**Ergonomics in Automotive Design**
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**Module-2**
**Lecture - 03**
**Anthropometric and Biomechanical Data in Automotive Design**

Welcome to the course Ergonomics in Automotive Design.

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Today we are going to discuss the second module that is Anthropometric and Biomechanical Data in Automotive Design. So, under this module, we will discuss three topics. First topic is; basic knowledge of anthropometry and biomechanics, second - application of percentile anthropometric data in automotive design and the third one is application of percentile biomechanical data in automotive design. So, these three topics will be covered. So, for understanding anthropometric and biomechanics; first, it is important to understand body planes and body landmarks.

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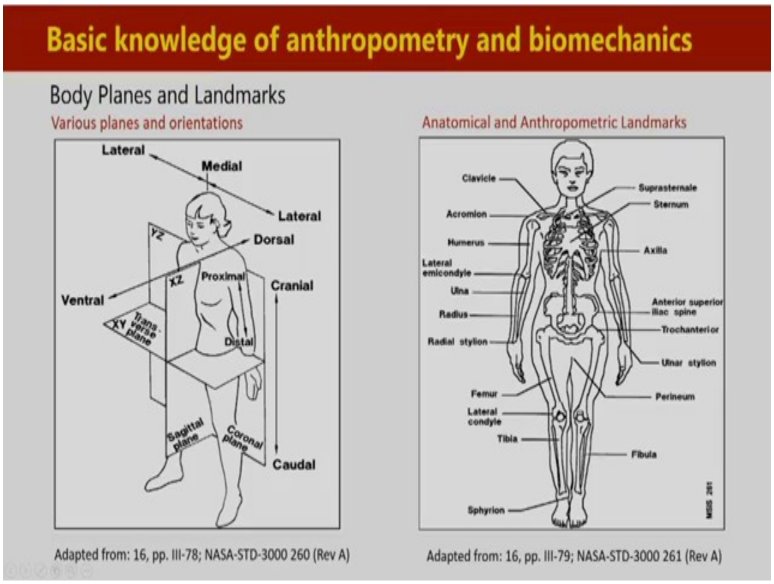


So, while we are discussing anthropometry or biomechanics, then how human body measurements are taken, at the same time how the human body moves, for that purpose, the knowledge of body planes is important. So, how body planes are defined? If you look at this image; then there are mainly three planes; first one - Sagittal plane; which divides our body in left and right half; another plane - Coronal plane, that divides human body into front portion and back portion. There is one more plane which is called Transverse plane, which divides the body into upper and lower half. So, this is actually a horizontal plane.

Now, the front side is called Ventral side, and the backside is called Dorsal side. Similarly, sidewise it is called Lateral side, and whenever it is towards mid-line, then it is called Medial. If the movement or measurement is happening towards the head; that is called Cranial, and if it is away from the heart, that is called Caudal side. Now, for understanding anthropometry; we also need to know different anatomical landmarks; for that purpose, basic understanding of anatomy, like which are the major bones, which are the major joints, we have to know.

So, in this image, various anatomical landmarks are presented.

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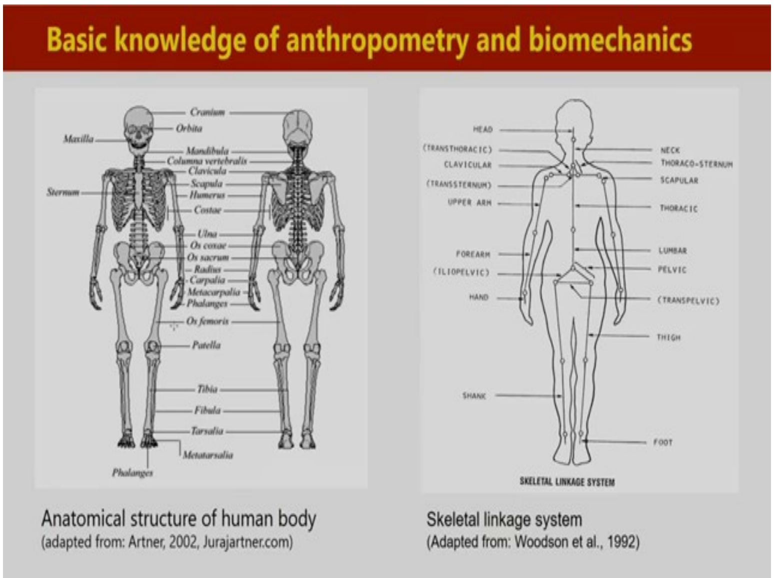


Now, anatomical structure of body; so, at least basic understanding, like which are the major bones, if we look, this is the skull, then vertebral column, pelvic girdle, then the leg bone; this is femur, then tibia and fibula and then the bones in the foot, where there is tarsal, metatarsal, phalanges bones are there. Similarly, if we look, this is the ribcage and if we consider the hand bones. So, which are the various bones in arms and hand? So, one is humerus, then here are two bones – radial and ulnar and similarly like foot; in hand also, there are various bones which are known as carpal, metacarpal and phalanges.

If we study human anatomy, then we can see; in the skull, there are immovable joints, on the other hand in the vertebral column, there are various movable joints. Human body is also described in terms of linked body segments. So, whatever is the skeleton structure, various joints are present on that skeleton structure, and similarly, we can represent that skeleton structure in linked body segments. So, various body segments, which are connected through various joints. So, those are depicted in this picture.

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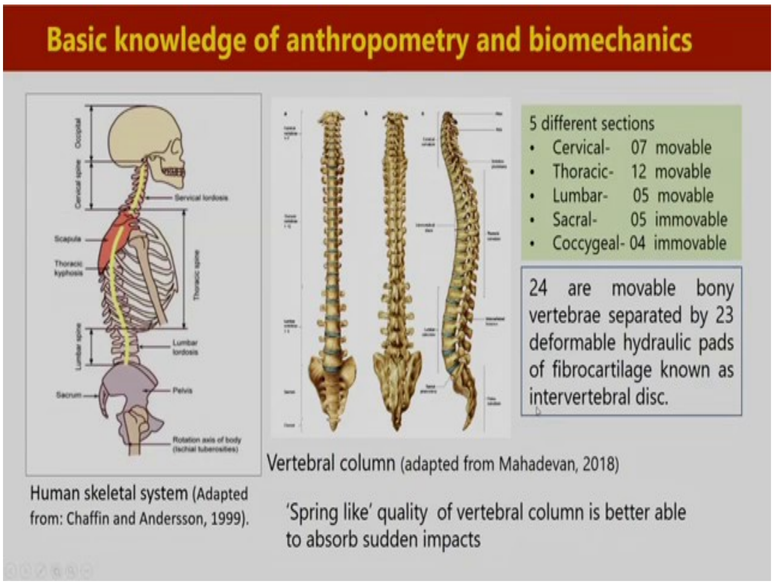


Now, particularly if we consider vertebral column, in the vertebral column, so, generally that is, this type of 'S' shaped and in that vertebral column, there are various segments. So, this is the image of the vertebral column. So, this is the back-view, this is the front-view in ventral side, this is the dorsal side, and this is the side-view. From the side-view, if we look at this particular portion near the neck, that is called cervical region.

In the cervical region, there are total seven moveable bones. Next portion; that is called the chest portion or thoracic portion. In thoracic portion, how many bones are there total? Twelve movable bones are there, means, 12 movable vertebrae are there. So, this is that 12 movable vertebrae portion. After that, there is this portion, that is called lumbar area; here it is the lumbar area. In lumbar area, how many bones are there? Five bones are there, and these five bones are also movable.

After the lumbar area, the next area is called sacral area. In sacral area, there are five bones, but these five bones are fused, and those are immovable. So, you can consider these five bones fused, and it is making only one structure, and that is immovable. Similarly, in the last portion; the tail portion, there is total of four immovable bones, and those four bones are also fused, it can be considered like one structure. So, overall in our vertebral column, total 24 movable boney vertebrae are there and which are separated by intervertebral disc which is cartilaginous and soft tissue material.

So, you can see, here in this vertebral column structure. So, in between two bones, there is this type of, where it is blue shaded. So, this is intervertebral disc; this is the soft tissue material made up of cartilage. So, spring-like quality of vertebral column is better to absorb the shock; when there is any shock in the body, someone is jumping or running; then the shock is there, or carrying a load, then the shock is absorbed in this vertebral column due to its spring-like structure.

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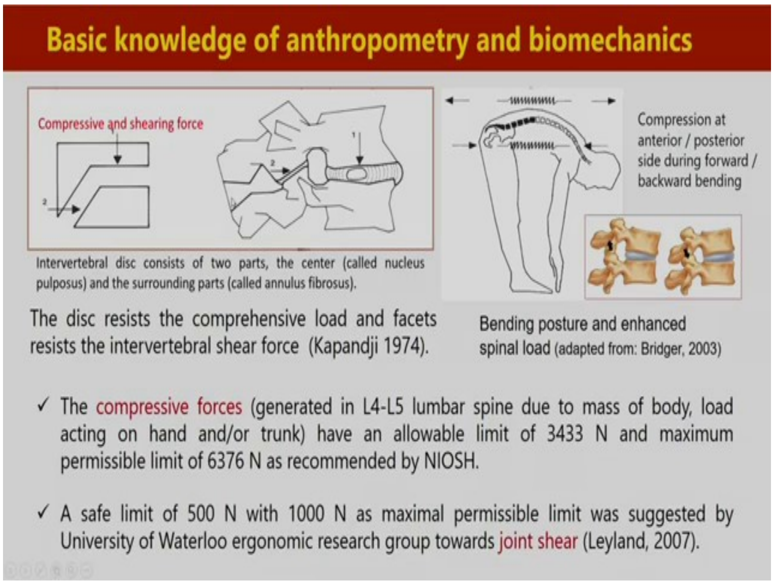


Now, in the vertebral column, this is the intervertebral disc. So, intervertebral disc consists of two parts - the central part is called nucleus pulposus and the surrounding part; this is a central portion and the surrounding part (peripheral portion) that is called annulus fibrosus. So, one is nucleus pulposus, and another is annulus fibrosus.

The disc resists the comprehensive load and the facets (this boney structure) that resists the intervertebral shearing force. So, while the human body is bending forward or bending backwards, then this intervertebral disc compression happens, and this is more prominent in the lumbar area. So, as we already mentioned; in lumbar area; if you go to the earlier slide, there are a total of five moveable bones in the lumbar area; maximum compressive and shearing forces occur.

Now, while this type of compressive or shearing force is happening, say, the human body is bending forward, then there is forward compression or there is compression at the anterior portion of the intervertebral disc. Similarly, while the human body is bending in the backward direction, then there is compression at the posterior portion of the intervertebral disc. Due to this type of compressive force or in other cases of shearing force; what happens? Sometimes, these intervertebral disc bulges out and that touches the spinal cord or spinal nerve passing by this intervertebral vertebral column.

So, our spinal cord is actually, if we go to the earlier image, this one; so, our spinal cord is actually passing through this area. So, while there the intervertebral disc bulges out and touching the spinal nerve or nerve fibres coming out from the spinal cord then there is sensation of pain.

So, mainly this is the reason for back pain, that intervertebral disc bulges out and is touching the nerve fibres and compressing the nerve fibres. The compressive forces are generated in the L4 and L5 segment of the lumbar spine due to mass of the body or due to load carriage in hand or on the trunk, there is compressive force. The allowable limit of this compressive force is 3433 Newton, and maximum permissible limit is 6376 Newton, as recommended by NIOSH.

On the other hand, this is related to a compressive force, but in case of shearing force the safe limit is 500 Newton. So, up to 500 Newton it is safe, but maximum allowable or maximum permissible limit is 1000 Newton; not more than that. So, this has been suggested by University of Waterloo Ergonomics Research group.

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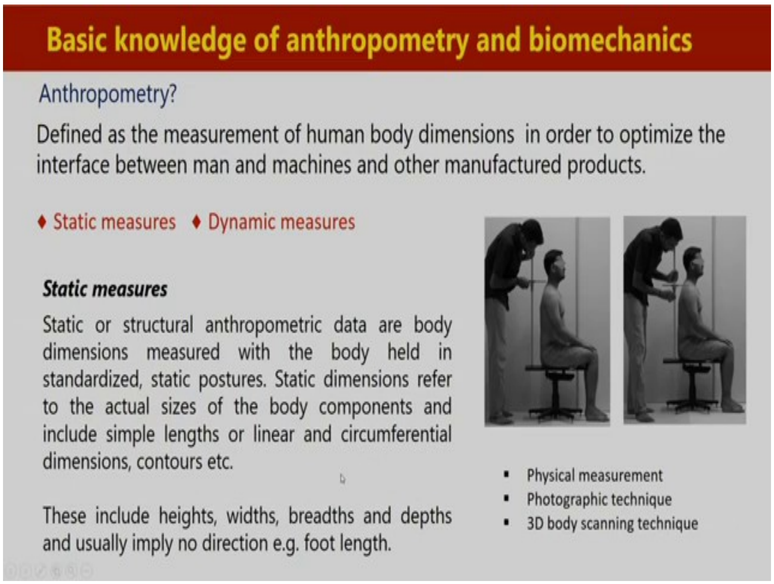

Now, after this basic understanding of human body planes, human anatomy and landmarks, now we are moving to study of anthropometry and biomechanics. So, first; what is anthropometry or what is the definition of anthropometry.

So, anthropometry can be defined as the measurement of human body dimensions in order to optimize the interface between man and machine and other manufactured product. So, in brief; what is anthropometry? Anthropometry is a measurement of the human body and use of those measured data for the purpose of design and evaluation of various facility or products. Anthropometry can be mainly categorized into two types; one is static measurement; another is dynamic measurement.

So, first; we are discussing about static measurement. So, in static measures; it is also called static or structural anthropometry. Static or structural anthropometric data are body dimensions measured when the body held in standardized or static posture. Static dimensions refer to the actual sizes of the body components and include simple lengths or linear and circumferential dimensions, contours etcetera.

So, during static anthropometric measurement, the human body is in static posture and at that time with anthropometric measurement kit, different body dimensions like length, breadth, circumference, skin-fold thickness, so, these types of various measurements are taken. Now for anthropometric measurement; there are various techniques; physical measurement with anthropometric kit that is possible, similarly there are other techniques like photogrammetric techniques or photographic techniques; at the same time 3D body scanning; nowadays 3D body scanners are available.

So, the whole body can be, or even individual body parts can be scanned with 3D imaging system.

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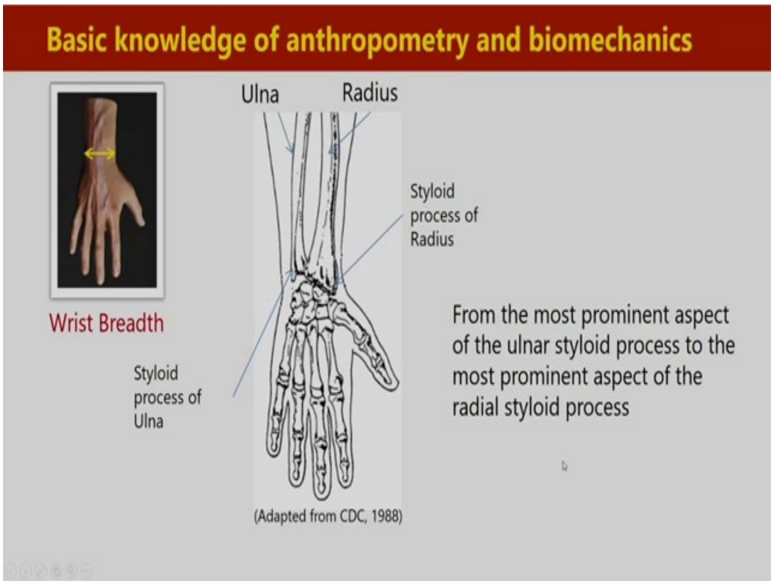


So, now as in the earlier section, we have discussed that understanding body landmarks and anatomy is very important for anthropometric measurement as well as for biomechanical measurement. For example, if we want to measure the wrist breadth. Now, if we look at the hand, it is not clear exactly which portion of the wrist is to be measured for measuring the wrist breadth. It may be this portion, this portion. So, exactly at which point we have to measure? For that purpose, we must have to know the body landmarks; based on the body landmarks; we can define the exact location.

So, body landmarks are boney protrusion which can be held below the flesh or skin. So, if we want to measure the wrist breadth, then we have to identify by pressing this flesh portion at the wrist that where is the location of styloid process of ulna. So, this is the ulna bone and where is the styloid process, on the lateral side. Similarly, on radius bone, where is the styloid process of the radial bone?

Now, if we can identify these two boney protrusion, then easily we can measure the distance as the wrist breadth using sliding callipers, we can use for this purpose, sliding callipers.

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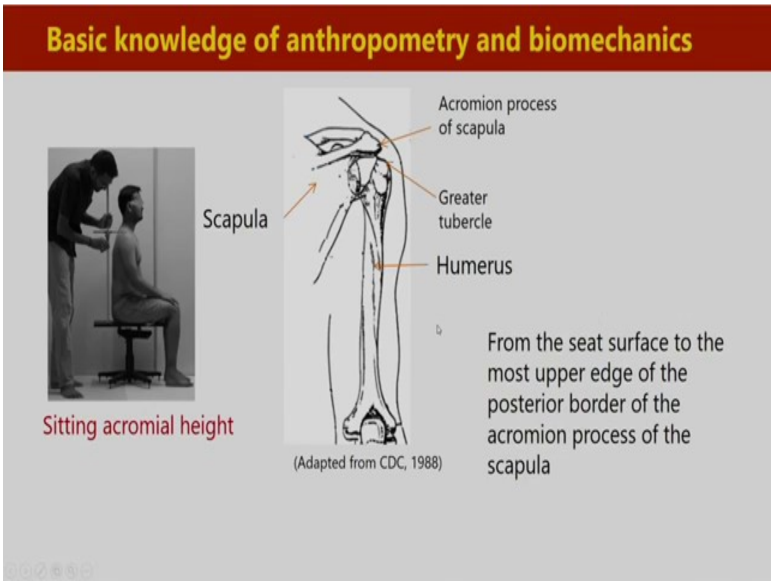


Similarly, while we are measuring the sitting acromial height, we have to identify where is the acromion process of the scapula. So, from the anatomical structure, you can see this is the scapular bone, from the scapula, this is the acromion process of the scapula and this is the humerus bone and this is the greater tubercle of the femur bone. So, now, for measuring the sitting acromial height, we have to measure from the seat surface to this height, the position of the acromion. So, how we measure? From the seat surface to the uppermost edge of the posterior border of the acromion process of the scapula.

