Height	Acromial Height, Sitting
Arm Length	Elbow-Fingertip Length	Foot Length	Head height	Shoulder Elbow Length
Biacromial Breadth:	Elbow Rest Height	Hand Breadth	Hip Breadth	Inter-pupil distance
Bideltoid Breadth	Eye Height, Sitting	Head Breadth	Knee Height, Sitting	Seated height
Buttock-Knee Length:	Foot Breadth	Head Length	Thump tip Reach	Length thigh Clearance
Ankle Height				

Approved by Dr. Dawood Idress, dept. of Industrial Engineering and Management

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Undertaking:

In signing this form, I confirm that:

1. I have read the participant information sheet and the nature and purpose of the research project has been explained to me
2. I understand the purpose of the research project and involvement in it.
3. I confirm that I have volunteered all health and medical information to the researcher for determination of my eligibility in to this trial and ensure my safety and well-being.
4. I understand that I may withdraw from the research project at any stage and that this will not effects status now or in the future and that my results will still be utilized in the trial
5. I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
6. I understand that new research question may be generated from this study and my result may be analyzed in a different way and my personal result will remain confidential.

Participant name	Participant signature	Date

Researcher Undertaking		
I have explained the study to subject and consider that he/she understand what is involved.		
Researcher Names	Signature	Date

Approved by Dr. Dawood Idress, dept. of Industrial Engineering and Management

Fig. 2 - Consent form for collecting anthropometric data of test participants.

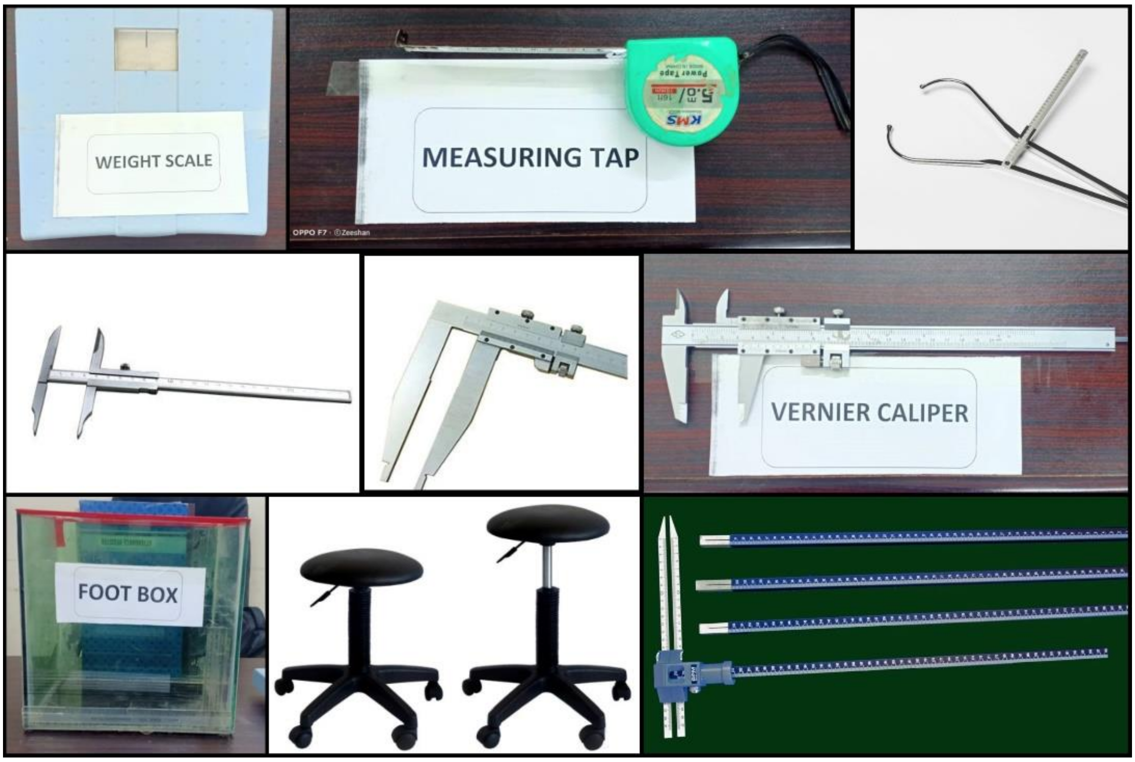


Fig. 3 - Photographs of the anthropometric equipment used for taking mentioned anthropometric dimensions.

2.1.4 Test Procedure

The participant was briefed about the purpose of this research study, each subject (Test Participant) was guided by measurer to follow certain directions in order to get the anthropometric data. Their consent on taking their body measurements was taken first. In the context of a human body, land marking refers to the procedure of identifying specific anatomical features or points on the body that serve as reference points for medical or scientific purposes. Landmarks on the body may include bony prominences, joints, muscles, and other structures that can be palpated or easily identified. For example, when taking measurements or conducting assessments, healthcare providers may use landmarks such as the acromion process on the shoulder or the iliac crest on the hip as reference points to ensure accuracy and consistency. The next step was to mark the joints and landmarks on the participant's body with stickers in order to get the accurate measurements. By comparing a key input with similar statistical data from the national anthropometric survey, it is possible to systematically prevent human errors that could happen when reading or recording measurements. This is done by comparing the difference between repeated measurements. To prevent a measurement error caused by misreading or by using an inconsistent measuring methodology, repetitive measurements were taken until their difference reached 2 mm [11].

2.1.5 Data Collection

The process of collecting anthropometric measurements from the 50 test participants was conducted meticulously to ensure accuracy and reliability. Each participant was scheduled individually to undergo the measurement procedure, allowing for focused attention, and minimizing potential errors. The measurements were taken following standardized protocols to maintain consistency and comparability. These protocols guarantee that the collected data accurately represent the participants' body dimensions and proportions. The use of anthropometric instruments, as shown in Fig. 3, ensured precise and standardized measurements, reducing variability, and enhancing the overall quality of the data. The dimensions were measured in the following manner of definitions.