So, if we can particularly identify this point, then only the measurement is correct; otherwise, the exact measurement will not be possible.

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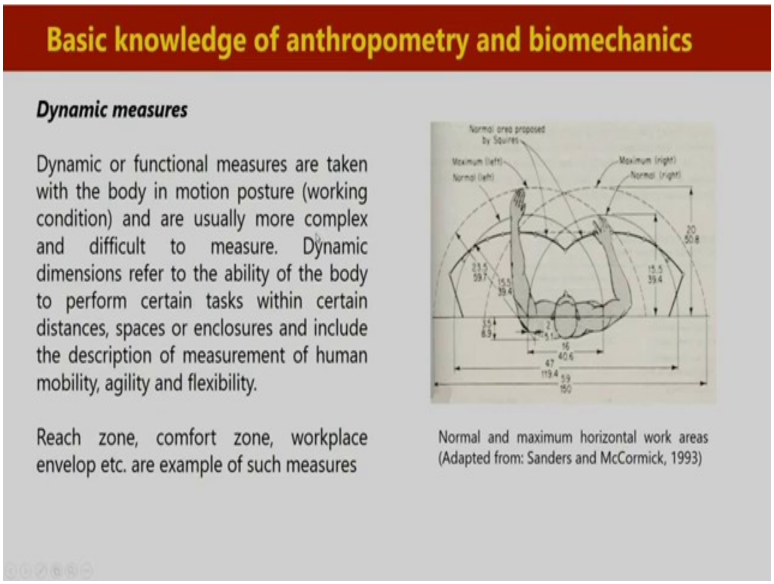


After static anthropometry, now we are discussing dynamic anthropometry or dynamic measures. Dynamic or functional measures are taken with the body in motion; in the working condition, these are usually more complex and difficult to measure. Dynamic dimensions refer to the ability of the body to perform certain tasks within certain distances, spaces or enclosures and include the description of measurement of human mobility, agility and flexibility.

So, during dynamic anthropometric measurement, these measurements are taken while human body parts are in motion, means, human are performing different types of activity. During that time, if we are measuring reach envelope, reach distance or say, for example, mobility of particular body joint, then that is coming under dynamic measures. But this mobility of body joint, range of motion, we are generally considering under biomechanics.

So, reach zones, comfort zones, workplace envelope etcetera are the example of such measurement under dynamic anthropometric measurement. So, here you can see the normal and maximum horizontal work areas. While some person is sitting in front of a table or working surface, then due to a swipe of both hands, how much area he can reach, which parts he can reach comfortably and maximum by extending the hand, how much area he can reach. So, that is the reach zone.

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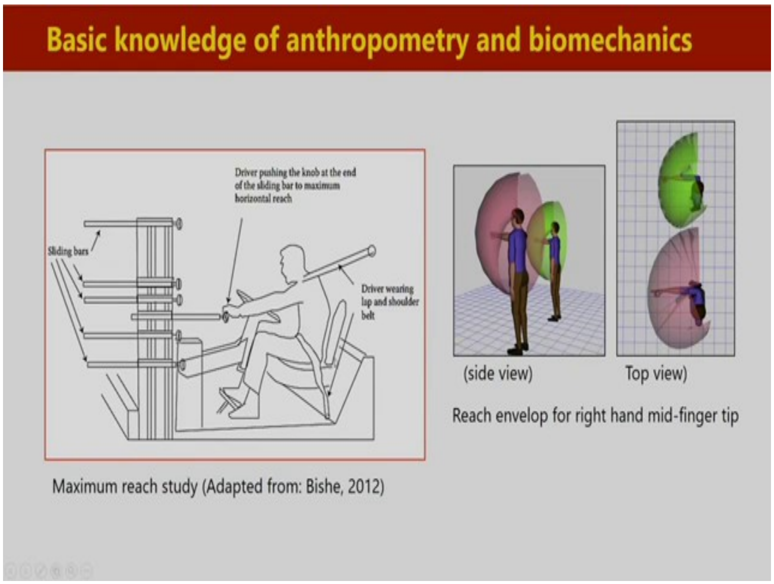


Comfortable reach zone as well as the extended arm reach zone. Similarly, we can also measure, say, in the driving simulator, say, for example, for measuring the reach envelope for driver while there is the seat belt or lap belt; at that time how much area or a volume, the driver can reach? So, for that purpose, this type of setup is prepared where the driver can push or pull this type of knobs attached with the sliding bar and based on that how much area he can reach, we can ultimately get the reach zone or reach envelope.

If we look at this slide; side images. So, here this is actually created with the digital human model. So, for the right-hand reach envelope, for larger person as well as smaller person, how is the shape? You can see; this is the reach volume for the side-view. Similarly, how much area can be reached with the fingertip of the right hand that is shown; this is the top view for larger human model as well as smaller human model. So, automatically you can see the area or reach area or reach envelope for larger human body dimension; obviously, it is a bigger one for the bigger person; for a smaller human model, it is a smaller one.

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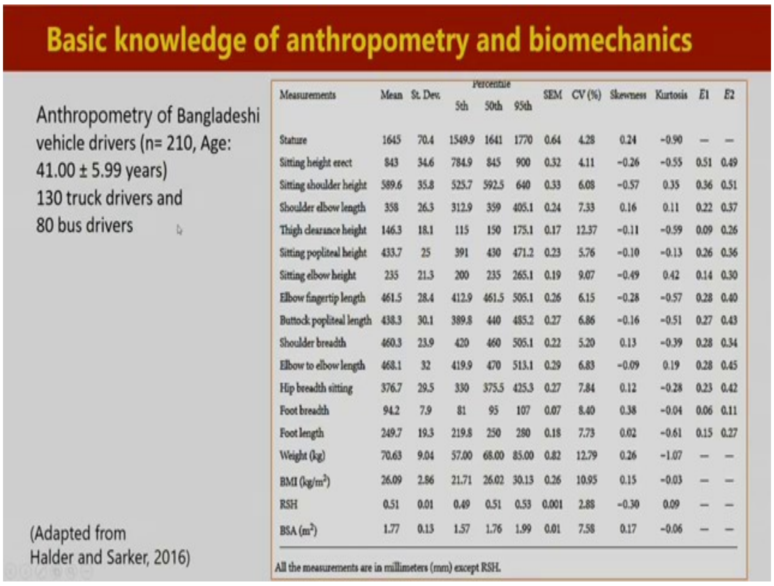


| Measurements | Mean | St. Dev. | Percentile 5th | Percentile 50th | Percentile 95th | SEM | CV (%) | Skewness | Kurtosis | E1 | E2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stature | 1645 | 70.4 | 1549.9 | 1641 | 1770 | 0.64 | 4.28 | 0.24 | −0.90 | — | — |
| Sitting height erect | 843 | 34.6 | 784.9 | 845 | 900 | 0.32 | 4.11 | −0.26 | −0.55 | 0.51 | 0.49 |
| Sitting shoulder height | 589.6 | 35.8 | 525.7 | 592.5 | 640 | 0.33 | 6.08 | −0.57 | 0.35 | 0.36 | 0.51 |
| Shoulder elbow length | 358 | 26.3 | 312.9 | 359 | 405.1 | 0.24 | 7.33 | 0.16 | 0.11 | 0.22 | 0.37 |
| Thigh clearance height | 146.3 | 18.1 | 115 | 150 | 175.1 | 0.17 | 12.37 | −0.11 | −0.59 | 0.09 | 0.26 |
| Sitting popliteal height | 433.7 | 25 | 391 | 430 | 471.2 | 0.23 | 5.76 | −0.10 | −0.13 | 0.26 | 0.36 |
| Sitting elbow height | 235 | 21.3 | 200 | 235 | 265.1 | 0.19 | 9.07 | −0.49 | 0.42 | 0.14 | 0.30 |
| Elbow fingertip length | 461.5 | 28.4 | 412.9 | 461.5 | 505.1 | 0.26 | 6.15 | −0.28 | −0.57 | 0.28 | 0.40 |
| Buttock popliteal length | 438.3 | 30.1 | 389.8 | 440 | 485.2 | 0.27 | 6.86 | −0.16 | −0.51 | 0.27 | 0.43 |
| Shoulder breadth | 460.3 | 23.9 | 420 | 460 | 505.1 | 0.22 | 5.20 | 0.13 | −0.39 | 0.28 | 0.34 |
| Elbow to elbow length | 468.1 | 32 | 419.9 | 470 | 513.1 | 0.29 | 6.83 | −0.09 | 0.19 | 0.28 | 0.45 |
| Hip breadth sitting | 376.7 | 29.5 | 330 | 375.5 | 425.3 | 0.27 | 7.84 | 0.12 | −0.28 | 0.23 | 0.42 |
| Foot breadth | 94.2 | 7.9 | 81 | 95 | 107 | 0.07 | 8.40 | 0.38 | −0.04 | 0.06 | 0.11 |
| Foot length | 249.7 | 19.3 | 219.8 | 250 | 280 | 0.18 | 7.73 | 0.02 | −0.61 | 0.15 | 0.27 |
| Weight (kg) | 70.63 | 9.04 | 57.00 | 68.00 | 85.00 | 0.82 | 12.79 | 0.26 | −1.07 | — | — |
| BMI ($kg/m^2$) | 26.09 | 2.86 | 21.71 | 26.02 | 30.13 | 0.26 | 10.95 | 0.15 | −0.03 | — | — |
| RSH | 0.51 | 0.01 | 0.49 | 0.51 | 0.53 | 0.001 | 2.88 | −0.30 | 0.09 | — | — |
| BSA ($m^2$) | 1.77 | 0.13 | 1.57 | 1.76 | 1.99 | 0.01 | 7.58 | 0.17 | −0.06 | — | — |

All the measurements are in millimeters (mm) except RSH.

Now, after collecting the anthropometric data; that is tabulated. So, here is one example; anthropometry of Bangladeshi vehicle drivers. This data was collected from 210 truck drivers and bus drivers. So, 130 truck drivers were there, and 80 bus drivers were there; total 210; in the age group 41 plus minus almost six years. So, hereafter collecting the anthropometric data for various anthropometric variables like stature, sitting height, sitting shoulder height, sitting elbow height, sitting elbow length, thigh clearance height. So, all the data tabulated here. So, data is presented like mean, standard deviation, then various percentile values - 5$^{th}$ percentile, 50$^{th}$ percentile 95$^{th}$ percentile.

So, all these statistical terms like percentile, mean, standard deviation; we will discuss in later sections. So, in this way, we get from the tabular datasheet, we can get various percentile values and those values, next, we can use for various facility or product design.

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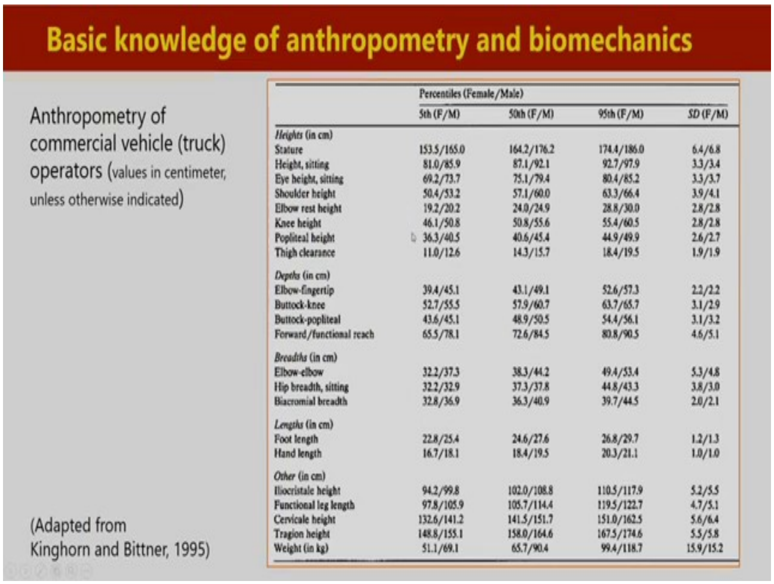


| | Percentiles (Female/Male) | | | |
|---|---|---|---|---|
| | 5th (F/M) | 50th (F/M) | 95th (F/M) | *SD* (F/M) |
| *Heights* (in cm) | | | | |
| Stature | 153.5/165.0 | 164.2/176.2 | 174.4/186.0 | 6.4/6.8 |
| Height, sitting | 81.0/85.9 | 87.1/92.1 | 92.7/97.9 | 3.3/3.4 |
| Eye height, sitting | 69.2/73.7 | 75.1/79.4 | 80.4/85.2 | 3.3/3.7 |
| Shoulder height | 50.4/53.2 | 57.1/60.0 | 63.3/66.4 | 3.9/4.1 |
| Elbow rest height | 19.2/20.2 | 24.0/24.9 | 28.8/30.0 | 2.8/2.8 |
| Knee height | 46.1/50.8 | 50.8/55.6 | 55.4/60.5 | 2.8/2.8 |
| Popliteal height | 36.3/40.5 | 40.6/45.4 | 44.9/49.9 | 2.6/2.7 |
| Thigh clearance | 11.0/12.6 | 14.3/15.7 | 18.4/19.5 | 1.9/1.9 |
| *Depths* (in cm) | | | | |
| Elbow-fingertip | 39.4/45.1 | 43.1/49.1 | 52.6/57.3 | 2.2/2.2 |
| Buttock-knee | 52.7/55.5 | 57.9/60.7 | 63.7/65.7 | 3.1/2.9 |
| Buttock-popliteal | 43.6/45.1 | 48.9/50.5 | 54.4/56.1 | 3.1/3.2 |
| Forward/functional reach | 65.5/78.1 | 72.6/84.5 | 80.8/90.5 | 4.6/5.1 |
| *Breadths* (in cm) | | | | |
| Elbow-elbow | 32.2/37.3 | 38.3/44.2 | 49.4/53.4 | 5.3/4.8 |
| Hip breadth, sitting | 32.2/32.9 | 37.3/37.8 | 44.8/43.3 | 3.8/3.0 |
| Biacromial breadth | 32.8/36.9 | 36.3/40.9 | 39.7/44.5 | 2.0/2.1 |
| *Lengths* (in cm) | | | | |
| Foot length | 22.8/25.4 | 24.6/27.6 | 26.8/29.7 | 1.2/1.3 |
| Hand length | 16.7/18.1 | 18.4/19.5 | 20.3/21.1 | 1.0/1.0 |
| *Other* (in cm) | | | | |
| Iliocristale height | 94.2/99.8 | 102.0/108.8 | 110.5/117.9 | 5.2/5.5 |
| Functional leg length | 97.8/105.9 | 105.7/114.4 | 119.5/122.7 | 4.7/5.1 |
| Cervicale height | 132.6/141.2 | 141.5/151.7 | 151.0/162.5 | 5.6/6.4 |
| Tragion height | 148.8/155.1 | 158.0/164.6 | 167.5/174.6 | 5.5/5.8 |
| Weight (in kg) | 51.1/69.1 | 65.7/90.4 | 99.4/118.7 | 15.9/15.2 |

Similarly, this is the datasheet for anthropometry of commercial truck operators adapted from Kinghorn and Bittner (1995). So, here both female and male driver data is presented. So, these are the 5th percentile data for female, and this is the 5th percentile data for male.

Similarly, these are the 50th percentile data, this is the 95th percentile data, and this is a standard deviation for both female and male. So, while there is requirement for various workstation component design, like, say, truck design or any other vehicle design, then these anthropometric data will be very much useful.

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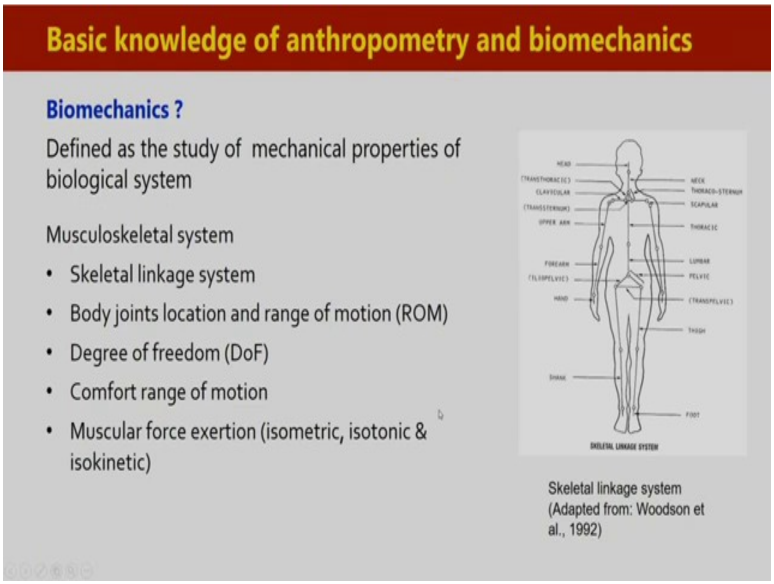


Now, after getting some idea about anthropometry, now we are going to discuss about biomechanics. So, first; what is the definition; what is the biomechanics? How we can define it? So, biomechanics can be defined as a study of mechanical properties of the biological system. As human body is a biological organism; so, obviously, there are various biomechanical properties. So, under these biomechanical properties, we discuss about musculoskeletal system which consists of various skeletal linkage segments, body joint location and range of motion, then for each of the body joints - degree of freedom; in how many directions it can move; then comfort range of motion.