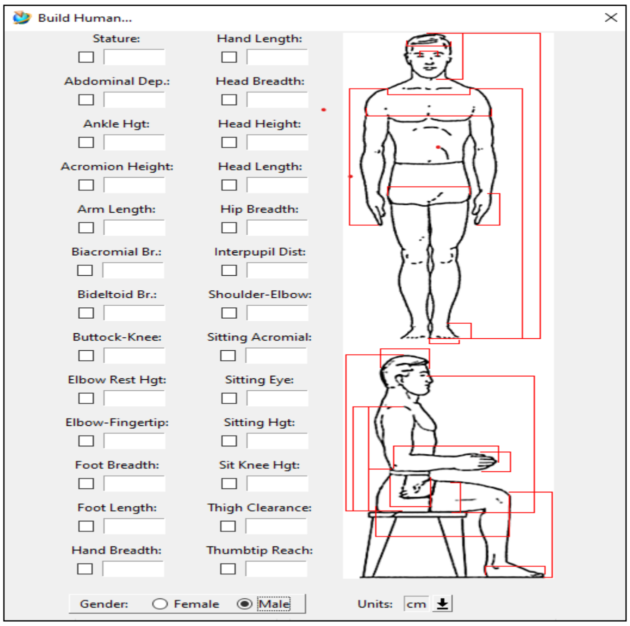


Fig. 4 - Anthropometric dimensions to create digital Human model.

- Stature

The height of the head measured vertically from a standing surface is known as stature. The test participant is asked to keep their head in the Frankfort Horizontal plane while standing in anthropometric position. Now by use of an anthropometer the distance (vertical) from the top of head to the standing surface of the test participant is measured while standing to the right of the TP. An appropriate pressure is applied to compress the hair of the test participant [12].

- Acromial Height (Standing)

The distance (vertical) measured from the standing surface to the right acromial landmark is known as the acromial height. The test participant is asked to keep the straight standing position. Now by use of an anthropometer the vertical distance from the surface to the test participant's right acromial landmark is measured [12].

- Thumb-Tip Reach

The distance (horizontal) from a back wall to the right thumb tip is considered as Thumb-Tip Reach, measured on a wall scale. The test participant is asked to keep the anthropometric standing position, having their feet joined and their heels 20 cm from the back wall while looking straight ahead. The right hand and arm are extended horizontally along a scale on the side wall with the palm facing front. The right shoulder of TP is pressed gently against the side wall. The Thumb-Tip Reach is then measured on the wall scale [13].

- Arm Length

When the participant adopts an upright posture while holding both arms out to the sides, palms facing the thighs is then the distance between the acromion landmark on the right shoulder and the dactyl ion III landmark at the tip of the middle finger of the TP is considered as Arm Length. The measurer uses the beam caliper to take this measurement.

- Shoulder-Elbow Length

The distance between the olecranon landmark on the bottom of the right elbow and the acromion landmark on the tip of the right shoulder is considered as Shoulder-Elbow Length. The test participant is asked to keep the anthropometric standing position with their feet together and the right upper arm hanging at the side. Then they are asked to flex elbow at 90 and to straighten their hand with the palm facing inward. The measurer uses beam caliper to take the measurements [13].

- Abdominal Depth

Abdominal depth is the horizontal distance between the anterior point of the abdomen and the back at the same level. The test participant is asked to keep the anthropometric sitting position while looking straight ahead. The measurer uses a beam caliper and gets a reading at the test participant's quietest point of respiration [13].

- Hip Breadth

The horizontal distance between the Lateral Buttock landmarks on the sides of the hips is called Hip Breadth. The test participant is asked to keep the anthropometric sitting position while looking straight ahead. The measurer uses a beam caliper and gets a reading at the test participant's quietest point of respiration [12].

- Bi-acromial Breadth

The horizontal distance between the Acromial landmarks on the points of both the shoulder is known as the bi-acromial breadth. The test participant is asked to keep the anthropometric sitting position while looking straight ahead. This distance between the right and left points is measured by using beam caliper. Standing behind the test participant measurer applied appropriate pressure to remain in close contact with the skin. The measurer uses a beam caliper and gets a reading at the test participant's quietest point of respiration [12].

- Bi-deltoid Breadth

The maximum horizontal distance between the lateral margins of the upper arms on the deltoid muscles is Bi-deltoid Breadth. The test participant is asked to keep the anthropometric sitting position while looking straight ahead. This measurement is taken by using beam caliper. Standing behind the test participant measurer applied appropriate pressure to remain in close contact with the skin. The measurer uses a beam caliper and gets a reading at the test participant's quietest point of respiration [12].

- Buttock-Knee Length

The horizontal distance between a buttock plates, placed at the most posterior point of either buttock and the anterior point of the right knee is Buttock-Knee Length. The test participant is asked to keep the sitting position while looking ahead with their arms relaxed on the lap. This measurement is taken by use of an anthropometer. While standing at the right of test participant an appropriate pressure is applied in order to make sure the contact between the instrument blade and the knee [12].

- Acromion Height (Sitting)

The vertical distance measured from a sitting surface to the right acromial landmark is known as the acromial height. The test participant is asked to keep the anthropometric sitting position and to look straight ahead and have their shoulders and upper arms completely relaxed. By using an anthropometer, the vertical distance from the sitting surface and the right acromial landmark of the test participant is measured [12].

- Elbow Rest Height

The vertical distance between a sitting surface and the olecranon landmark on the base of the flexed right elbow. The test participant is asked to keep the anthropometric sitting position while looking straight ahead with the shoulders and up-per arms relaxed. The participant is then asked to extend forward his forearms and hands horizontally with the palms facing each other and to have shoulders and upper arms relaxed. The measurer uses an anthropometer to take measurements of Elbow Rest Height [13].

- Eye Height, Sitting

The vertical distance between the outer corner of the right eye (ectocanthion) and the sitting surface. The test participant is asked to keep their head in the Frankfort Horizontal plane while sitting in anthropometric position while looking straight ahead and to keep their shoulders and upper arms relaxed. The participant is then asked to extend forward his forearms and hands horizontally with the palms facing each other and to have shoulders and upper arms relaxed. The measurer uses an anthropometer and gets a reading at the test participant's quietest point of respiration.

- Elbow-Fingertip Length

It is the horizontal distance between the tip of the right middle finger (dactyl ion III) and the back of the tip of the right elbow (olecranon, rear) when the right elbow is twisted at 90 degrees. The test participant is asked to keep the anthropometric sitting position while looking straight ahead with the shoulders and upper arms relaxed. The participant is then asked to extend forward his forearms and hands horizontally with the palms facing each other and to have shoulders and upper arms relaxed. The Elbow-Fingertip measurement is taken with the use of a beam caliper.

- Sitting Height

The height of the top of head measured vertically from a sitting surface is known as sitting height. The test participant is asked to keep their head in the Frankfort Horizontal plane while sitting in anthropometric position. Now by use of an anthropometer the vertical distance from the top of head to the sitting surface of the test participant is measured while standing to the right of the TP. The measurer applies appropriate pressure to compress the hair of the test participant [12].