So, the first one was this; range of motion, that is the total range of motion in one individual body joints, how much it can move. But comfort range of motion; out of the total range of motion, in which portion or how much area human can move very comfortably. Then muscular force exertion, it can again be classified as – isometric, isotonic, isokinetic. So, muscular force management is also coming under biomechanical measurement. So, as we discussed earlier, human body can be explained in terms of linked body segments, and these are the various linkages.

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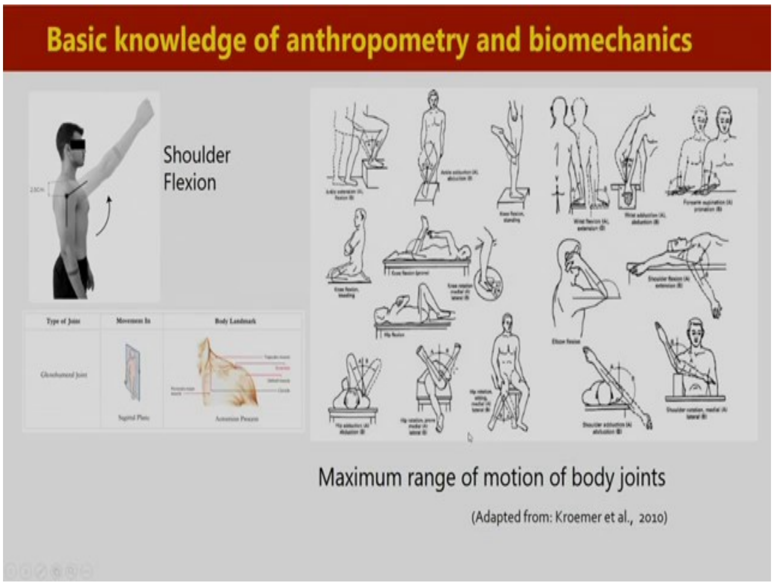


Now, for maximum range of motion or total range of motion for different body parts or different body joints, there are various measurement techniques and we have to follow those measurement techniques for measuring, say, for example, shoulder joint. In case of shoulder joint, there is 3 degree of freedom. So, one is flexion/extension; one is adduction/abduction, another is rotation.

Similarly, for elbow joint; only flexion and extension is possible; similarly for knee joint; only flexion is possible. So, in this way, there are various body joints where total range of motion, means, how much is the starting point and the endpoint of the body joint motion is recorded. If we take the example of shoulder flexion; how it is measured? For measurement purpose we use goniometer. So, goniometer needs to be positioned at this point, again that has to be identified with the help of body landmark, so, as it is defined here. So, it should be on the upper arm, at this particular point and that is 2.5 centimetres below the location of acromion.

This is the acromion point, so, it is 2.5 centimetres below the acromion point, we have to position the fulcrum of the goniometer, and the stationary arm of the goniometer should be vertical. For that purpose, we can take the help of plum bob. And so, this is a vertical line and after that when the hand will be moved in an upward direction for measuring the shoulder flexion, then the movable arm of the goniometer should be kept on that arm and accordingly we will measure the angle. So, in this way, we measure the shoulder flexion.

So, for measurement of shoulder flexion or any other body joints and range of motion; the anatomical landmark is very important, at the same time where to position the goniometer, how to measure those aspects, we have to take very critically to ensure the correct measurement.

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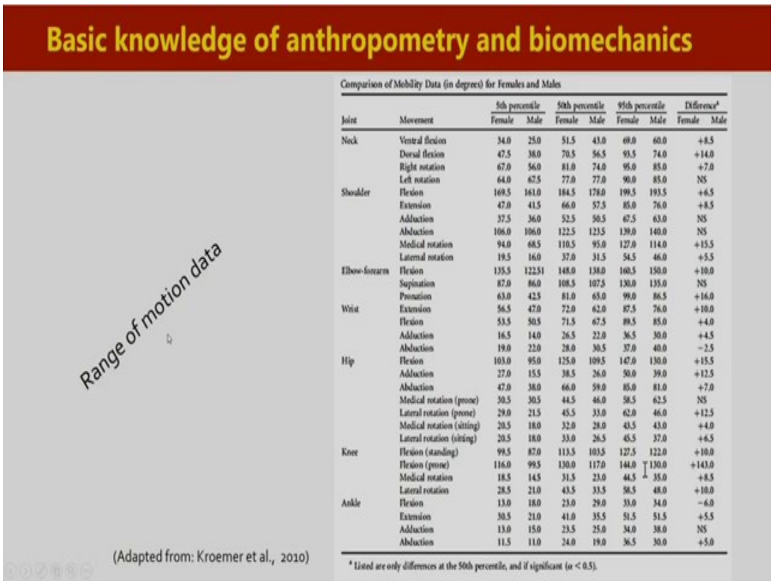


Comparison of Mobility Data (in degrees) for Females and Males

| Joint | Movement | 5th percentile Female | 5th percentile Male | 50th percentile Female | 50th percentile Male | 95th percentile Female | 95th percentile Male | Difference[a] Female Male |
|---|---|---|---|---|---|---|---|---|
| Neck | Ventral flexion | 34.0 | 25.0 | 51.5 | 43.0 | 69.0 | 60.0 | +8.5 |
| | Dorsal flexion | 47.5 | 38.0 | 70.5 | 56.5 | 93.5 | 74.0 | +14.0 |
| | Right rotation | 67.0 | 56.0 | 81.0 | 74.0 | 95.0 | 85.0 | +7.0 |
| | Left rotation | 64.0 | 67.5 | 77.0 | 77.0 | 90.0 | 85.0 | NS |
| Shoulder | Flexion | 169.5 | 161.0 | 184.5 | 178.0 | 199.5 | 193.5 | +6.5 |
| | Extension | 47.0 | 41.5 | 66.0 | 57.5 | 85.0 | 76.0 | +8.5 |
| | Adduction | 37.5 | 36.0 | 52.5 | 50.5 | 67.5 | 63.0 | NS |
| | Abduction | 106.0 | 106.0 | 122.5 | 123.5 | 139.0 | 140.0 | NS |
| | Medical rotation | 94.0 | 68.5 | 110.5 | 95.0 | 127.0 | 114.0 | +15.5 |
| | Lateral rotation | 19.5 | 16.0 | 37.0 | 31.5 | 54.5 | 46.0 | +5.5 |
| Elbow-forearm | Flexion | 135.5 | 122.51 | 148.0 | 138.0 | 160.5 | 150.0 | +10.0 |
| | Supination | 87.0 | 86.0 | 108.5 | 107.5 | 130.0 | 135.0 | NS |
| | Pronation | 63.0 | 42.5 | 81.0 | 65.0 | 99.0 | 86.5 | +16.0 |
| Wrist | Extension | 56.5 | 47.0 | 72.0 | 62.0 | 87.5 | 76.0 | +10.0 |
| | Flexion | 53.5 | 50.5 | 71.5 | 67.5 | 89.5 | 85.0 | +4.0 |
| | Adduction | 16.5 | 14.0 | 26.5 | 22.0 | 36.5 | 30.0 | +4.5 |
| | Abduction | 19.0 | 22.0 | 28.0 | 30.5 | 37.0 | 40.0 | −2.5 |
| Hip | Flexion | 103.0 | 95.0 | 125.0 | 109.5 | 147.0 | 130.0 | +15.5 |
| | Adduction | 27.0 | 15.5 | 38.5 | 26.0 | 50.0 | 39.0 | +12.5 |
| | Abduction | 47.0 | 38.0 | 66.0 | 59.0 | 85.0 | 81.0 | +7.0 |
| | Medical rotation (prone) | 30.5 | 30.5 | 44.5 | 46.0 | 58.5 | 62.5 | NS |
| | Lateral rotation (prone) | 29.0 | 21.5 | 45.5 | 33.0 | 62.0 | 46.0 | +12.5 |
| | Medical rotation (sitting) | 20.5 | 18.0 | 32.0 | 28.0 | 43.5 | 43.0 | +4.0 |
| | Lateral rotation (sitting) | 20.5 | 18.0 | 33.0 | 26.5 | 45.5 | 37.0 | +6.5 |
| Knee | Flexion (standing) | 99.5 | 87.0 | 113.5 | 103.5 | 127.5 | 122.0 | +10.0 |
| | Flexion (prone) | 116.0 | 99.5 | 130.0 | 117.0 | 144.0 | 130.0 | +143.0 |
| | Medical rotation | 18.5 | 14.5 | 31.5 | 23.0 | 44.5 | 35.0 | +8.5 |
| | Lateral rotation | 28.5 | 21.0 | 43.5 | 33.5 | 58.5 | 48.0 | +10.0 |
| Ankle | Flexion | 13.0 | 18.0 | 23.0 | 29.0 | 33.0 | 34.0 | −6.0 |
| | Extension | 30.5 | 21.0 | 41.0 | 35.5 | 51.5 | 51.5 | +5.5 |
| | Adduction | 13.0 | 15.0 | 23.5 | 25.0 | 34.0 | 38.0 | NS |
| | Abduction | 11.5 | 11.0 | 24.0 | 19.0 | 36.5 | 30.0 | +5.0 |

[a] Listed are only differences at the 50th percentile, and if significant ($\alpha < 0.5$).

Now, like anthropometric data, range of motion data for various body joints like neck, shoulder, elbow, forearm, then wrist, hip. So, for various body joints and the various degree of freedom like ventral flexion and dorsal flexion. So, flexion angle, extension angle, rotation angle. So, those angle values are measured, and then those are presented in percentile value - $5^{th}$ percentile, $50^{th}$ percentile, $95^{th}$ percentile value. So, here it is tabulated like female data and male data - $5^{th}$ percentile and these are the data for various body joints.

Similarly, this is the $50^{th}$ percentile data for both female and male, and this is the $95^{th}$ percentile data. So, from this tabular datasheet, we can use this data as per our requirement for various facility design, and we will discuss later that how these anthropometric data are used; the biomechanical data are used for various product and facility design.

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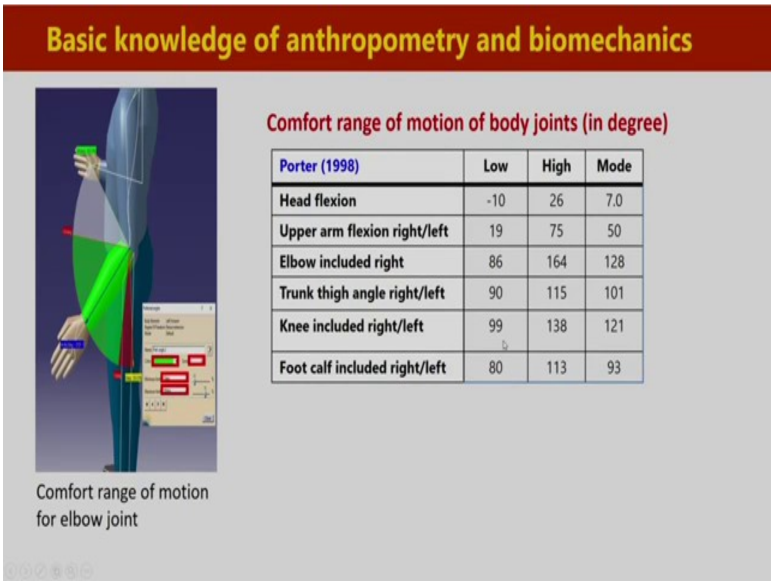


Like the total range of motion, again we need to measure the comfort range of motion. Generally, the comfort range of motion is a particular portion. If you look at this image, particular portion of the total range of motion, where human body segments can be moved comfortably.

So, in this case, if we consider the elbow joint, the initial position, if you consider zero degrees and the final position of the hand movement, lower arm movement, that is say, 170 degree. So, 0 degree to 170 degrees is the total range of motion; for this elbow joint. But out of this total range of motion; only the mid-range, indicated with this green colour, that is the comfort zone for working in standing posture. So, while someone is working in standing posture on a raised surface, on a platform, then this range of motion is considered as the; out of the total range of motion; this middle portion, as for example, here, say, from 15 degrees to almost 100 degree; this range of motion is called as the comfort range of motion.

So, out of the total range of motion, this range is the comfortable range of motion. Similarly, in automotive industry; Porter (1998) he defined that how much will be the comfortable range of motion for various body joint, means, this is for automotive driving only. So, hip flexion; low value it is starting from minus 10 degree, high 26 degree and mode value is 7 degree. So, similarly for foot calf; including right and left. So, lower value is 80-degree, higher value is 113 degree, and mode value is 93 degree. So, in this way, the various types of comfort range of motion databases are available for various types of activity.

So, activity to activity; range of motion data and particularly comfort range of motion data varies based on the working condition or use context. Say for example, whatever is the comfortable range of motion for driving posture that may not be applicable for standing workstation, whatever is the range of motion that is comfortable for the standing workstation that may not be applicable for the sitting workstation. So, while we are measuring the comfort range of motion for particular body joints, then we have to mention it in a particular task context.

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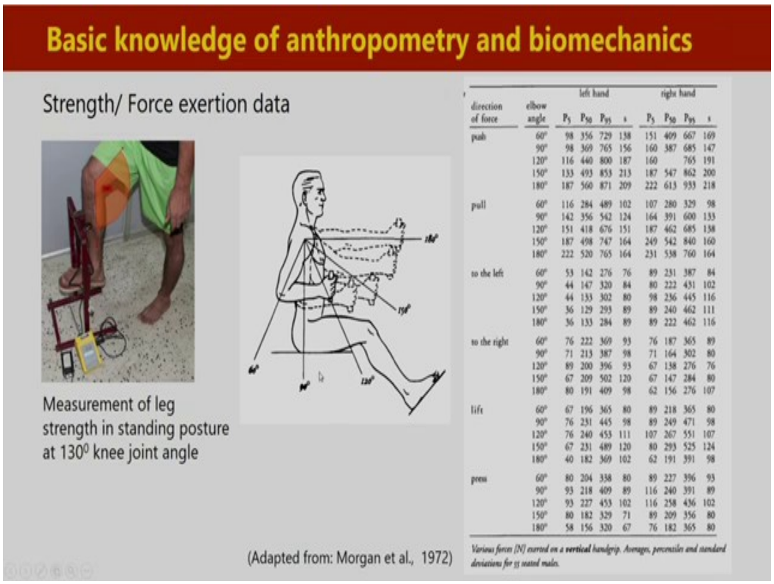


| direction of force | elbow angle | left hand $P_5$ | left hand $P_{50}$ | left hand $P_{95}$ | left hand s | right hand $P_5$ | right hand $P_{50}$ | right hand $P_{95}$ | right hand s |
|---|---|---|---|---|---|---|---|---|---|
| push | 60° | 98 | 356 | 729 | 138 | 151 | 409 | 667 | 169 |
| | 90° | 98 | 369 | 765 | 156 | 160 | 387 | 685 | 147 |
| | 120° | 116 | 440 | 800 | 187 | 160 | | 765 | 191 |
| | 150° | 133 | 493 | 853 | 213 | 187 | 547 | 862 | 200 |
| | 180° | 187 | 560 | 871 | 209 | 222 | 613 | 933 | 218 |
| pull | 60° | 116 | 284 | 489 | 102 | 107 | 280 | 329 | 98 |
| | 90° | 142 | 356 | 542 | 124 | 164 | 391 | 600 | 133 |
| | 120° | 151 | 418 | 676 | 151 | 187 | 462 | 685 | 138 |
| | 150° | 187 | 498 | 747 | 164 | 249 | 542 | 840 | 160 |
| | 180° | 222 | 520 | 765 | 164 | 231 | 538 | 760 | 164 |
| to the left | 60° | 53 | 142 | 276 | 76 | 89 | 231 | 387 | 84 |
| | 90° | 44 | 147 | 320 | 84 | 80 | 222 | 431 | 102 |
| | 120° | 44 | 133 | 302 | 80 | 98 | 236 | 445 | 116 |
| | 150° | 36 | 129 | 293 | 89 | 89 | 240 | 462 | 111 |
| | 180° | 36 | 133 | 284 | 89 | 89 | 222 | 462 | 116 |
| to the right | 60° | 76 | 222 | 369 | 93 | 76 | 187 | 365 | 89 |
| | 90° | 71 | 213 | 387 | 98 | 71 | 164 | 302 | 80 |
| | 120° | 89 | 200 | 396 | 93 | 67 | 138 | 276 | 76 |
| | 150° | 67 | 209 | 502 | 120 | 67 | 147 | 284 | 80 |
| | 180° | 80 | 191 | 409 | 98 | 62 | 156 | 276 | 107 |
| lift | 60° | 67 | 196 | 365 | 80 | 89 | 218 | 365 | 80 |
| | 90° | 76 | 231 | 445 | 98 | 89 | 249 | 471 | 98 |
| | 120° | 76 | 240 | 453 | 111 | 107 | 267 | 551 | 107 |
| | 150° | 67 | 231 | 489 | 120 | 80 | 293 | 525 | 124 |
| | 180° | 40 | 182 | 369 | 102 | 62 | 191 | 391 | 98 |
| press | 60° | 80 | 204 | 338 | 80 | 89 | 227 | 396 | 93 |
| | 90° | 93 | 218 | 409 | 89 | 116 | 240 | 391 | 89 |
| | 120° | 93 | 227 | 453 | 102 | 116 | 258 | 436 | 102 |
| | 150° | 80 | 182 | 329 | 71 | 89 | 209 | 356 | 80 |
| | 180° | 58 | 156 | 320 | 67 | 76 | 182 | 365 | 80 |

*Various forces [N] exerted on a vertical handgrip. Averages, percentiles and standard deviations for 55 seated males.*

Like range of motion; we also measure the strength capability of our various body segments and in those body segments various muscles are there; due to muscular contraction of the skeletal muscle; we exert force. But our force exertion capability is different in a different direction. If we consider this elbow joint and the pull force, elbow joint while it is at 60-degree angle with the upper arm. Then how much force it is exerting? That is different; when the elbow angle is 90 degree or elbow angle is 120 degree. So, based on the elbow joint angle the force capability of the push/pull capability of the arm also varies. So, that is why; during measurement of force data, whether it is for hand or leg, for any other body parts, then we have to define in which direction and at which angle the force is being applied.

So, here one tabulated dataset, where we can see, it is measured for the left hand and right-hand force, at/for the elbow joint. While there is push force or pull force, to the left to the right, lift or press, for different types of force at different elbow angle it is applied, then how is the value? So, these are the 5th percentile value; these are the 50th percentile, similarly 95th percentile value. In lower value, medium value and higher value. This is for left arm; similarly, there is also data for the right hand. So, based on the work activities; whether that work is performed by right hand or left hand or combination of both, so, accordingly we have to select the particular data from this table and accordingly we have to use as per our requirement.

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Now, for this anthropometric or biomechanical measurement, there are various types of measurement techniques, but traditional techniques like, with physical measurement equipment like, for anthropometric measurement - anthropometric rod, various type of sliding callipers, measuring tape for measuring length, similarly circumference, then depth callipers for measuring depth like, chest depth; then measurement of body weight, then body composition analyzer. So, different types of equipment are there, as from these images, you can see - anthropometric rod, anthropometric tape, various types of callipers. Then, this type of skinfold callipers, these are available, and these are used for different types of anthropometric variables measurement.

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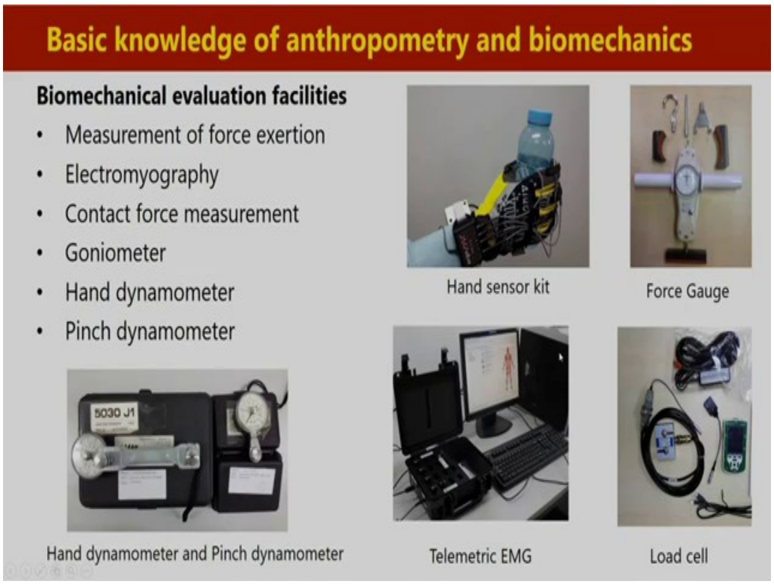


Like anthropometric measurement, there is also various tools and equipments are available for measurement of biomechanical data. So, there is equipment for like, force gauge for measurement of pull force, push force; there is load cell; again, for measuring different types of force exertion, there is electromyographic machine for electromyography, muscle activity measurement or muscle force measurement. There is hand sensor kit for measuring the contact force, while someone is holding some particular object, how much is the contact force between the palm and the surface of the object, that we can measure.

Similarly, there is hand dynamometer, pinch gauge. So, different types of force gauges are available, which are also used for measuring either hand force or pinch force measurement. So, in this way, you can see the list. So, there are various types of equipment which are used for biomechanical measurement; that may be the range of motion measurement, force measurement or comfort range of motion measurement.

Now, after studying at least basic definition of anthropometry, biomechanics, now as during the discussion of anthropometry and biomechanics we are discussing percentile, anthropometric data - 5$^{th}$ percentile, 50$^{th}$ percentile, 95$^{th}$ percentile anthropometric or biomechanical data. So, for understanding these anthropometry and biomechanics, basic knowledge of statistics, particularly the central tendency of the dataset, then percentile calculation, these are very important. So, for that purpose, we are going to discuss some statistical parameters.

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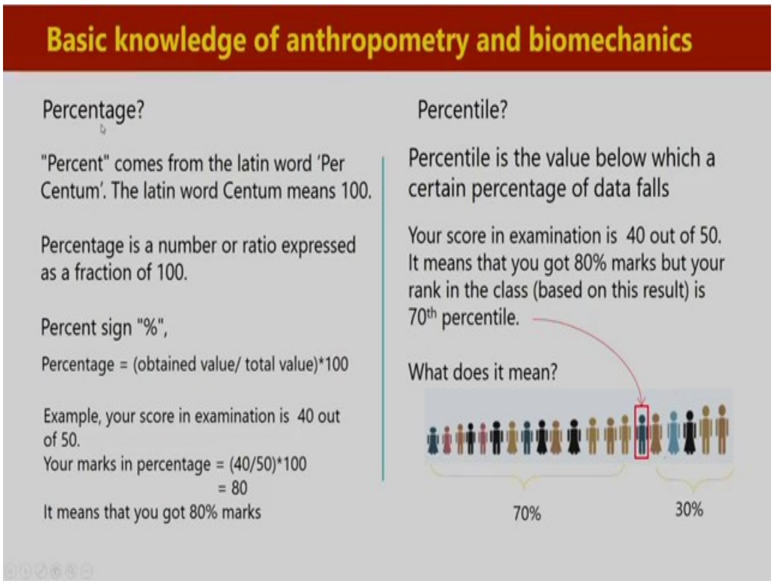


So, first; we are discussing about percentage. So, what is the difference between percentage and percentile? So, if we look at the percent. So, percentage is a; when a data or a value is expressed out of 100, then that is called percentage and this sign (%), we use this particular sign for the percentage. So, percentage is equal to; obtained value divided by the total value into 100. So, it means, proportion out of 100. For example, say, if your score in an examination is 40 out of 50, then how is the percentage of marks? Percentage of marks is 40 divided by 50 into 100 that is 80; it means, you got 80 percent marks.

But in case of percentile; the same marks. So, you got 80 percent marks, but we are mentioning that your percentile or ranking in the class is $70^{th}$ percentile. So, what does it mean? Although you got 80 percent marks, but your rank; your rank means; the marks in comparison to others is $70^{th}$ percentile, means, whatever marks you got, if that is $70^{th}$ percentile, it means, your marks, that 80 percent marks are greater than 70 percent student marks and less than 30 percent student marks. So, actually the percentile is the ranking of your marks; whereas the percentage is the proportion out of 100, means, out of 100 marks, how much you got.

Now, again, we are taking one more example; if we mention that if someone's height is 5th percentile. What does it mean? 5th percentile height means, if we measure from the, in the dataset, 5th percentile height of a particular individual, means, he is taller than 5 percent of the population; if that is the data from the student population and here one particular student's height is, if we mention as the 5th percentile, it means, he is taller than 5 percent student and he is shorter than 95 percent students. Similarly, 95th percentile height, someone's height, say, 160 centimetre and if we mention that this 160-centimetre height is 95th percentile; it means, 95 percent students height is less than 160 centimetre and 5 percent students height is more than 160 centimetre.

Now, how this percentile is calculated? For percentile calculation, there are various methods. So, one of these methods is frequency diagram; cumulative frequency diagram.

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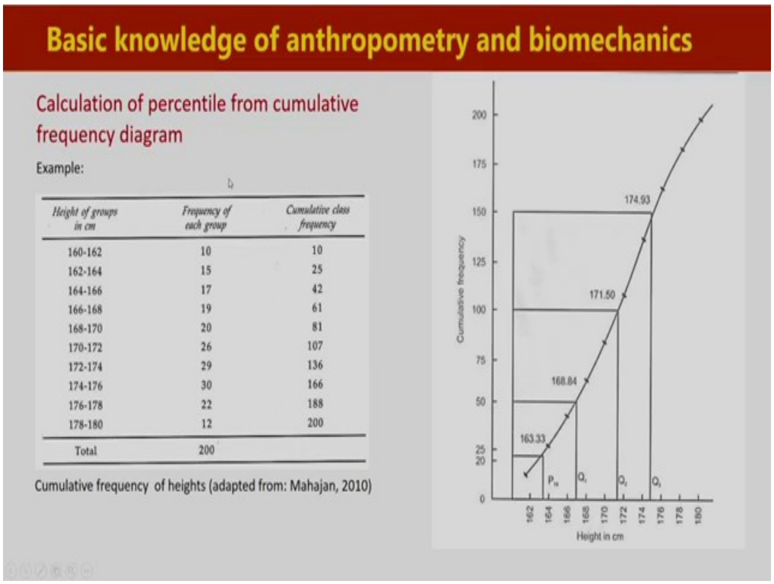


In cumulative frequency diagram, what we do? The total range, say, if in this particular case we are taking the example of heights value. So, if the total range of height; starting from 160 to 180 centimetre; within this range, we can divide in small segment; 160 to 162 centimetres; next segment 162 centimetres to 164 centimetres.

In this way, we can give a small equal segments and in each of the segments; how many students are present; that is 10, 15, these are the number in a particular height group; how many students are there; that is the frequency or the number in that particular height group. Now, while we are presenting this frequency in terms of cumulative frequency;

then what we do? We add; although it is mentioning as that in 160 to 162 centimetres, how many students are there? Ten students are there, but for 162 to 164 centimetres; how many? Total 15 students are there, but while we express in cumulative frequency, then we will mention, we will sum up the earlier ones, 10 plus 15 equals to 25. It means, in this particular age-group; the height range, that is, although we are mentioning 162 to 164 centimetres, actually we are mentioning the number which is present starting from 160 centimetres to 164 centimetres. Similarly, while we are mentioning the cumulative frequency in the group 172 centimetre to 174 centimetres, that is 136, this is the number, cumulative frequency, actually, in that case, we are summing up all these values, means, starting from 160 centimetres to 174 centimetres.

So, 160 centimetres to 174 centimetres, within this range, total how many students are present, that is the 136 students. So, in this way; in cumulative frequency, we actually sum up the frequencies of the earlier groups. Now, if these cumulative frequencies are presented like this way, height in centimetre on X-axis and the number or the frequency - cumulative frequency on the Y-axis. Then in that individual group 160 to 164, how many students are present? 10. So, we are putting that number 10; then the number is 25, then next group, there is 25, so, in that way if we plot; then we will get this type of curve, and that is the cumulative frequency diagram.

From that cumulative frequency diagram, we can calculate various percentile. So, the total number of students, that is 200. That 200 students; that the cumulative frequency 200, that is actually 100 percent students. So, 100 percent students height is covered starting from 160 centimetres and ending at 180 centimetres. Now, these 200 students; that is 100 percent student is within that height range. Now, if we want to calculate 50th percentile, that is. So, if 200 students is 100 percent; then 50 percent is 100 number of students.

So, 100 number; from that if we go laterally and then the line is intersecting at this particular point and then going down on X-axis, then this value, that one point something, assume this particular point is 171.4. So, that particular location is mentioned as the 50$^{th}$ percentile. This location is called 50$^{th}$ percentile; why, because below this height, how many students are present? Fifty percent students are present; 50 percent, means, in this particular case 100 students are there and above this, how many students are there? Above this 50 percent students are there.

So, this particular height value is such a height, if we go back, like this way, this particular point. So, it is indicating that this is the 100 number of students, means, 50 percent students. So, below this height range, 50 percent students are there and above this height range, the remaining 50 percent are there; that is why it is $50^{th}$ percentile. Similarly, if we consider $10^{th}$ percentile; in $10^{th}$ percentile if that value is, say, 63.8. So, this is, you can see, below that 10 percent students are there. So, this is the 10 percent student and above that, this portion. So, this is that one particular height value.

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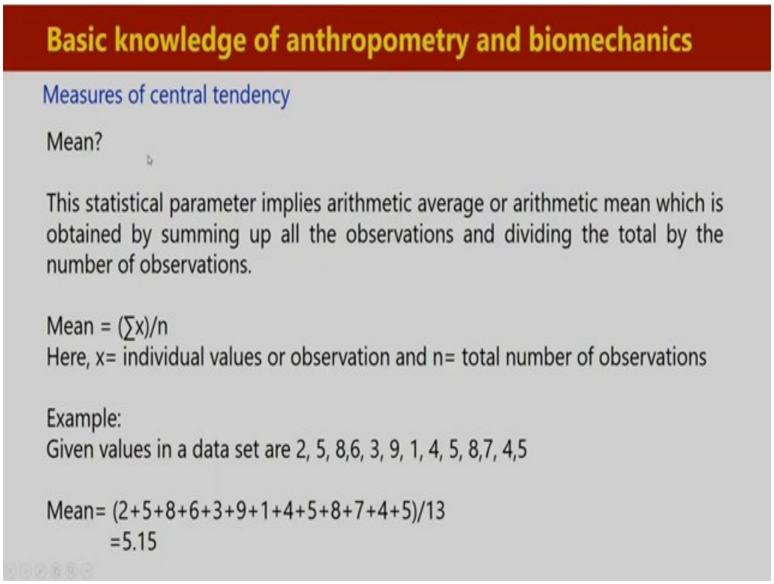


If we have mentioned that is the $10^{th}$ percentile, then this is the 10 percent student and above this portion is the 90 percent student. So, in this way from the cumulative frequency diagram, we can calculate various percentile value; then few other statistical parameters like 'mean' and these are for measurement of central tendency; central tendency of a dataset. So, what is 'mean'? This is a statistical parameter; which implies arithmetic average or arithmetic mean, which is obtained by summing of all the observations or all the values and dividing the total by the total number of observations. So, it is expressed like that, means, summation of 'X' that is the individual observation divided by 'n'; 'n' is the total number of observations; the total number of values.

Now, if your given dataset is like this; as you can see, this is a dataset, now if you want to calculate the 'mean'; arithmetic mean and how to calculate? We will sum up all the values, and then we will divide it by the total number. If you count, there are total thirteen numbers. So, if we divided by 13, then we are getting the value 5.15, that is the 'mean' for this dataset.

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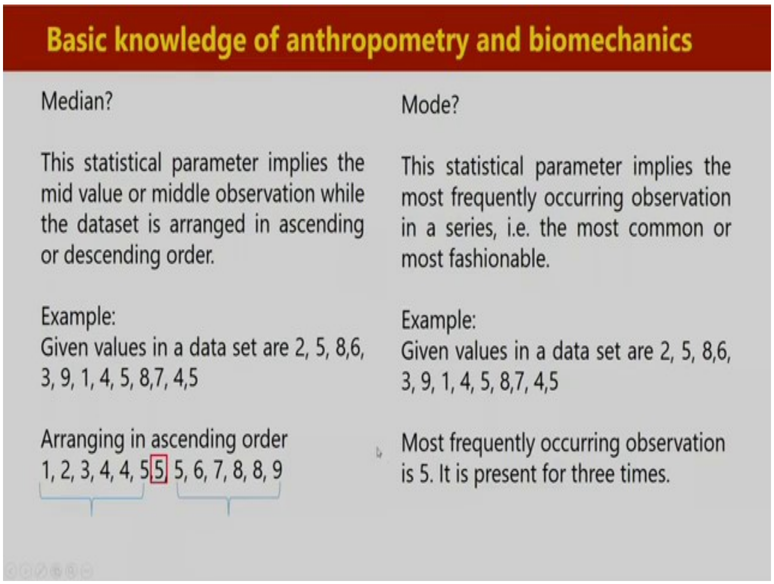


Similarly, there are other central tendency, like 'median' and 'mode'. So, what is the median? Median is the mid-value in a dataset. So, if we arrange the data points in a dataset in ascending order or descending order, then the mid-value of that dataset is called median.

If there is the odd number, then obviously, we can identify the mid-value; but if there is even number, then what we have to do? The mid two data points, we have to sum up and divide it by two, to get the median value. On the other hand; if we go for 'mode'. So, the 'mode' is the most frequently occurring value in a dataset, say, here one example is given. So, most frequently occurring value in the dataset is called mode. So, in this dataset most frequently occurring value is 5, because 5 is coming once, twice and thrice, but others are either only one time or two times. So, that is why, in this case, in this dataset, 5 is the mode value.

So, generally, we use 'mean' value, but there are many situations where mode or median is preferable than the 'mean' value. For example, where there is, in a dataset which is not normally distributed, where there are outliers, means, some values, few data points are very low or very high, due to that central tendency may differ and in that case instead of median value, better representation can be achieved through median or mode value.

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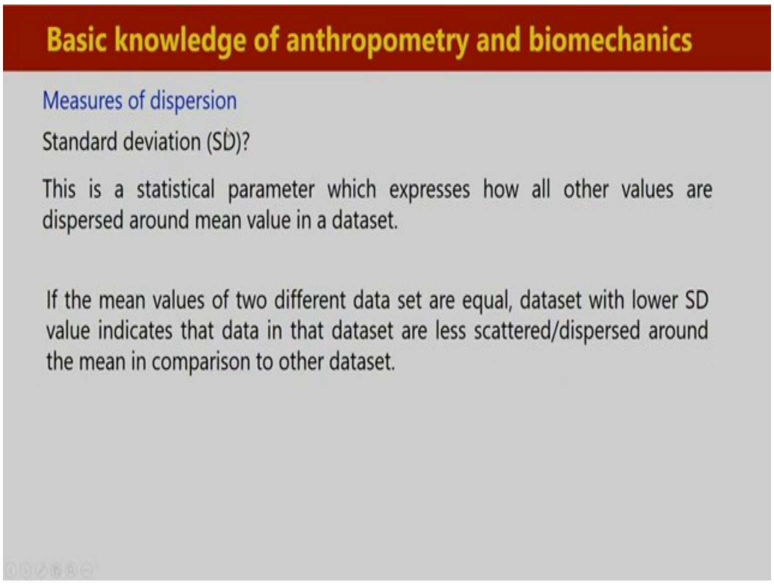


Then after 'mean'; now we are going to discuss about standard deviation. So, this is also an important statistical parameter. So, what is the standard deviation? This is a statistical parameter which expresses; how all other values are dispersed or scattered around the mean value in a dataset. So, why this is important? If the mean values of two different datasets are equal; dataset with lesser value of standard deviation indicates that in the dataset values are close to 'mean value', means, there is less dispersion. On the other hand, if the mean values of both datasets are same, but the standard deviation value in a particular data set is more, it means, in that particular dataset where standard deviation value is more, data points are more dispersed around the 'mean value'.