- Knee Height

Knee Height Sitting is the vertical distance between a flat surface while the subject is seated and the Suprapatellar landmark. The test participant is asked to sit on the table while keeping the anthropometric sitting position looking ahead and to keep the shoulders, upper arms relaxed while having thigh levels and knees at 90 degrees. The measurer take the readings by the use of an anthropometer to determine the vertical distance between the flat surface and the stickered Suprapatellar landmark at the top of the knee while standing to the right of the test participant [12].

- Length thigh Clearance

The height of the right thigh at its highest point measured vertically from a sitting surface is Length thigh Clearance. By using an anthropometer, the measurer takes the measurement. The test participant is asked to sit on the table while keeping the anthropometric sitting position looking ahead, to have their shoulders, upper arms relaxed and to have thigh levels and knees at 90 degrees [13].

- Hand Length

The length of the right hand from the stylion landmark on the wrist to the middle finger tip. With the fingers interlocked and the thumb adducted, the test participant is asked to place their palm on a table. The long axis of the forearm and the middle finger are parallel. To measure the Hand length a Poech sliding caliper is used by the measurer [13].

- Hand Breadth

A sliding caliper is used to measure the width of the right hand between the landmarks at metacarpals II and V. The test participant sets their palms flat on a surface, their fingers joined, and their thumbs adducted. The long axis of the forearm and the middle finger are parallel [13].

- Head Length

The head length is measured between the brow ridges at the Glabella landmark and the Opisthocranion. The test participant is asked to keep their head in the Frankfort Horizontal plane while sitting in anthropometric position. The measurer uses a spreading caliper to measure the distance between the Glabella landmark and Opisthocranion while standing at the right of test participant. An appropriate pressure is applied to compress the hair of the test participant [12].

- Head Height

An anthropometer is a specialized measuring tool used for anthropometric measurements. Measurer asked the subject to stand up straight with their feet together, back against a wall, and their head looking straight ahead. Position the anthropometer on the top of the subject's head, making sure that the arms of the anthropometer are perpendicular to the floor and the measuring head is in contact with the top of the subject's head.

- Head Breadth

The maximum horizontal breadth of the head above the ears is referred to as head breadth. The test participant is asked to keep their head in the Frankfort Horizontal plane while sitting in anthropometric position. The measurer measures the euryon, right, and left with a spreading caliper while standing behind the test participant applying appropriate pressure so that caliper contacts the skin.

- Foot Length

The maximum length of the foot is called foot length. The test participant is asked to keep the anthropometric standing position and place the right foot in the Foot box while equally distributing his weight on the feet. The Foot box is consist of scales, according to which the foot is to be placed in that. When the foot is correctly positioned, the measurement is taken from the horizontal scale [12].

- Foot Breadth

Foot Breadth is the maximum breadth of the foot. To measure it, the test participant is asked to keep the anthropometric standing position and place the right foot in the Foot box while equally distributing his weight on the feet. The Foot box is consist of scales, according to which the foot is to be placed in that. When the foot is correctly positioned, the measurement is taken from the horizontal scale [12].

- Ankle Height

Ankle Height is the height of the level of minimum circumference of the leg from the flat surface where foot is placed. The test participant is asked to keep the relaxed standing position and place the right foot in the Foot box while equally distributing his weight on the feet. The Foot box consists of scales, according to which the foot is to be placed in that. When the foot is correctly positioned, the measurement is taken from the vertical scale.

- Inter-pupil Distance

Inter-pupillary distance (PD) is a measurement of the distance between the centers of your two eyes. The test participant is asked to keep the anthropometric standing position and to look straight into the device. The measurer captures the photo of participant with which the inter-pupil distance is then measured.

There are several mobile applications available that can help measure inter pupillary distance (IPD) using the camera on your smartphone or tablet. a mobile application was used for taking measurements. The measured data of concerned anthropometric dimensions is shown in Table 1.

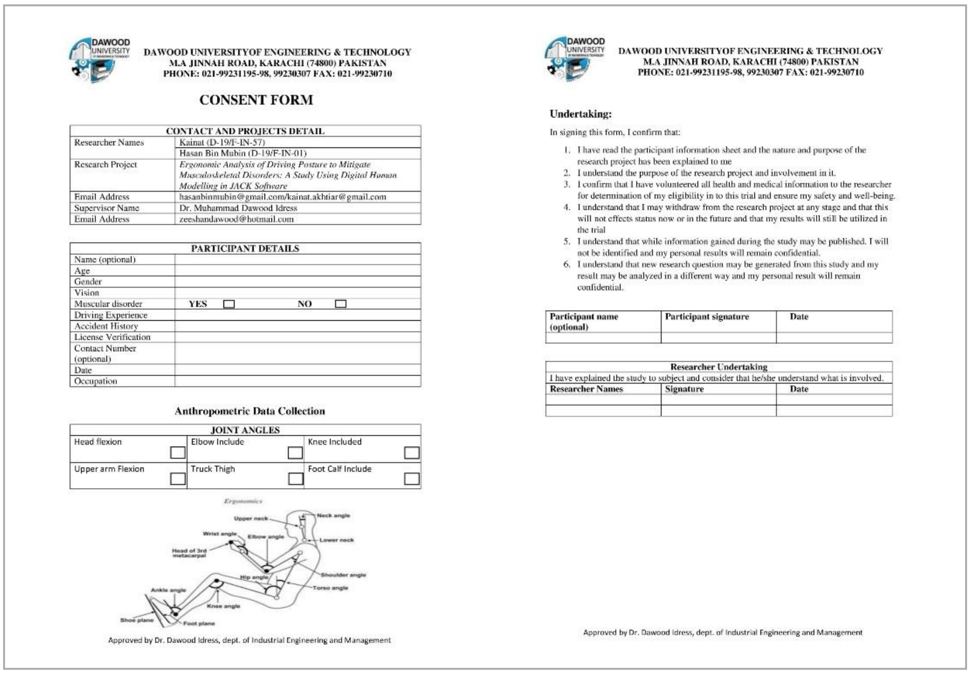
Table 1 – Collected Anthropometric data of 50 test participants to create digital Human Model in JACK software