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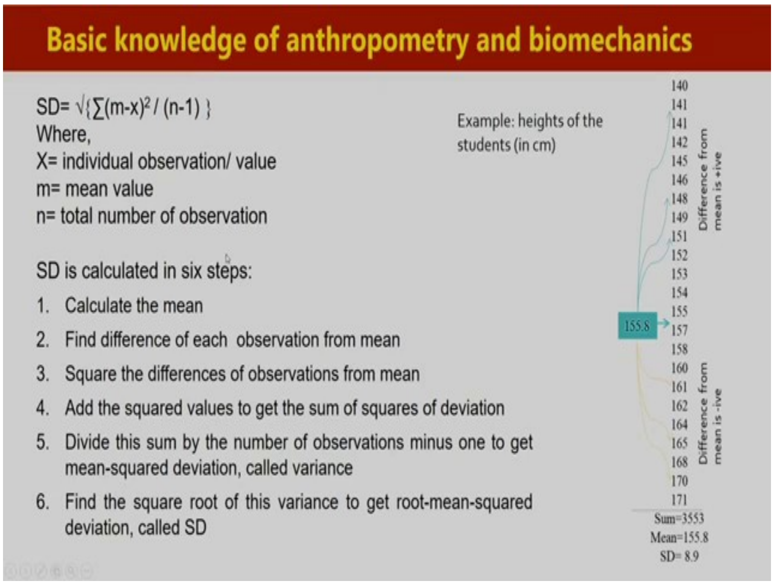


Now, how this mean value; this standard deviation value is calculated? This is the formula for calculation of standard deviation value, and this is the, you can see, step by step, we can follow this process for calculation of standard deviation. Now, we are taking one example of height value for a particular classroom. Say, it is starting from 140 centimetres to 171 centimetre and the collected anthropometric data, here say, stature or height value, we are arranging in ascending order; gradually it is increasing.

Then, from this dataset easily we can calculate the arithmetic mean and so for that purpose, already we discussed, how to calculate that one, we have to calculate the sum of all these data points, then we have to divide by the number and we will get the mean value. Then, how to calculate standard deviation value and what is the standard deviation value? Now, if in this particular case, mean value is 155.8 centimetre.

So, if this is the mean value; from mean value, how other values, these individual values are dispersed? Some values are nearby mean value; some values are away from the mean value that may be greater than the mean value; some value may be less than the mean value. So, in this dataset few values are nearby mean value; on the other hand, some values are away from the mean value.

So, the standard deviation is a statistical calculation which explain; how these individual data points are dispersed around this mean value, whether they are nearby mean value or away from the mean value. So, for this purpose, how it is calculated? So, first we have to see, how much is the difference between mean value and individual value. For that purpose, first, if we go to the formula, then we calculate the mean value and how mean value is nearby or away from the individual observation. So, mean minus individual observation.

So, here we can calculate the individual value, we can minus from the mean value. So, while we will minus the lower values from the mean value, we will get the positive value, but while we will minus the higher value from the mean value, then we will get the negative value. To avoid these positive and negative issues, what we are doing?

That mean value minus individual value, we are putting in a square, then that, those squared value we will sum up to get the total differences. After getting the total difference, we are dividing by the 'n' or 'n minus 1'; we can use 'n' also if the dataset is bigger otherwise 'n minus 1' as the degree of freedom, then we can calculate the standard deviation value.

So, standard deviation value, what we are calculating? How individual value is away from the mean value and as there may be a negative value and positive value for that purpose, we are putting a square and we are making its average. Then, as we earlier squared the value, so, ultimately after this calculation, we are putting a square root; to get one statistical expression which will indicate that how individual values are dispersed around the mean value.

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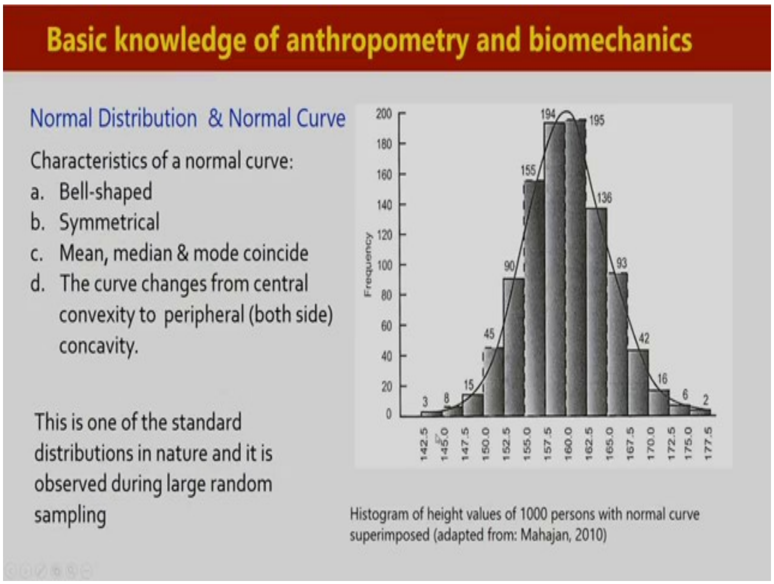

Now, we are discussing about normal distribution. So, if the values or in a particular dataset are presented with this type of frequency diagram.

So, on X-axis; if we take the example of height value, so, these are the height of different students, and on Y-axis, this is the number of students in that particular height group. This is not cumulative frequency diagram; this is only frequency; a height versus frequency in that particular group. So, if the data is normally distributed, then we will get this type of bell-shaped curve. So, this is one of the standard distributions in nature and it is observed during large sampling, when random data collection is there, sample size is large, then we will get this type of distribution pattern. So, this is called normal distribution, and there are various characteristics of normal distribution of our dataset.

So, for example, one is, it should be bell-shaped, this should be symmetrical. So, from the mid-line, on both sides, it will be similar. 'Mean', 'median' and 'mode' in this particular case, while the data, any dataset following normal distribution pattern, then mean value, median value and mode value will coincide with the $50^{th}$ percentile value or all these values will be same. Now there are various statistical techniques as well as for visual representation for normality.

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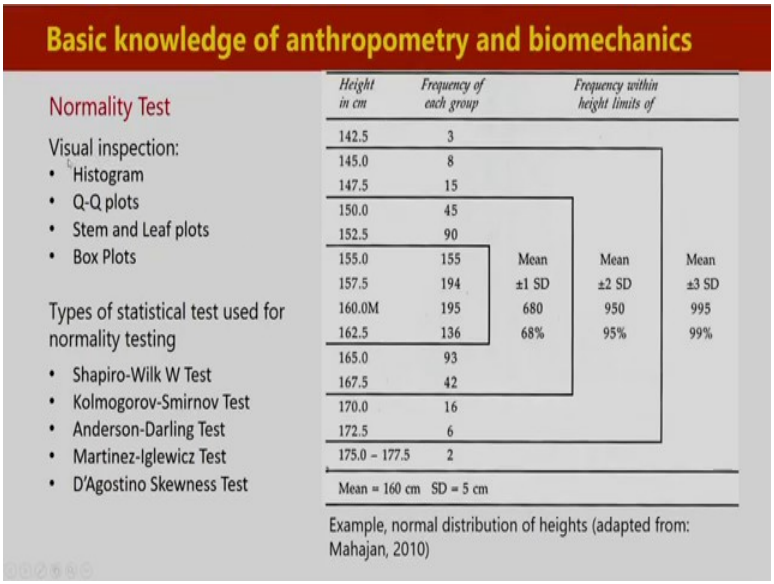


So, visual inspection methods are there, like histogram, Q-Q plots, Stem and Leaf plots, box plots. So, by plotting the data, with these techniques, we can understand whether the dataset is following a normal distribution pattern or not. And there are also various statistical techniques, like Shapiro-Wilk test, Kolmogorov-Smirnov test. So, these are the list of tests which we can also apply to test the normality of the dataset. If the data is following normal distribution pattern, then only we can go for various percentile calculation.

And based on that percentile calculation, means, whenever we are dealing with anthropometric data, biomechanical data, so, our assumption is that data is following normal distribution pattern and from that assumption, we are calculating. So, first, we have to test that whether the data is following normal distribution pattern, if the data is following normal distribution pattern, then it will be very easy for us to calculate mean value and standard deviation value and from mean value and standard deviation value, we can calculate other percentile values as per our requirement.

So, it is observed that if the data is following normal distribution pattern, then say, assume, in this dataset of the height in centimetre value. If this is the mean value 160 centimetres; from that mean value, if we go one-time standard deviation in negative side or positive side, then what will happen? Sixty-eight percent of the dataset will be covered. So, mean value plus minus one standard deviation actually covers 68 percent of the data points; condition is that the data set must follow normal distribution pattern.

Similarly, the mean value plus minus two times standard deviation covers 95 percent of the dataset, data point. Similarly, mean value plus minus three times SD covers 99 percent of the data points.

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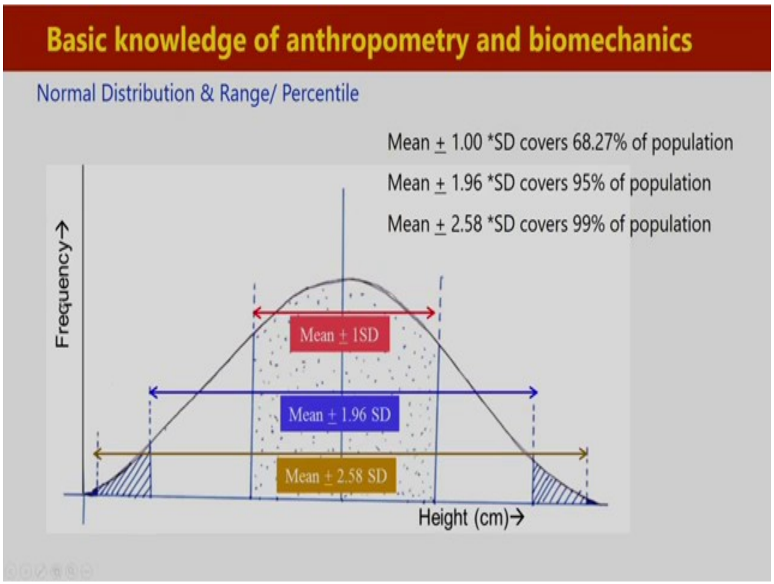


Again. So, this is a normal distribution curve; from that, this is the mid-point. So, if we, on X-axis we are putting the height values in centimetre, on Y-axis we are putting the frequency, that is the number of individuals present in a particular height group. In that case, this is the mid-point of the dataset; this is called 50$^{th}$ percentile or mean value. From that mean value, if we go 1-time standard deviation in an upward direction or downward direction, this mid-zone, how many data points will be covered? As we mentioned earlier 68 percent, exact value 68.27 percent data points will be covered.

Similarly, from this mid-point or mean value, if we go 1.96 SD in upward direction as well as 1.96 SD in downward direction, then it will cover 95 percent of the population. Similarly, from the mean value, if we go 2.58 SD in upward direction and 2.58 SD in downward direction. So, within this range, from this point to this point, how many data points will be covered? Total 99 percent of the data points will be covered. So, by calculating mean and standard deviation value, we can calculate that what percentage of the data points will be covered and these calculations are very much important for various types of workstation and facility design to accommodate good percentage of people.

Now, while we are calculating mean plus minus 1 times standard deviation. So, this is the mean value, from this if we go 1 standard deviation up and 1 standard deviation down, we are covering 68 percent of the population. It means, from the 50$^{th}$ percentile or mean value, we are going half of the 68 percent, means, 34; 50 plus 34 that is 84, this is the point. So, this particular point will be 84th percentile point.

Similarly, this is the 50th percent or a mean value, from that if we go down 1 SD, this point will be, 50 minus 34, that is 26th percentile. So, in that way, from the 'mean' and standard deviation calculation, we can calculate the percentile value.

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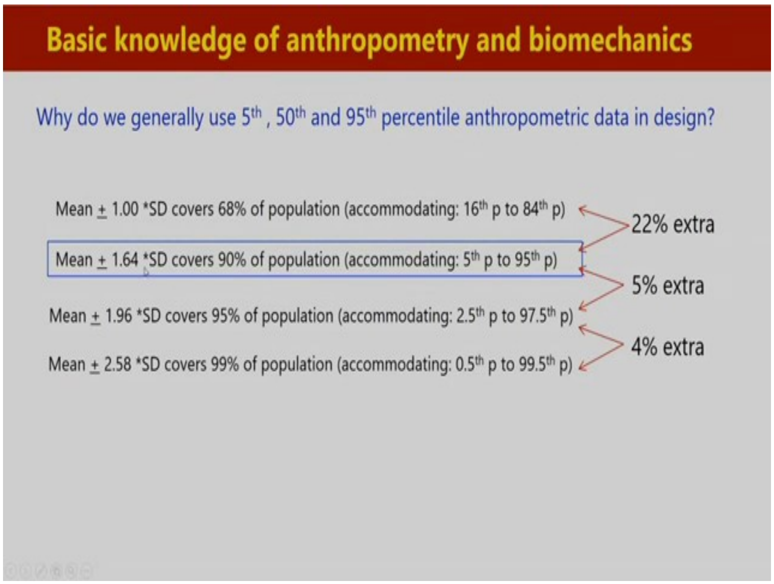


Now, why in the design or engineering, we use 5th, 50th and 95th percentile anthropometric or biomechanical data? At many places you will see that 5th percentile manikin, 95th percentile manikin or 50th percentile manikins are being used. So, what is the justification? Why these three percentile values are more important? Because, say, mean plus minus 1 times standard deviation covers 68 percent of the population, it means it starting from the 16th percentile to 84th percentile. Similarly, mean plus minus 1.64 SD it covers 90 percent of the population, means, it is starting from 5th percentile and ending at 95th percentile.

So, mean value and 1-time standard deviation can cover 68 percent, whereas the mean value and plus minus 1.64 times standard deviation covers 90 percent. So, if we increase the standard deviation value from 1 time to 1.64, then it is increasing from 68 percent to 90 percent. So, 22 percent extra data points have been covered, means, for a particular facility design we can accommodate 22 percent of the population, but if we increase the standard deviation value more, from 1.64 SD to 1.96 SD, then mean plus minus 1.96 SD will cover 95 percent of the population. It means, the starting point is 2.5th percentile and the last point is 97.5th percentile.

Although, we are increasing the standard deviation value from 1.64 SD to 1.96 SD, but how much extra population or extra data point is covered? Only 5 percent. Again, if we increase the standard deviation value from 1.96 SD to 2.58 SD, how much population will be covered? Extra 4 percent. So, although in this case from 1.64 SD, we are increasing the standard deviation value, but the number of populations covered is very less, only 5 percent. So, that is why, this is the optimal compromise, we are increasing the standard deviation value, but at the same time we are accommodating good range of population, means, 90 percent of the population will be covered, where the starting point will be the 5th percentile dimension or 5th percentile anthropometric variable to 95th percentile anthropometric variable.

That is why in design, we use 5th percentile and 95th percentile because that is the optimal compromise. We are increasing the standard deviation value from, we can use 1 time standard deviation, but it will cover only 68 percent, but instead of one time standard deviation, if we use 1.64 times standard deviation, it is actually accommodating 22 percent extra, means, 68 percent to 90 percent; these 22 percent extra will be covered, by little increment of the standard deviation value, 0.64 SD; if we increase then good number of people will be accommodated.

But if we further increase the standard deviation value, the percentage of increase in accommodation will be very less. So, that is why, we will restrict ourselves at this level, means, in the design of a facility or any product, we will use 5th percentile, 95th percentile and the 'mean' that is called 50th percentile. So, 50th percentile value, 5th percentile value and 95th percentile value for any product or facility design.

Because if we increase the standard deviation value, means, the adjustable range for a particular product, then the product will become fragile, but we will obviously try to make the product adjustable, we will give the adjustable feature, but we have to think about that whether that is beneficial for us. So, we should not go for higher standard deviation value with higher adjustable range, in that case, we can accommodate everybody, but it will not cost as well as the fragility of the product will increase but the number of population will be less, less number of population will be covered.

So, that is why, in case of design, we use 5th, 50th and 95th percentile to accommodate 90 percent of the population, starting from 5th to 95th percentile.

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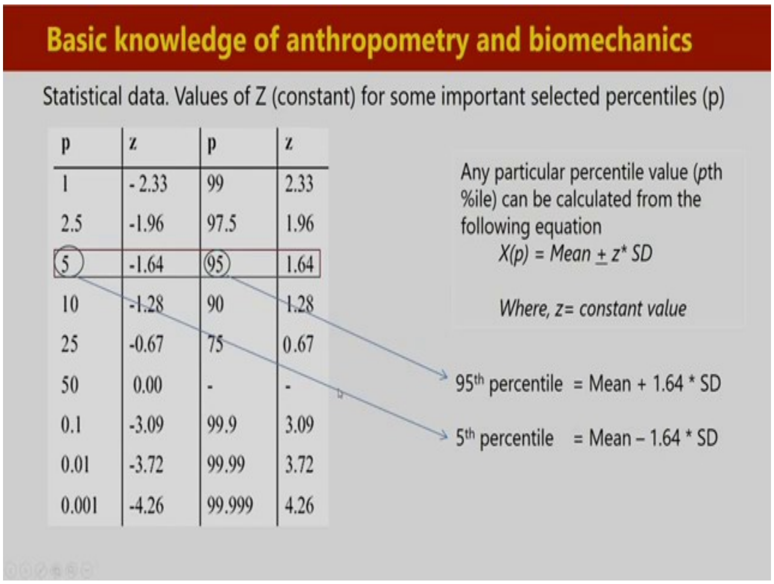


Now, how we calculate these 5th percentile or 95th percentile value or first percentile or 99th percentile value? For that purpose, as we mentioned, if the data is following normal distribution pattern, and if we can calculate mean value and standard deviation value, then already there is this type of calculated table, these are the standard table for ‘z’ value or the constant value, from that constant value, we can calculate the specific percentile value.