Posture	ANTHRPOMETRIC DATA	MEAN	MINIMUM	MAXIMUM
Standing	Weight (Kg)	68.24	49	97
	Stature	172.4	164	191
	Acromial Height	144.4	137	160
	Thumb-Tip Reach	75	66	84
	Arm Length	78.37	70	87
Sitting	Shoulder Elbow Length	36.56	34	39.5
	Abdominal Depth	20.23	16	29
	Hip Breadth	35.67	29	41.5
	Biacromial Breadth	33.69	30.5	41
	Bideltoid Breadth	43.14	25	50
	Buttock-Knee Length	58.73	52	63.5
	Acromion Height	54.78	49.5	66
	Elbow Rest Height	17.78	14	26
	Eye Height, Sitting	70.38	64	86
	Elbow-Fingertip Length	48.18	43	52
	Sitting Height	81.96	75	95
	Knee Height	54.75	51	59
	Length thigh Clearance	11.62	8.5	18
Hands	Hand Length	18.7	17.1	20.3
	Hand Breadth	8.279	7.5	9.8
Head	Head Length	16.57	15.5	18.4
	Head Height	22.41	20.5	25
	Head Breadth	14.57	13.6	15.8
Feet	Foot Length	25.48	23.2	28
	Foot Breadth	9.558	8.9	11
	Ankle Height	7.442	6.8	9.5
Eyes	Interpupil Distance	6.55	6	8

2.2 Measuring Angles of Joints

2.2.1 Selecting Test Participants (Subjects)

25 males having age range of 18 – 30 were selected for the test. The Department of Motor Vehicles' minimum standard requirement, which is 20/40 or better vision in one or both eyes, was employed in selecting participants in the tests. Participants also had to have at least one year of experience driving a car [14] and they should not be having any history of musculoskeletal disorder. The detailed description of the experiment procedure was explained to all test participants before initiating the experiment. Another consent form was given to the all-test participants in order to get their consent on the mentioned undertakings as shown in Fig. 5.



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CONSENT FORM

CONTACT AND PROJECTS DETAIL	
Researcher Names	Kainat (D-19/F-IN-57)
	Hasan Bin Mubin (D-19/F-IN-01)
Research Project	*Ergonomic Analysis of Driving Posture to Mitigate Musculoskeletal Disorders: A Study Using Digital Human Modelling in JACK Software*
Email Address	hasanbinmubin@gmail.com/kainat.akhtiar@gmail.com
Supervisor Name	Dr. Muhammad Dawood Idress
Email Address	zeeshandawood@hotmail.com

PARTICIPANT DETAILS	
Name (optional)	
Age	
Gender	
Vision	
Muscular disorder	YES ☐ NO ☐
Driving Experience	
Accident History	
License Verification	
Contact Number (optional)	
Date	
Occupation	

Anthropometric Data Collection

JOINT ANGLES		
Head flexion ☐	Elbow Include ☐	Knee Included ☐
Upper arm Flexion ☐	Truck Thigh ☐	Foot Calf Include ☐

Approved by Dr. Dawood Idress, dept. of Industrial Engineering and Management

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Undertaking:

In signing this form, I confirm that:

1. I have read the participant information sheet and the nature and purpose of the research project has been explained to me
2. I understand the purpose of the research project and involvement in it.
3. I confirm that I have volunteered all health and medical information to the researcher for determination of my eligibility in to this trial and ensure my safety and well-being.
4. I understand that I may withdraw from the research project at any stage and that this will not effects status now or in the future and that my results will still be utilized in the trial
5. I understand that while information gained during the study may be published. I will not be identified and my personal results will remain confidential.
6. I understand that new research question may be generated from this study and my result may be analyzed in a different way and my personal result will remain confidential.

Participant name (optional)	Participant signature	Date

Researcher Undertaking		
I have explained the study to subject and consider that he/she understand what is involved.		
Researcher Names	**Signature**	**Date**

Approved by Dr. Dawood Idress, dept. of Industrial Engineering and Management

Fig. 5 - Consent form for measuring angles of Joints of test participants

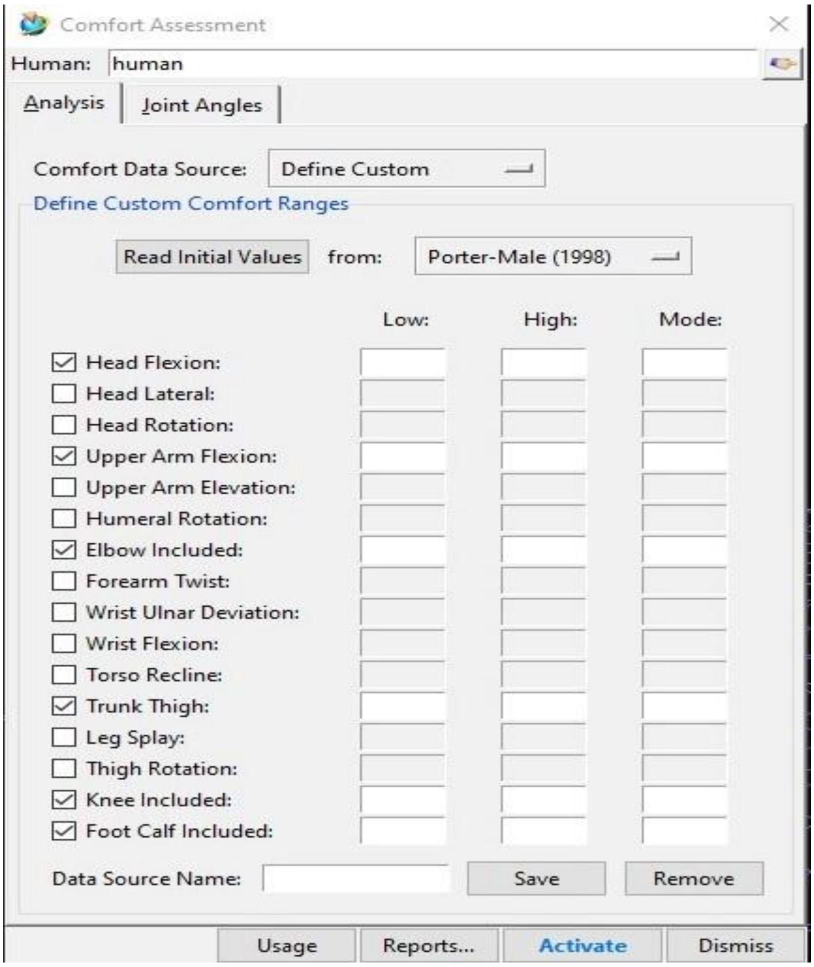

Fig. 6 -Comfort Assessment window of Jack simulation software

2.2.2 Joint Angles

According to the requirement of Jack simulation software as shown in Fig. 6, for comfortability assessment test, we need to measure the following six angles of joints of test participants while they are sitting in a driving posture.