For example, if we want to calculate the 95th percentile value, then how will you calculate? Mean value plus 95th percentile value, mean value plus 1.64 times standard deviation value. So, this constant value is already available in the table. From the table, we can use that value, and if we have the mean value and standard deviation value and easily, we can calculate, what will be the 95th percentile value. Similarly, if we want to calculate 5th percentile value, then from the mean value, we have to minus 1.64 times standard deviation value.

So, in a similar pattern, we can calculate, first percentile, we can calculate 99th percentile, we can calculate 25th percentile, 75th percentile, by only calculation of mean and standard deviation and using this type of specific ‘z’ value or constant value.

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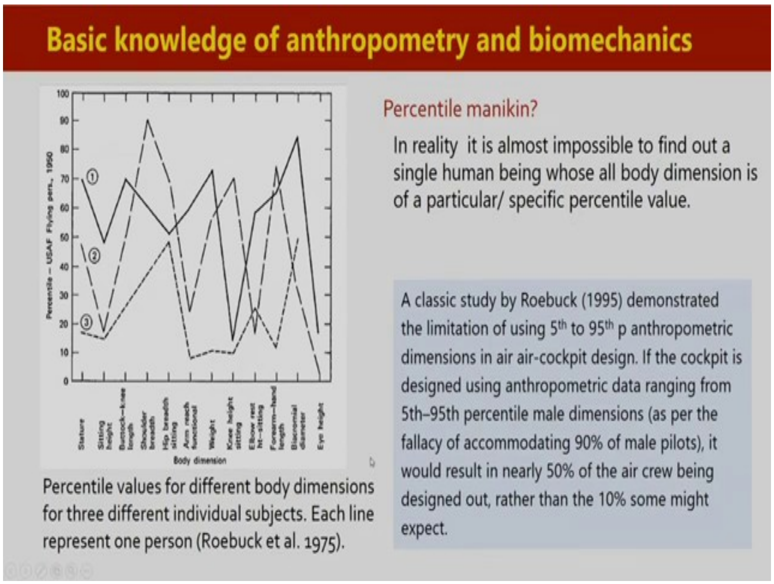


Now, this percentile, although in reality, there is not a single individual whose all body dimension or anthropometric variable, even strength capability is not of specific percentile value. If we take this example, percentile values for different body dimensions for three different individual subjects, so, here is the individual 1, individual 2 and individual 3 and these are the various anthropometric variables.

So, for individual 1, for some body dimension, say, ‘stature’ that is 70$^{th}$ percentile, but for another dimension ‘sitting height’ it is only 50$^{th}$ percentile. Similarly, for that individual 1, for another variable, say, for example, this one; sitting hip-breadth that is near about 50$^{th}$ percentile. On the other hand, if we look at this particular point, say, bi-acromial diameter, that is again going to 80$^{th}$ percentile. So, for a single individual, for different anthropometric variables, different percentile values are present. It does not mean that, if someone’s height or stature value is 90$^{th}$ percentile, it does not mean his or her all other body dimensions will be of 90$^{th}$ percentile, it may be of different percentile value.

So, a classic study by Roebuck (1995) demonstrated that limitation of using 5$^{th}$ percentile and 95$^{th}$ percentile anthropometric dimension in air cockpit design. If the cockpit is designed using anthropometric data ranging from 5$^{th}$ to 95$^{th}$ percentile dimension, then people will think probably we will be able to accommodate 90 percent of the population, that is starting from 5th percentile to 95th percentile. This is a fallacy of our understanding that 90 percent of the people or the 90 percent of the pilots will be accommodated.

But in reality, it does not happen because while we are considering, if it is a single anthropometric dimension, only univariate analysis, then there is no problem. 5th percentile to 95th percentile anthropometric variable will cover 90 percent of the population, but while there is multivariate consideration, means, there are so many variables, then there will be many people who will be designed out or who will be discarded due to their one or many of the body parts are out of that range, means, say for example, someone's majority of the body dimensions are coming within 5th to 95th percentile, but one or two body dimension is not coming within that range. So, that person is eliminated from this 90 percent. So, in that way, in this particular case, in the Roebuck's study, he found that ultimately if we consider 5th to 95th percentile male dimension, hardly nearly 50 percent of the aircrew is being designed out, rather than the 10 percent.

So, although we expected that only 10 percent, means, less than the 5th percentile dimension and higher than the 95th percentile, that both ends, this 5 percent and this 5 percent will be designed out, but actually in real scenario, 50 percent of the crew member were designed out due to consideration of 5th percentile and 95th percentile range of the anthropometric dimensions.

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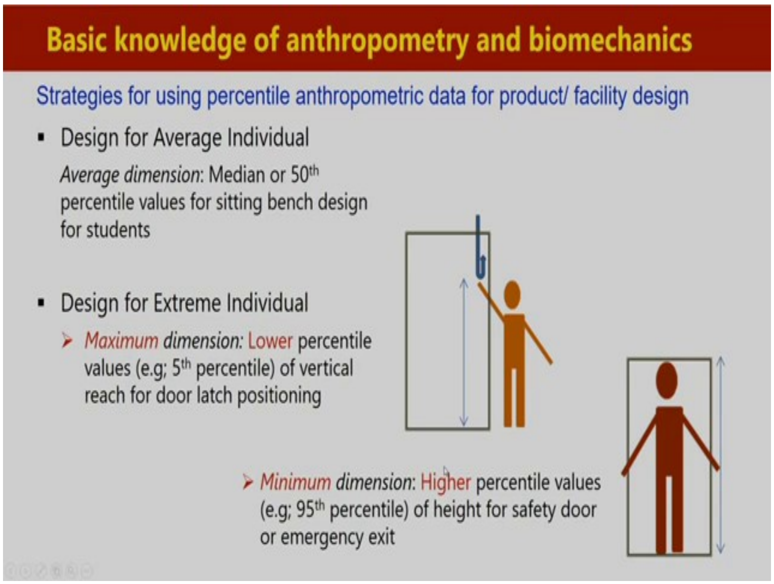

Now, while we are using various types of anthropometric and biomechanical data and percentile value, then various strategies are followed by designers or engineers. So, sometimes designers use dimension of average individual. So, design for average individual; in that case median value or 50th percentile value, for sitting bench height of the students.

So, while we are designing a bench height or deciding what should be the height of a bench, in that case, in that particular bench many students are sitting and their leg height is also different, the particular term is called popliteal height, the popliteal height of the student populations are different.

So, while they are sitting on the fixed height wooden bench, then what should be the anthropometric consideration, which percentile data should we consider? So, in that case to accommodate good number of people, we will consider 50th percentile of the popliteal height because from the bell-shaped curve, we have seen that majority of the students popliteal height value will be nearby mean value, because from the bell-shaped curve the central portion of the bell-shaped curve, as we mentioned, the end portion of the bell-shaped curve is flat, but the central portion is like a bell shape.

So, that is why, while we are considering the 50th percentile value, more number of individuals or more number of students will be easily accommodated, as more number of values are nearby mean value or 50th percentile value.

Similarly, design for extreme individual. For example, here you notice this one, for maximum dimension while we are designing maximum dimension, then we need to use lower percentile value. So, for example, 5th percentile value of arm-reach is used for deciding what should be the height of the door latch. For door latch height, if it is positioned at the arm-reach value of 5th percentile arm-reach, for the particular population, then 95 percent of the people whose arm reach value is more than 5th percentile they will be easily able to operate. On the other hand, while you are thinking of the minimum dimension, then we consider the higher percentile value. So, minimum height of the door should be the maximum height of the population.

So, in this case, what value we should use, as we mentioned earlier, we generally use 50th and 95th percentile value. So, in this particular case, we will use 95th percentile 'stature' or head height for deciding the door height. So, that 95 percent of the people can go easily through that door, only 5 percent people will need to bend their head to go through that door. So, for minimum dimension, we consider the higher percentile value, whereas, for maximum dimension, we consider the lower percentile value.

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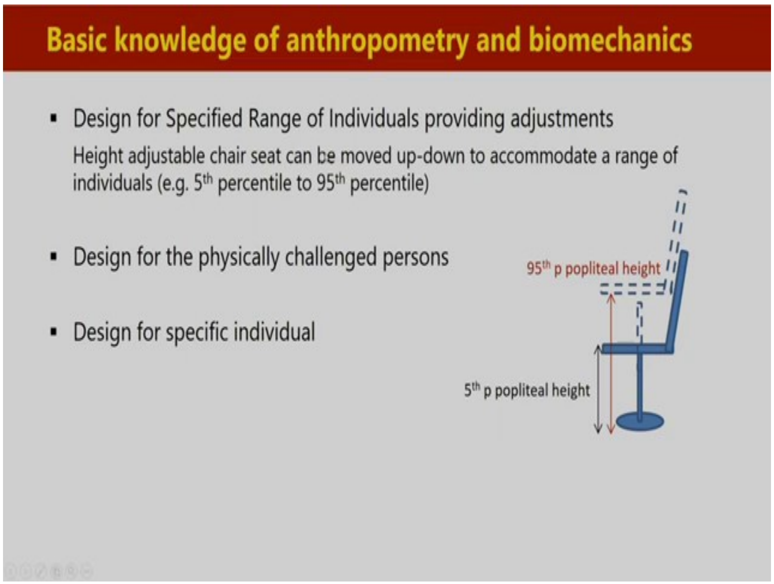


Then, design for specific range of individual providing adjustable features; so, if this is a height adjustable chair, in this height-adjustable chair if we consider the minimum and maximum height, so, that we can do; how much will be the adjustability range. So, that people with 5th percentile popliteal height can sit, at the same time people with 95th percentile popliteal height; they can also sit. So, if we know the value of 5th percentile popliteal height as well as 95th percentile popliteal height, then we can decide what should be the movement range of that seat or seat height adjustability.

Similarly, design for physically challenged person. Physically challenged person they have different requirement; different body parts are with different types of mobility problem. So, for that purpose, for specially-abled or physically challenged people, for them the anthropometric data or biomechanical database, we have to develop separately and those data, again, from the dataset, we have to calculate percentile values and we have to use for the various design purposes.

On the other hand, design for the specific individual: while you are designing a particular product for a particular individual, for a specific individual, then we need not to go for percentile calculation. We can directly measure the anthropometric or biomechanical data from that individual and we can use those data for an individual; specific product or facility design. For example, Director's chair, if the director's chair is being used only by the director, then we need not to go for the population data and percentile calculation, we will use the body dimension of that particular individual.

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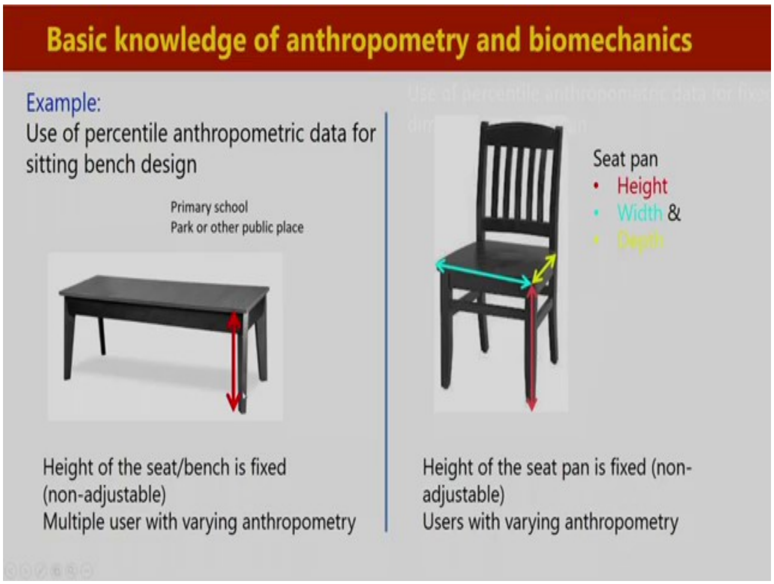


Now, as we are discussing, that fixed height bench, fixed height wooden bench. So, if we consider this, what should be the height; which percentile, that we know for this purpose which is the corresponding anthropometric variable. Corresponding anthropometric variable is the popliteal height of the student population. Now, on this; in this particular bench, 4-5 students can sit, and their popliteal heights are different. So, now, the question is whether we will use 5$^{th}$ percentile data or 50$^{th}$ percentile or 95$^{th}$ percentile popliteal height, so, that we can accommodate a good number of students.

Now, in this particular case, if we use 50$^{th}$ percentile popliteal height, then what will happen? We will be able to accommodate a good number of people. Because from the normal distribution curve, we can see, majority of the data points are concentrated, or they are nearby the mean value or 50$^{th}$ percentile value. So, in this case 50$^{th}$ percentile popliteal height value will be more preferable for deciding the height of the bench.

On the other hand, while we are thinking about this type of fixed height or fixed dimension wooden chair, there is no adjustable feature, then there are various design dimensions. Say, for example, seat width, seat depth and seat height; for different design variables, there are corresponding anthropometric variables. So, for example, seat width; for seat width; what is the corresponding anthropometric variable? Corresponding anthropometric variable is the hip breadth. Now, which percentile of the hip breadth should we use? If there are, these three options, $5^{th}$, $50^{th}$ and $95^{th}$; obviously, we will go for $95^{th}$ percentile hip breadth, so that 95 percent of the people whose hip breadth is lower than that particular value, then they will be easily accommodated.

On the other hand, if we consider this seat depth; in seat depth; which is the corresponding anthropometric variable? Corresponding anthropometric variable is the thigh length; the exact variable name is buttock-popliteal length. Now which percentile should we use? So, in this case also, if there are only three options; $5^{th}$, $50^{th}$ and $95^{th}$ percentile, then $5^{th}$ percentile will be the better option so that all the people with larger than $5^{th}$ percentile buttock-popliteal length; they can easily use.

So, 95 percent of the people will be able to use. Although their thigh support will be relatively less, but in this case, thigh support is not that much important because weight of the thigh is being borne on the floor by the feet. Already we have discussed, that in case of the height of the chair, we can use $50^{th}$ percentile popliteal height.

So, we can see, for a single product, for its different design dimension, we need to consider different anthropometric variables and its corresponding percentile value. Like percentile anthropometric data, we also follow different strategies for using percentile biomechanical data.

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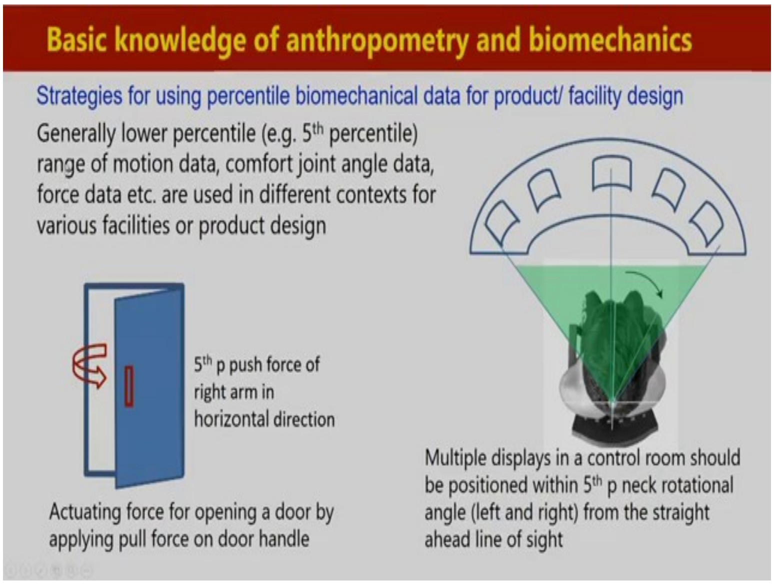


For biomechanical data, generally lower percentile value, for example, 5th percentile range of motion data, comfort joint angle data, force data etcetera are used in different context for various facility and product design.

If we think about the, how much force to be exerted for opening a door? What should be the actuating force for opening a door? How much pull force will be applied on the door handle? So, obviously; if we design the door in such a way, that the 5th percentile right arm, generally we are right-handed, in our population people are right hand dominant. So, 5th percentile push force of the right arm in horizontal direction can be considered as the actuating force for opening the door.

Similarly, in another example, while we need to position multiple displays in front of some individual in our workstation like metro station or nuclear power plant. So, how those displays should be positioned around that person, so that his neck movement, he will be able to move his neck to see the displays. So, for that purpose, we have to develop the database, for the range of motion data, for the neck, a lateral movement of the neck or rotation movement of the neck.

And from that data, we will use 5th percentile neck rotation data either in the left side or in right side and from that this 5th percentile data will be used, so that for 95 percent of the people it will be easy to move the neck because it is within the 5th percentile range of motion range. So, accordingly we can decide the position of the displays.

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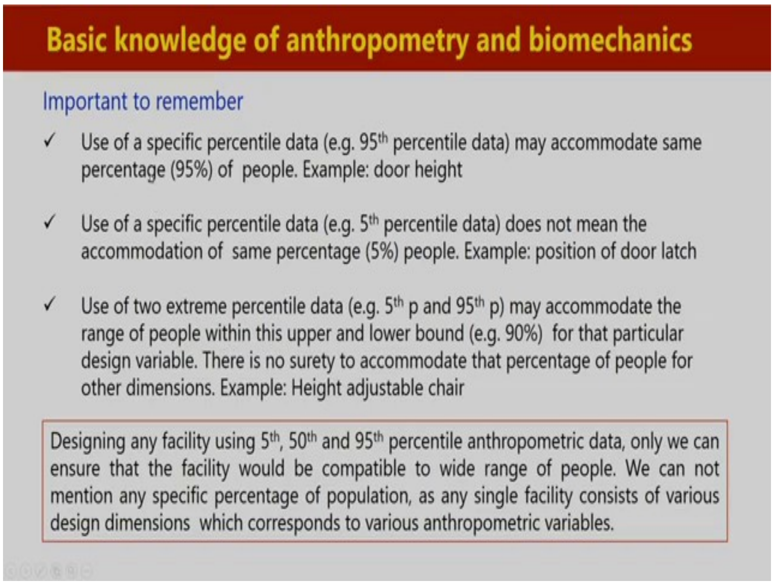


So, now some important points to remember, so, use of a specific percentile data, for example, 95th percentile data may accommodate same percentage of the people, for example, of door right. While we are using 95th percentile stature, then 95 percent of the people can use that door, and they can go through that door. So, 95th percentile data is accommodating 95 percent of the population.

On the other hand, use of specific percentile data, for example, 5th percentile data while we use the 5th percentile arm-reach for the door latch, then 95 percent of the people are able to use that door latch. It does not mean that if we use 5th percentile data, then only 5 percent people will be accommodated. So, the use of 5th percentile data, in this case, is accommodating 95 percent data; 95 percent of the population.

Similarly, use up to extreme percentile; starting from 5th percentile to 95th percentile, may accommodate the range of people within that upper and lower bound, that is a 90 percent of the people. While we are considering a particular single anthropometric variable or biomechanical variable, there is no surety to accommodate the percentage of people for other dimensions, for example, height adjustable chair. While we are considering only one variable, then starting from 5th percentile to 95th percentile, 90 percent people will be accommodated.

But it does not mean that 90 percent of the population will be accommodated for other variables also. So, while there is the multivariate requirement, means, more than one anthropometric variable are considered for designing a particular facility, then we are not sure, that exactly what percentage of the population will be covered, while we are using 5th to 95th percentile anthropometric dimensions.

So, that is why, by designing any facility using 5th, 50th and 95th percentile anthropometric data we can only ensure that the facility would be compatible to a wide range of people, we cannot mention any specific percentage of the population; as any single facility consists of various design dimensions which correspond to various anthropometric variables.

Now, we are going to discuss about user percentile anthropometric data in automotive design.

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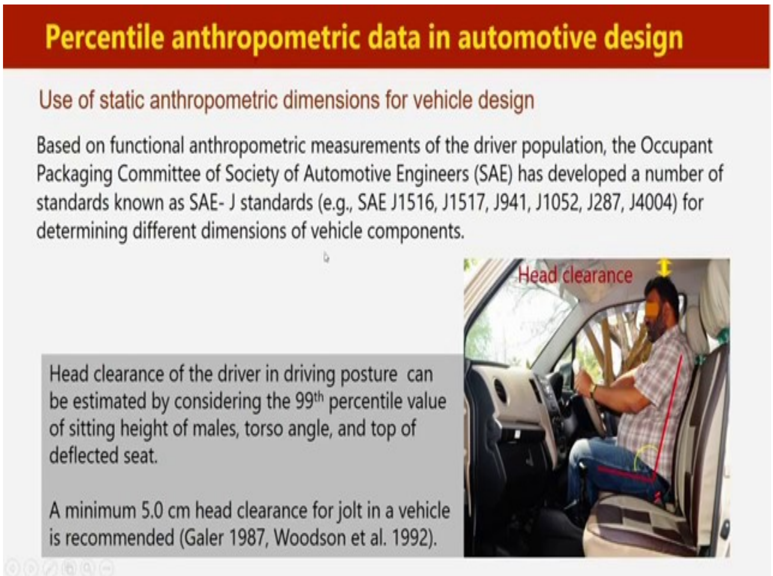


See, first; use of static anthropometric dimension for vehicle design. So, based on functional anthropometric measurements of the driver population, the Occupant Packaging Committee of Society of Automotive Engineers, that is SAE has developed the number of standards which are known SAE J standards like SAE J1516, J1517, J941, J1052, J287 and J4004. So, these various ‘J’ standards are there for determining different dimensions in vehicle components.

Now, we are discussing about head clearance, how much head clearance should be there in the vehicle. So, that while there is any jerking or vibration, the head should not touch with the roof. So, head clearance of the driver in driving posture can be estimated by considering 99th percentile value of the sitting height of male, then torso angle and another is the top deflected seat. So, based on these variables, we can calculate how much should be the head clearance. A minimum 5-centimetre head clearance for jolt in a vehicle (jolt or jerk or during vibration) it is recommended that at least 5-centimetre clearance should be there, so that during all these situations head should not touch with the surface of the roof.

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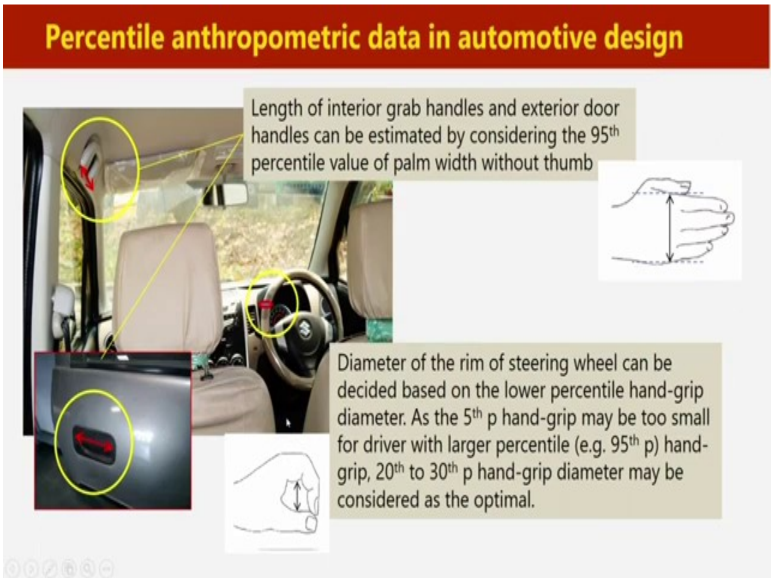


Now, various other vehicle components which are also needed to be designed based on the anthropometric variables. For example, when we are positioning this type of interior grab handles or door handles, then we need to consider this hand dimension and that hand dimension is the 95th percentile palm width.

So, we have to measure this dimension or that is the width of the palm and 95th percentile of palm width should be used for deciding the length of the handle that maybe grab handle or this type of door handle. Not only 95th percentile palm dimension, palm width, apart from that additional allowances can also be given, so that majority of the people, of the particular driver population, or even passengers, can be accommodated.

Then, if we think about how much should be the diameter of the steering wheel. For diameter of the steering wheel rim, we can decide that it should be as per the 5th percentile handgrip, but the situation is that if we use 5th percentile handgrip that may be too narrow for the people with larger hand-grip diameter. So, for that purpose, it will be more appropriate to consider 20th to 30th percentile hand-grip diameter while we are deciding the diameter of the steering wheel rim.

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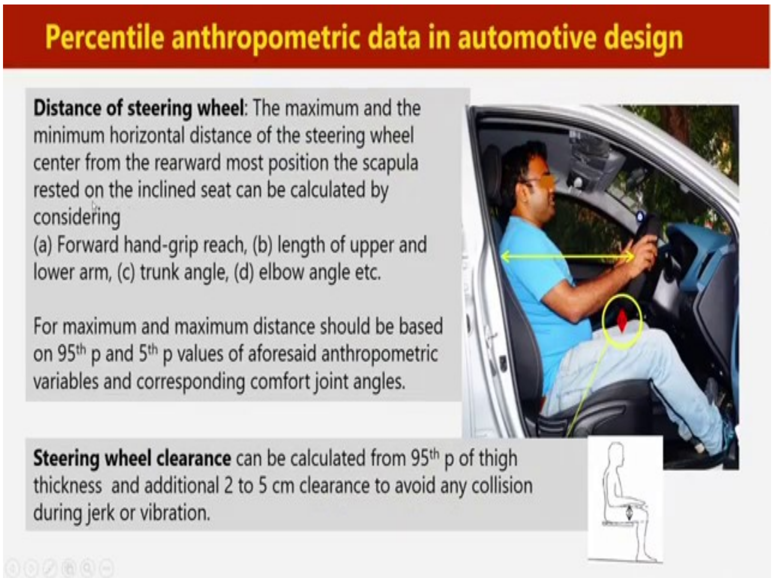


Now, the distance of steering wheel; the steering wheel centre to the seat back distance. So, the maximum and minimum horizontal distance of the steering wheel centre from the rearmost position of the scapula rested on the inclined seat can be calculated by considering these variables; one is forward hand-grip reach, length of upper and lower arm, trunk angle and elbow angle. So, based on these variables, we can calculate how much these maximum and minimum distance should be there.

Accordingly, we can also adjust the steering wheel. Nowadays, the steering wheel can be designed in such way, so the steering wheel can be moved forward/backwards, at the same time there can be change in the inclination of the steering wheel. For maximum/ minimum; distance should be based on 95th percentile and 5th percentile value of aforesaid anthropometric variables and corresponding comfort joint angles.

Now, steering wheel clearance; so how much space should be there above the thigh; so that that the thigh should not touch with the bottom of the steering wheel? So, how this dimension is decided? It can be calculated from the 95th percentile thigh thickness and additional 2 to 5-centimetre clearance is provided to avoid any collision/jerk while the vehicle is running, means, when vehicle is going on the road; if there is any jerk or vibration or jolt, at that time the thigh should not touch with the steering wheel.

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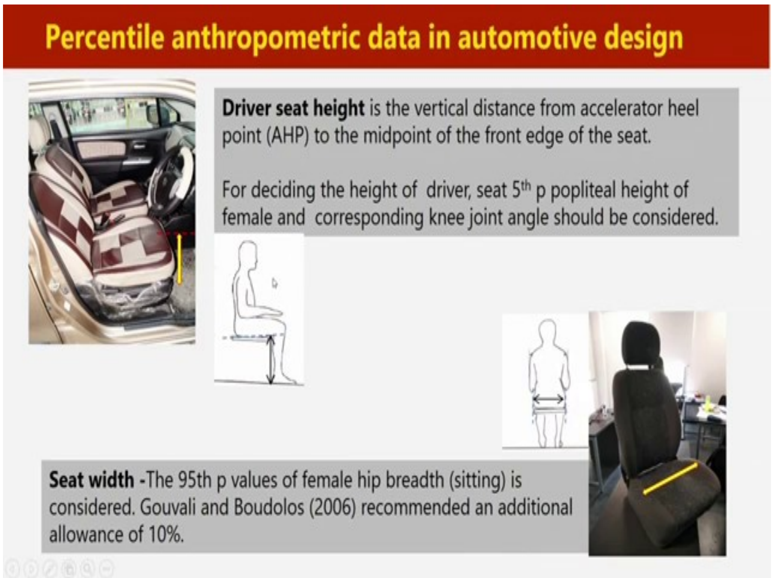


Now, driver seat height; how much should be the height of the middle of the front edge from the floor. Driver seat height is the vertical distance from the Accelerator Heel Point (AHP) to the mid-point of the front edge of the seat. For deciding the height of this driver seat, 5$^{th}$ percentile popliteal height of female and corresponding knee joint angle should be considered.

So, as 5$^{th}$ percentile, popliteal height is low in comparison to others. So, in this case, we will consider the female body dimension, and that is the popliteal height, that value of that popliteal height will be 5$^{th}$ percentile. So, that female with 5$^{th}$ percentile popliteal height or shorter lower limb dimension, they will not have any problem to sit on this type of driver seat and at the same time to reach the foot controls.

Now, related to seat width. While we are deciding the seat width dimension, the corresponding human anthropometric variable is hip breadth. Now, for hip breadth, which percentile of hip breadth we should consider? We should consider 95$^{th}$ percentile sitting hip breadth of female and additionally we can provide 10 percent allowance, so that everybody can be accommodated on that seat.

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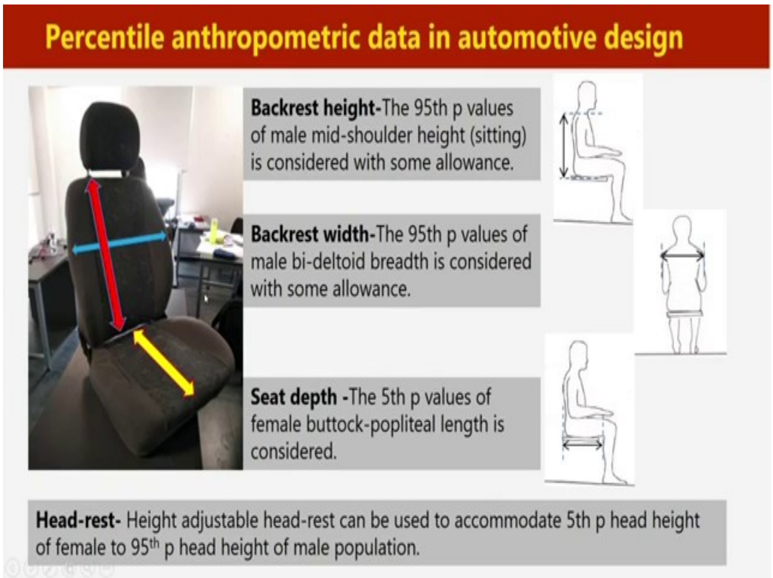


Now, for backrest height, this dimension. For backrest height; which is the corresponding anthropometric variable? For this purpose, anthropometric variable which we should consider that is the mid-shoulder height.

Now, the mid-shoulder height; obviously, it should be mid-shoulder height of the male population, and that value should be 95$^{th}$ percentile. So, 95$^{th}$ percentile mid-shoulder height of male driver population should be considered for deciding this backrest height. On the other hand, if we think about the width of the backrest, then what should we consider? We should consider 95$^{th}$ percentile value of male bi-deltoid breadth. So, you can see from this image. So, this is the bi-deltoid muscle on upper arm. So, the distance between these two bi-deltoid muscles that is called bi-deltoid breadth. 95$^{th}$ percentile value of the bi-deltoid breadth is used for this purpose.

Similarly, for seat depth, means, forward/backwards, this distance. While you are deciding this dimension, which is the corresponding anthropometric variable? The corresponding anthropometric variable will be buttock-popliteal length. Now, either buttock- popliteal length of male or female should be considered? Obviously, we should consider, in this case, female buttock-popliteal length and that should also be 5$^{th}$ percentile, so that the popliteal area of the female with shorter body dimension, the front edge of the seat should not touch with the popliteal area of the 5$^{th}$ percentile of the buttock-popliteal length of lower percentile female driver.

So, for seat depth, that is the forward-backwards distance, while we are deciding these dimensions, the corresponding anthropometric variable is the buttock-popliteal length. And in this case, as female's body dimension is relatively smaller than the male, we should consider 5$^{th}$ percentile female buttock-popliteal length, so that the front edge of the seat should not touch with the popliteal area of the female driver.

Next is the headrest. If this is adjustable headrest, so, adjustable headrest height should be decided, so that we can accommodate 5$^{th}$ percentile head height of female to 95$^{th}$ percentile head height of the male population.

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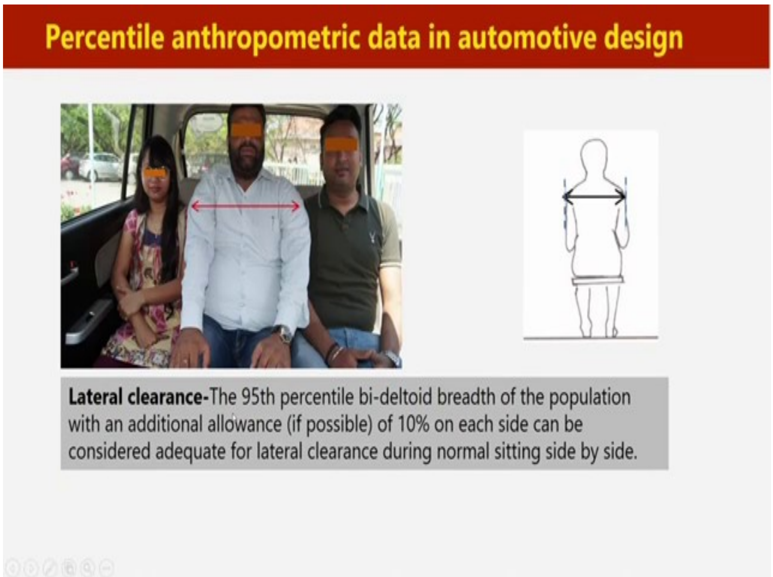


Now, if we think about the lateral clearance, while 2-3 persons or passengers are sitting side by side, then so that they can sit comfortably. So, there should be sufficient lateral clearance. So, for lateral clearance, we consider the anthropometric dimension, that is bi-deltoid breadth.

So, during this, deciding that space for lateral clearance, we should calculate at least, whatever the number of passengers we are planning to accommodate; see if it is 2 or 3. So, multiplied by the bi-deltoid breadth of 95$^{th}$ percentile male population because the male population's bi-deltoid breadth is bigger or larger and 95$^{th}$ percentile dimension is used for this purpose. So, 95$^{th}$ percentile bi-deltoid breadth and if it is possible, some additional allowances can also be provided and accordingly comfortable seating arrangement with sufficient lateral clearance can be designed.