- Head flexion
- Upper arm flexion
- Elbow
- Truck thigh
- Knee
- Foot calf include

2.2.3 Test Instruments

The angles of joints were measured using GONIOMETER as shown in Fig. 7. The method of taking measurements is considered from the Measurement of Joint, A guide of Goniometry 4th edition [15]. Stickers were used to locate the landmarks and tight clothing was wore by participants.

Fig. 7 - Anthropometric Equipment used for measuring angle of joints

2.2.4 Test Procedure

The test procedure was divided into 3 steps:

- Briefing

The participant was briefed about the purpose of this research study, each subject (Test Participant) was guided by measurer to follow certain directions in order to get the anthropometric data. Their consent on taking their body measurements was taken first. Subject was allowed to adjust their driving seat once[16], [17]. Test Participant was asked to wear tight clothing and to sit in the most comfortable posture that they usually prefer whilst semi-depressing the accelerator, holding the steering wheel and looking straight ahead on the road as like they were driving. The test participant must see through windshield 4 meter in front of the car [18], [19].

- Land marking

In the context of a human body, land marking refers to the procedure of identifying specific anatomical features or points on the body that serve as reference points for medical or scientific purposes. Landmarks on the body may include bony prominences, joints, muscles, and other structures that can be palpated or easily identified. For example, when taking measurements or conducting assessments, healthcare providers may use landmarks such as the acromion process on the shoulder or the iliac crest on the hip as reference points to ensure accuracy and consistency. The next step was to mark the joints and land marks on the anatomical landmarks of participant's body through clothing with stickers in order to get the accurate measurements. The following anatomical landmarks were stickered on the participant's body.

- 7th cervical vertebrae
- Ulnar styloid
- Lateral malleolus
- Acromion
- Lateral epicondyle
- Lateral condyle
- Greater trochanter

The definitions and understand of the above anatomical landmarks was reviewed and understood with the help of [20], [21].

2.2.5 Data Collection

A total of 25 Test participants were measured, each participant was asked to come one by one for measurement of angles of Joints. The test participant were asked to sit at the driver seat in the posture that they usually prefer while semi-depressing the accelerator and looking 4 meter ahead of the car. The vision of participants was tested and it was ensured that the selected participants meet the Department of Motor Vehicles' minimum requirement which is 20/40 or better vision in one or both eyes [14]. To measure the angles of joint a GONIOMETER as shown in Fig. 7 was used, the joints were visualized through stickers that we attached previously [22], [23].
The collected anthropometric data is shown in 2.

Table 2 -Collected Data of Angle of Joints of 25 Test Participants

COLLECTED DATA OF ANGLES OF JOINTS				
JOINT ANGLES	Mean	Minimum	Maximum	Mode
Head Flexion	5.65	5.37	6.03	5.37
Upper Arm Flexion	48.3	38.37	56.33	52.37
Elbow Included	138.51	110.17	166.07	148.2
Trunk Thigh	103.37	87.67	115.47	115.47
Knee Included	116.86	105.03	128.1	121.96
Foot Calf Included	73.15	64.7	80.33	75.5

2.3 Creating Virtual Environment

2.3.1 Creating Digital Human Model / Manikin (DHM) Selecting Test Participants

The creation of a Manikin or DHM was an essential step in this study, as it provided a virtual representation of a human subject. The advanced scaling option in JACK software was used to create the DHM, which was then updated with anthropometric data collected from a survey. The survey data was crucial in determining the accurate representation of the human subject in the virtual environment. The updated DHM was saved as a student profile (DUET) for future reference and use (see Fig. 08). The use of a DHM in this study allowed for a comprehensive analysis of the driving posture and comfort level of a hu-man subject without the need for physically testing it in real world. This not only saves time and resources, but also eliminates the risk of injury to the human subject. The use of a DHM in this study provided a new and innovative approach to traditional comfort and posture analysis methods [7].

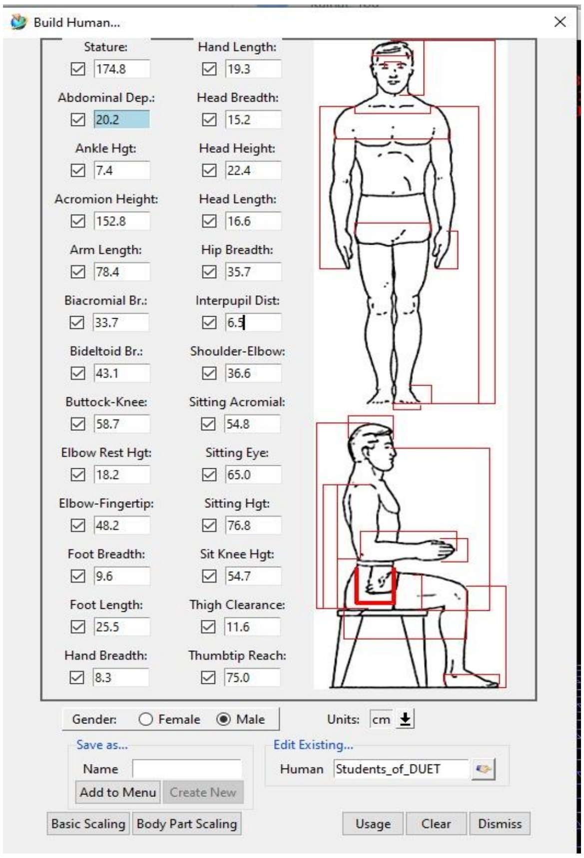

Fig. 8 - Build Human Tab of JACK Simulation Software.

2.3.2 Integrating Anthropometric data to create (DHM) by using advance scaling

The integration of anthropometric data into the Digital Human Modeling (DHM) system involves the utilization of the Advanced Scaling option, specifically designed to accommodate segmented human dimensions. This feature empowers users to define up to 26 anthropometric measurements as shown in figure 8, for the creation and scaling of manikins in the DHM system. The anthropometric dimensions encompass various aspects such as stature, foot breadth, abdominal depth, acromion height, and more, allowing for precise customization of human models. (Jack Human Modelling Tool: A Review) [7]. Utilizing the Advanced Scaling Panel under the command sequence Human > Create > Custom > Advanced Scaling provides enhanced control over segmented human dimensions, enabling users to precisely define various anthropometric measurements. This feature allows for the creation of manikins with specific dimensions, offering flexibility beyond the standard "5th and 95th" models. Jack's Advanced Human Scaling Panel empowers users to tailor manikins to unique anthropometric specifications, providing a comprehensive and customizable approach to modeling human figures. (Jack Manual 2019)

2.3.3 DHM Accuracy and Comparative Analysis

To validate the accuracy of this DHM representation, a comparison was made with another DHM created using JACK's built-in anthropometric databases. JACK Software provides access to various anthropometric databases, including ANSUR, ANSUR II, NHANES, Mexican_Jalisco, CDN_LF_97, NA_Auto, CHINESE, Asian Indian Anthropometric Database, German Anthropometric Database, Japanese, Korean, and Child Figures. [Digital Human Modeling Cecilia Berlin, Caroline Adams] [https://www.ubiquitypress.com/site/chapters/m/10.5334/bbe.i/].

- Validity and Accuracy

Alignment with Manual Data: The DHM created for Pakistani drivers was matched against the DHM generated using the Asian Indian Anthropometric Database from JACK. The minimal difference of less than 5% in segment and joint dimensions indicates a high level of alignment between the manually collected data and the database-driven DHM.
Comprehensive Representation: The inclusion of diverse databases in JACK, such as the Asian Indian Anthropometric Database, contributes to a comprehensive representation of various populations. This enhances the software's capability to create accurate DHMs for ergonomic analysis across different demographic groups. (Jack manual).

- Limitations and Assumptions

Population Specificity: While the comparison yielded positive results, it's essential to acknowledge that databases may not cover every nuance of regional anthropometric variations. The Asian Indian Anthropometric Database might provide a close match, but subtle differences in body proportions within the Pakistani population may exist.

- Homogeneity Assumption

The comparison assumes a certain degree of homogeneity within the Asian Indian Anthropometric Database and the Pakistani drivers. Individual variations and outliers may not be fully accounted for in this process.

- Reliability for Analysis

Minor Discrepancies- The minimal difference in segment and joint dimensions enhances confidence in the reliability of DHMs created using JACK Software. This suggests that, despite limitations, the DHM can be a reliable tool for ergonomic analysis for Pakistani drivers.
Human Subject Comparison: Additionally, measurements of the created DHM using data collected from real human subjects were compared using Human Control Panel and Human Scaling in JACK software, revealing a remarkable match of up to 95%. This alignment was achieved by employing mean values of all dimensions considered during the anthropometric data collection process to create our own digital model.

2.4 Virtual Driving Seat and Steering

Next, we carefully positioned the DHM on the seat and placed his hands on the steering wheel, adjusting his posture to simulate a realistic driving scenario as shown in Fig. 9. This step involved precise calculations and attention to detail, to ensure that the digital human model was placed in a realistic driving position. The aim was to recreate a real-life driving scenario in a virtual environment, which would allow us to conduct further analysis and evaluations. In this virtual environment, the DHM was able to interact with the driving seat and steering wheel, allowing us to observe and analyze his posture and comfort level while driving. This information was crucial in determining the overall comfort and safety of the driver while operating the vehicle. By creating a virtual environment that accurately represents a real-life driving scenario, we were able to gather more accurate and relevant data, which could be used to make informed decisions in the future.

2.5 Driving Posture

To ensure a realistic simulation of driving a car, we took great care in positioning the DHM on the seat and placing his hands on the steering wheel. Attention was paid to every detail, including the angle of the Digital Human Model's hands on the steering wheel, the position of his legs, and the tilt of the seat. This level of detail was crucial in creating a realistic driving posture for the DHM, which would allow us to accurately evaluate the comfortability level of the posture as shown in Fig. 10. By simulating the driving posture, we were able to better understand the ergonomic considerations involved in designing a vehicle, and to make data-driven decisions about the design and placement of controls, seats, and other components. To validate the alignment of the DHM's posture with real human subjects, we leveraged the information available in the joint angle section of the comfort assessment tool in JACK Software. This tool provided crucial insights into the angles of joints within the DHM, allowing us to verify that the DHM's posture faithfully reflects the collected data from drivers. By cross-referencing the joint angles, we ensured a close match between the simulated posture in the DHM and the actual postures observed in the drivers we studied. This meticulous validation process contributes to the accuracy and reliability of the DHM in replicating realistic human postures. For this emphasized the importance of transitioning from subjective analyses to precise and objective measurements. Jack provides various measurement methods, including the use of rulers to precisely measure distances between objects or locations. Additionally, I utilized the Collision Detection tool in Jack, a powerful analysis tool that helps identify the proximity of objects or humans to each other. This tool allows the definition of multiple collision sets and provides feedback on whether collisions have occurred. It was instrumental in checking collisions between different entities such as humans, JT objects, and native Jack geometry, enhancing the accuracy of the assessments in my study.

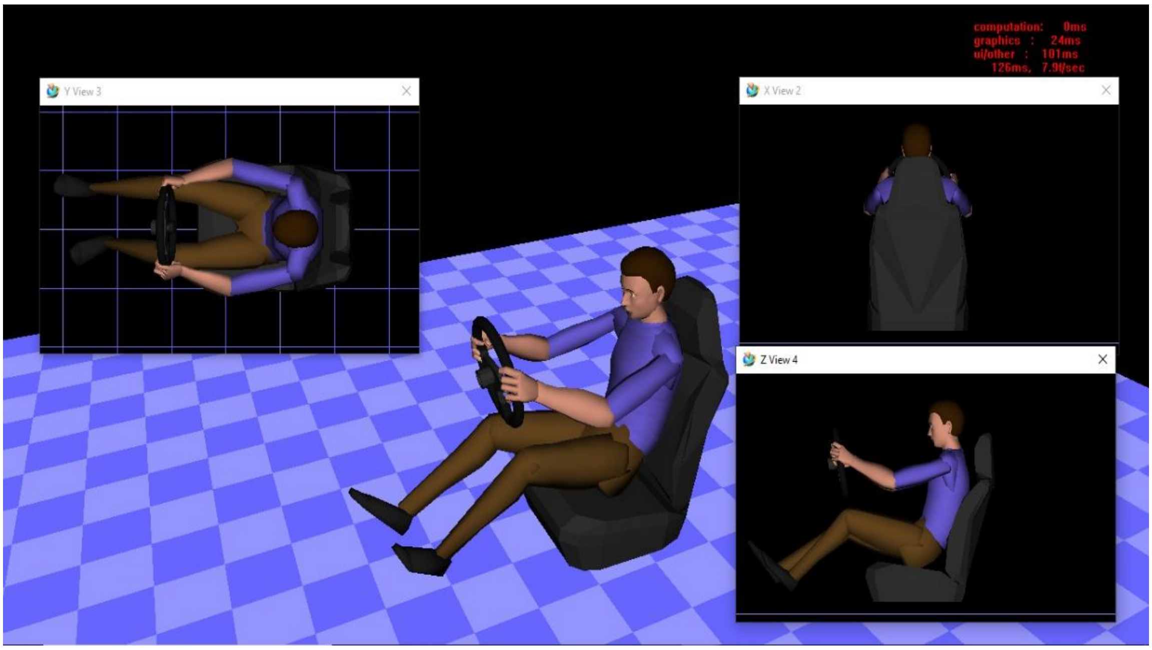

Fig. 9 - Virtual Environment created in JACK simulation Software.

2.6 Comfort Analysis

2.6.1 Setting up Comfort Assessment Tool

The comfort assessment tools in JACK software are essential for evaluating the posture and comfort of a driver while operating a vehicle. These tools are designed to help analyze the movements and positions of joints in the body, such as the hips, knees, ankles, shoulders, and neck, and provide feedback on how these joints can impact comfort levels. In the setup and calibration of the comfort assessment tools within the JACK software, precision was paramount. Leveraging the Human Control Panel, we meticulously adjusted each joint angle of our DHM, aligning them with the comprehensive joint angle data gathered from our survey at the University premises. This meticulous calibration ensured that the assessments conducted were not only accurate but also representative of real-world scenarios, enhancing the reliability of our ergonomic analysis. This allowed us to evaluate the driving posture, the comfort of the digital human model and to make any necessary adjustments to ensure that the posture was in line with the comfort range defined by the collected data as shown in Fig. 10.

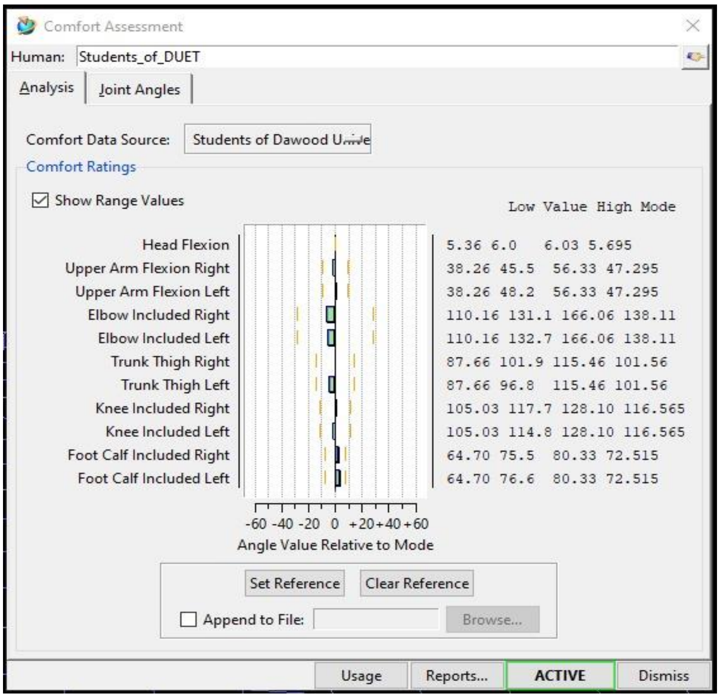

Fig. 10 - Comfort Assessment results of most preferred driving posture among population

2.6.2 Setting the Digital Human Model for optimal posture

The objective of this step was to ensure that the virtual model was as close to a real-life scenario as possible. By using the comfort assessment tools in JACK software, we were able to assess and make necessary adjustments to the DHM's posture and joints to ensure that they fell within the comfort range defined by the survey data. This involved considering fac-tors such as the angle of the back, the positioning of the hands on the steering wheel, and the height and tilt of the seat. The goal was to create a virtual environment that accurately reflected the posture and movements of a real driver. This was crucial for conducting a reliable and accurate Lower Back Analysis (LBA) in the next step.

2.7 Lower Back Analysis (LBA)

In this study, we used the Task Analysis Tool set in the Jack Simulation software to perform a Lower Back Analysis (LBA) and assessed the potential risk of lower back discomfort associated with different driving postures. This toolset incorporates a comprehensive Lower Back Analysis (LBA) module that utilizes a biomechanical model of the spine to estimate forces, stresses, and moments acting on various spinal segments during simulated driving tasks. The LBA was essential for establishing how comfortable the driving position was, as extended sitting can harm the ligaments and muscles in the lower back. The sophisticated lower back model of the Manikin i.e. Digital Human Model (DHM) was examined using the LBA module of JACK to gauge the effects of forces on the L4 and L5 vertebrae [24]. Downward stresses of 2kg were applied to the DHM's hands during analysis to replicate the driver holding the steering wheel. The analysis's findings demonstrated that in this driving posture, the left and right erector spine muscles (ES-1 and ES-r) were subjected to the greatest stresses. However, as shown by the low compression and AP Shear values, the green bars in the chart, and the relatively tiny moments at L4/L5 of the spine in each direction, the forces at L4/L5 were within an acceptable range.

To evaluate if the lower back forces encountered by the driver while driving a vehicle were within an acceptable range for comfort, the LBA results were compared to suggested values from the National Institute for Occupational Safety and Health [24]. The analysis suggests that the driver's lower back was under normal force while driving the vehicle (Fig. 11). The LBA results from the Jack Simulation software provided valuable insights into the driving posture and its impact on the lower back, helping to ensure the comfort and well-being of drivers. This can help to reduce the risk of injury or discomfort associated with prolonged driving and improve the overall driving experience.

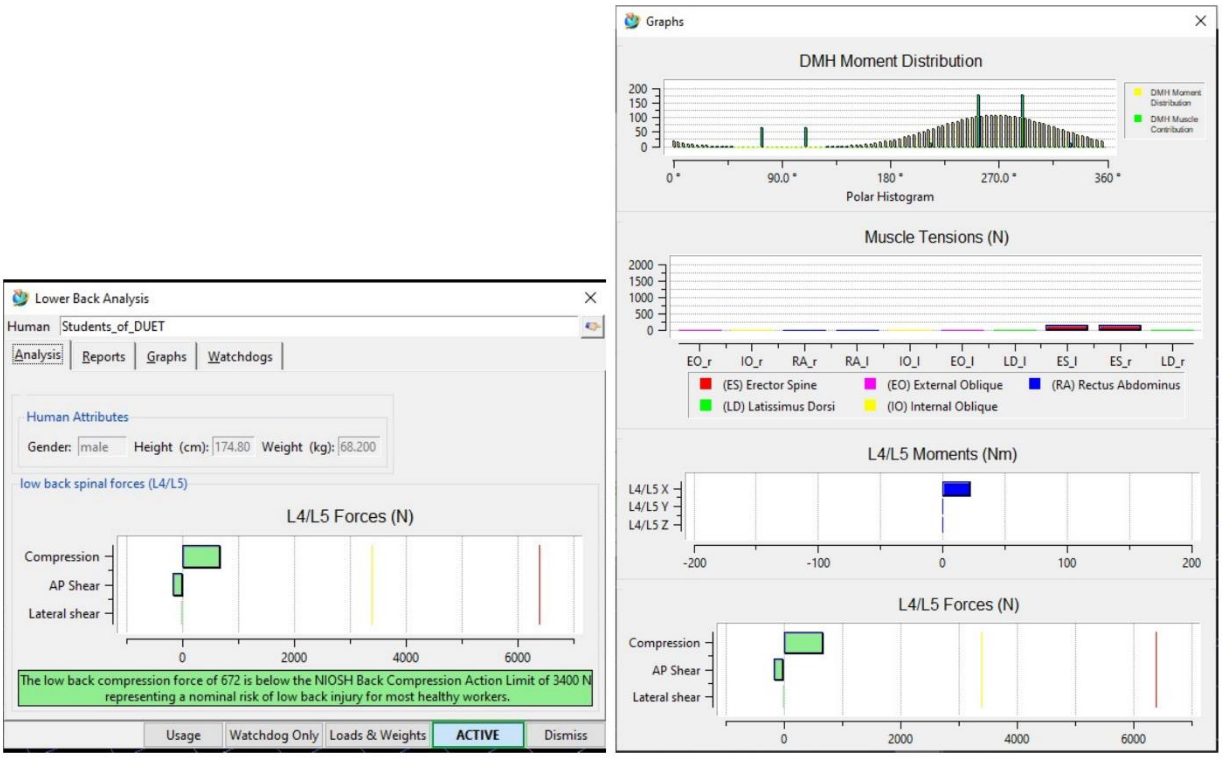

Fig. 11 - Lower Back Analysis LBA results of most preferred driving posture.

3. Results

The result of the Comfort Analysis and Lower Back Analysis (LBA) conducted using the JACK software yielded positive outcomes. The comfort assessment tools in JACK software were updated with angle data collected from the University premises survey, ensuring accurate and representative evaluations of the driver's posture and comfort. The digital human model (DHM) was adjusted to fall within the comfort range defined by the survey data, providing an optimal posture simulation. During the LBA, the analysis revealed that the forces exerted on the lower back were within an acceptable range for comfort. The left and right erector spine muscles (ES-1 and ES-r) experienced the greatest forces, but the moments at L4/L5 of the spine were relatively small in each direction. The compression and AP shear values were low, indicating that the forces at L4/L5 were within acceptable limits. This finding was compared to the recommended values from the National Institute for Occupational Safety and Health (NIOSH), confirming that the lower back forces were with-in an acceptable range for comfort. The LBA results provided valuable insights into the driving posture and its impact on the lower back. The analysis indicated that the driver's lower back was under normal force while operating the vehicle. The low back compression force of 672.00 was below the NIOSH Back Compression Action Limit of 3400 N, signifying a nominal risk of low back injury for most healthy workers. Overall, the Comfort Analysis and LBA demonstrated that the optimized posture and ergonomic design of the driver's position in the vehicle reduced the risk of discomfort and potential injury associated with prolonged driving. These findings contribute to enhancing the comfort, well-being, and overall driving experience for drivers. This tool employs a validated spine model to estimate internal spinal loads during a driving task, providing quantitative data on potential biomechanical effects. Despite model simplifications, the LBA tool offers a standardized approach for comparable data. However, environmental factors like vibrations and sudden maneuvers were not explicitly considered in this analysis, suggesting areas for future research.

4. Conclusion and Future Scope

This approach can serve as a valuable tool for evaluating and improving the comfort of various seating configurations and has the potential to be widely adopted throughout the state. With the confidence in the accuracy of the survey data, the DHM can now be used to evaluate the posture of individual drivers and determine if they are within a comfortable range. DHM simulation provided valuable insights into the biomechanics of driving posture, we acknowledge areas for further refinement. Incorporating dynamic muscle activation models, individual anatomical variations, and real-world vehicle dynamics could enhance the simulation's accuracy and applicability. Additionally, validating results with real-world biomechanical data and exploring long-term postural impact would strengthen the comprehensiveness of future studies. These advancements hold promise for DHM simulations to become even more powerful tools in optimizing driving posture for comfort and long-term musculoskeletal health. This study provides valuable insights into the relationship between posture and comfort and offers a practical approach for evaluating and enhancing seated comfort in various settings. This study can offer valuable insights not just for better understanding and improving the comfort of everyday drivers, but also serve as a useful guide for vehicle manufacturers in designing more comfortable driving seats, especially for those who make driving their profession. Consequent to this investigation, it is deduced that the driving posture typically adopted by the average Pakistani male populace is deemed safe, aligning effectively with the stipulated benchmarks set forth by the National Institute for Occupational Safety and Health (NIOSH). This affirmation serves to validate that the observed driving posture maintains a level of safety well within the confines of the prescribed safety parameters, as outlined by NIOSH guidelines.

The current study presents a systematic approach for evaluating the comfort levels of drivers while operating a vehicle. The methodology and results obtained from this study can serve as a foundation for future work in this field. There are several areas where the current study can be expanded upon, including:

- Extending the Study to a Wider Population: The study was conducted using a single digital human model and a small sample of participants. Future studies could expand the sample size and consider different body types and sizes to obtain a more comprehensive understanding of driver comfort levels.
- Adding More Complex Postures: The current study focused on a single posture, that of a driver operating a vehicle. Future studies could consider other postures, such as passengers or drivers operating other types of vehicles, to obtain a more comprehensive understanding of human comfort levels in different situations.
- Incorporating Real-Time Monitoring: The current study relied on survey data to gather joint angle information. Future studies could incorporate wearable sensors to monitor joint angles in real-time, providing a more accurate and up-to-date understanding of driver comfort levels.
- Integrating Vehicle Design: The current study focused on the comfort levels of drivers but did not consider the design of the vehicle. Future studies could integrate vehicle design and evaluate the impact of different vehicle features, such as seat design and placement, on driver comfort levels.

In conclusion, the study provides a valuable contribution to the field of driver comfort and offers a promising foundation for future research in this.

Acknowledgement and Data Inclusion statement

We would like to express our sincere gratitude to all the participants (subjects) who volunteered for this study and cooperated in data collection. Their willingness to contribute their time and efforts has been invaluable to the success of this research project. We are deeply thankful for their participation and cooperation, without which this study would not have been possible. The data collected in this study ensure the privacy and confidentiality of the participants.

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