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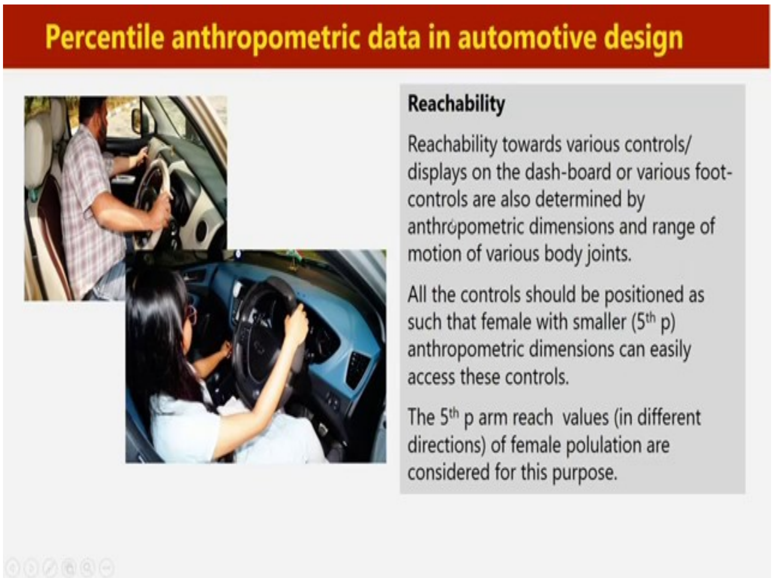


Now, reachability. For driving, drivers or passengers also, they need to do different activities inside the vehicle, particularly while the driver is reaching to the various types of controls or display, that may be hand controls or that many foot controls, like accelerator, brake, clutch. So, while drivers are operating those controls, those control should be easily accessible. So, for that purpose, $5^{th}$ percentile arm-reach value; that may be normal arm-reach, that may be extended arm-reach or even while the seat belt is not there, while the driver is extending their trunk forward, that time they should be able to access those controls. So, for this purpose, generally $5^{th}$ percentile arm-reach is calculated.

But in this case, we also have to remember that, generally, in driving condition, while seatbelt is attached, so, it is very difficult to forward-leaning. So, in that situation, we have to think that forward-leaning will not be possible. So, maximum we can consider, the most important control should be within the comfortable forward or side arm-reach of the 5th percentile dimension of female driver population.

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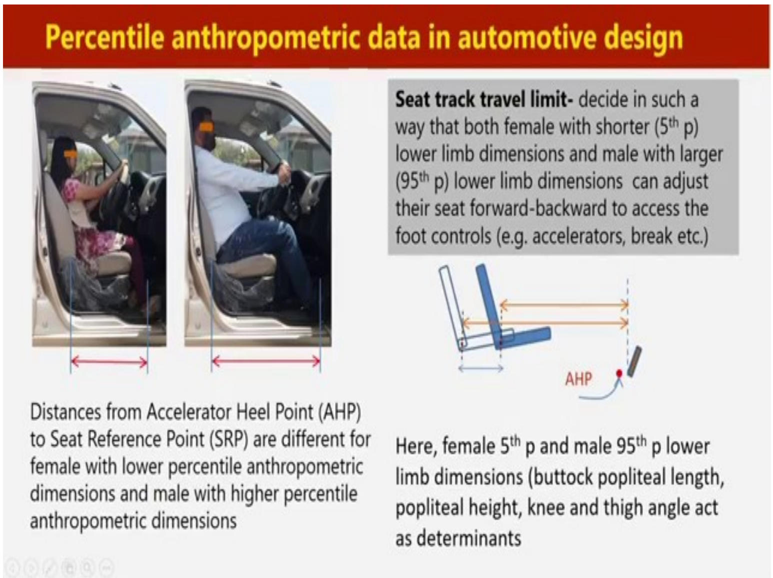


Now, if we think about the seat track travel limit. So, how much should be the seat track travel limit? So, for that purpose, if we look at this image; for female with shorter body dimension, they adjust the seat forward, so that they can access the foot controls, at the same time they can hold the steering wheel. On the other hand, male with larger body dimension, they move the seat backwards, so that they can sit comfortably, access the steering wheel and foot controls.

So, if we look at these two images, then you can easily understand; the distance from the accelerator or accelerator heel point to the seat reference point is more in case of male with larger body dimension in comparison to female with shorter body dimension. So, seat track travel limit is decided in such a way that both female with shorter dimension, for example, 5th percentile lower limb dimension as well as male with larger dimension, that is the $95^{th}$ percentile, lower limb dimension; can adjust their seat forward and backward to access foot controls like accelerator, clutch, brake etcetera.

Now, if we look into this image, then if this is the accelerator and this is the accelerator heel point on the ground, that is when the driver is keeping their foot on the accelerator, the heel is touching on the ground, at this point. So, this is the accelerator heel point. So, while the driver is keeping their leg on the accelerator, keeping their heel at this accelerator heel point location and according they are adjusting their seat forward and backward, then this distance, if we assume for the 5th percentile female driver, and if this distance is for 95th percentile male driver, then the seat track travel limit is this point, means, SRP to SRP, this distance, means, at least seat should move forward and backward, at least this much, so that 5th percentile female with lower body dimension, at the same time male with 95th percentile higher body dimension or higher limb dimension can be accommodated in that vehicle. So, here 5th percentile female, as I mentioned and 95th percentile lower and higher limb dimension, that is buttock-popliteal length, popliteal height, knee and thigh angle are acting as the determinants.

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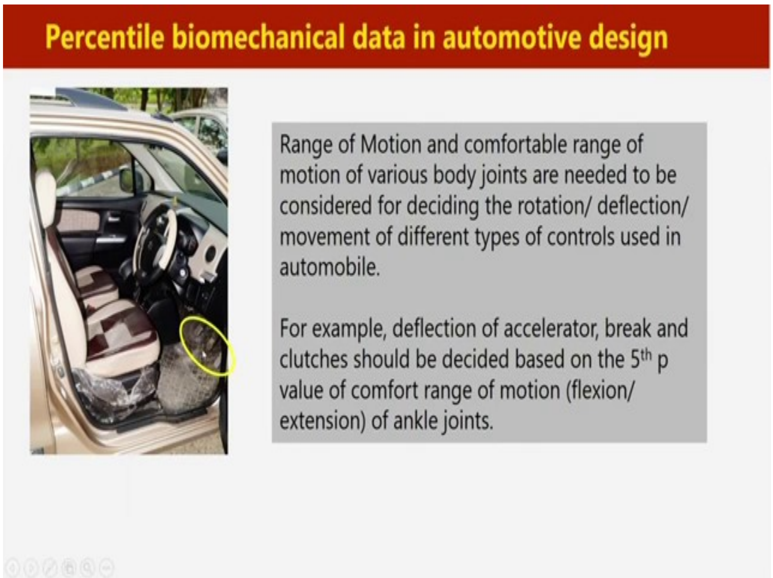


Now, apart from the anthropometric data, biomechanical data is also important for automotive component design. For various component operations, either that is foot control or different types of controls on the dashboard, it requires a different type of range of motion of our hand or leg, at the same time different amount of force is required for actuating those controls.

So, if we take the example of these foot controls, like an accelerator, brake, clutch; then these are operated by left, and right hands, and mainly by the joint angles, which are involved for these operations, e.g. the ankle joint.

So, for deflection of these controls, we should consider the comfortable range of motion of 5th percentile, that is the 5th percentile value of comfort range of motion, either flexion or extension of ankle joint, for deciding the deflection or movement level of these controls.

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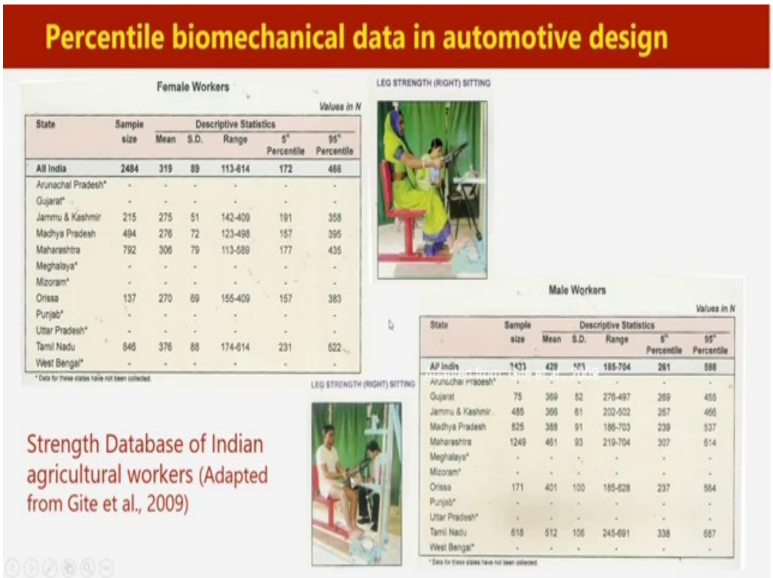


Now, as we discussed earlier also, we can also develop strength database for our targeted population. So, here is one example, the strength database of Indian agricultural workers, this is adapted from Gite et al. (2009) and here is the database for the agricultural worker, both female and male, from different states of India. From these references, we can get force value for leg force, hand force, for different body parts; the force data we can get from this reference.

So, here for the female workers, leg strength value is presented, and in this case, the leg strength value of the male population is presented.

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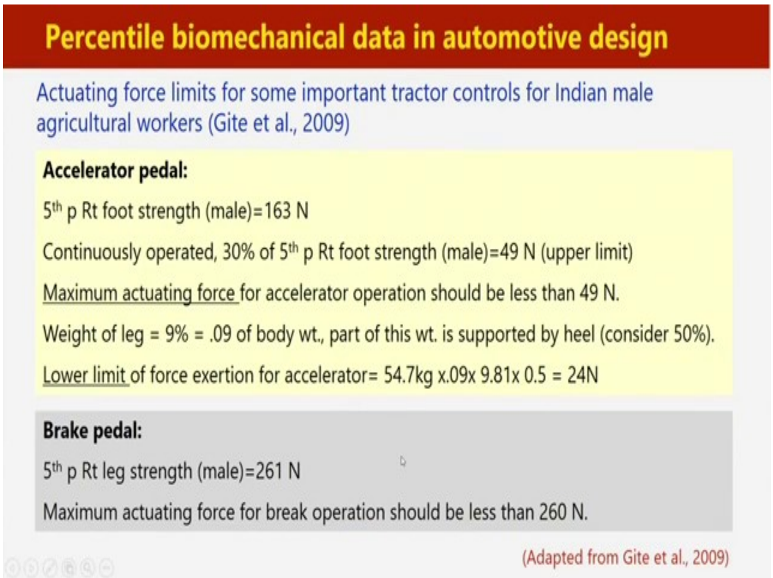


Generally, while we are deciding the actuating force, generally, lower percentile, means, 5th percentile force value of leg strength or hand strength value is considered. So, that the majority of the population, almost 95 percent of the population can operate that particular control. So here, from that above aforesaid reference, we are discussing some of the control operations and its corresponding actuating force requirement. So, this is mainly for tractor design.

So, if we consider that; how much force is required for actuating accelerator pedal of a tractor, then we need to consider 5th percentile right foot strength because accelerator is operated by right foot and it is generally, tractor is operated by male operators. So, 5th percentile right foot strength is 163 Newton, as this control is continuously operated, so, Gite et al. suggested that 30 percent of the 5th percentile right foot strength of male operators should be considered and that 30 percent value is coming as 49 Newton, that is the upper limit.

So, that is why maximum actuating force for accelerator operation should be 49 Newton. If we consider the weight of the leg as the 9 percent of the body weight, then, and parts of this weight is supported by the heel, if we consider 50 percent is being borne by the heel, in that case lower limit of the force exertion of the accelerator will come; bodyweight into 0.9 into gravitational acceleration value and 0.5, that is the 50 percent.

So, now it is coming to 24 Newton. So, upper bound and lower bound limit of the actuating force for accelerator should be 24 Newton to 49 Newton.

Now, for brake pedal; as brake is also operated with the right leg. So, 5th percentile right leg strength, that is 261 Newton of the male population is considered. Maximum actuating force for brake operation thus can be considered as 260 Newton.

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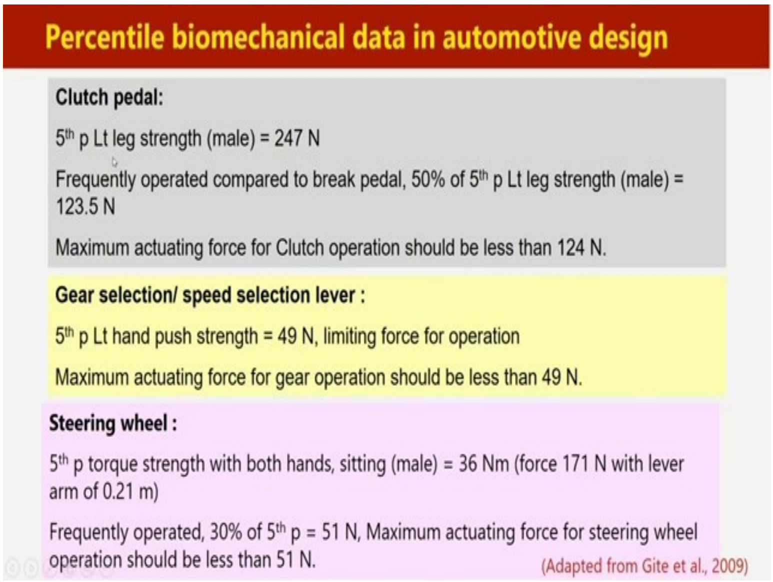


In case of the clutch pedal; as clutch is operated by left leg. So, 5th percentile left leg strength of male, that is 249 Newton, that value is considered and from that; as this clutch is also frequently operated like leg pedal. So, 50 percent of the 5th percentile left leg strength of the male, that is half of this value 247 Newton, it is coming to 123.5 Newton, that is considered for the clutch operation. So, ultimately the maximum actuating force for clutch operation for the tractor should be 124 Newton.

Now, for gear selection/speed selection lever; 5th percentile hand push strength is required; is used and that value is 49 Newton in case of 5th percentile hand strength. So, the maximum actuating force for gear operation should be less than 49 Newton. In case of steering wheel, both hands are used. So, 5th percentile torque strength of both hands of male population and that value is 36 Newton meter is considered because the force value here is 171 Newton and lever arm distance is 0.21 meter. As this is frequently operated, so, 30 percent of the 5th percentile value, that is 51 Newton, we can decide and maximum actuating force for steering wheel operation should be less than the 51 Newton.

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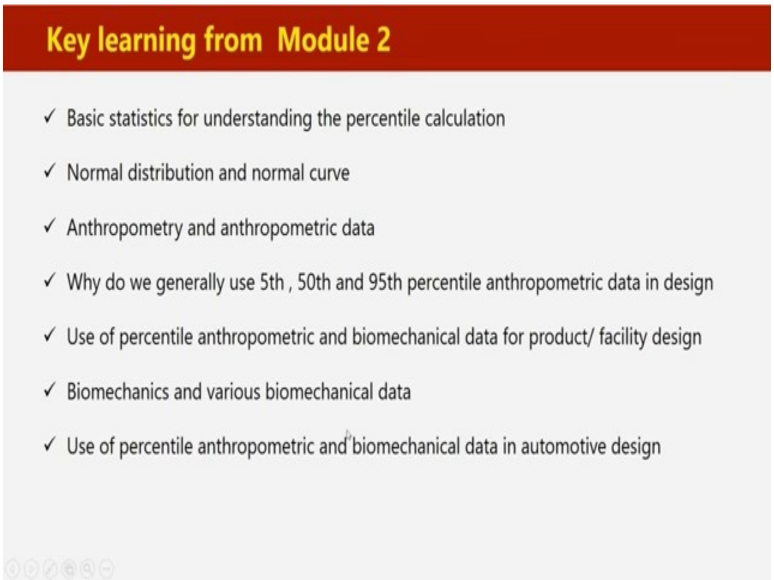


Now, from this module, module two, what are the key learnings? So, first one; we understood basic statistics of percentile calculation, normal distribution pattern of the dataset and normal curve properties, anthropometry and anthropometric data, why do we use $5^{th}$, $50^{th}$ and $95^{th}$ percentile anthropometric and biomechanical data for design of various equipment or automobile components, that we also discussed, then use of percentile anthropometric and biomechanical data for different types of product and facility design.

Then, we discussed about the biomechanics and various biomechanical data and which are used for automobile design, then particularly, we used, how we can use this percentile anthropometric and biomechanical data in the automotive design process.

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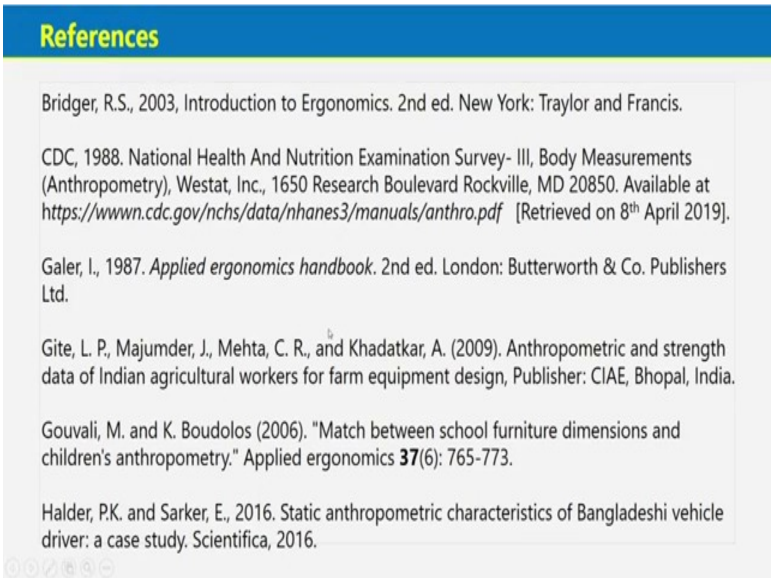


These are the references which have been consulted during this slide preparation.

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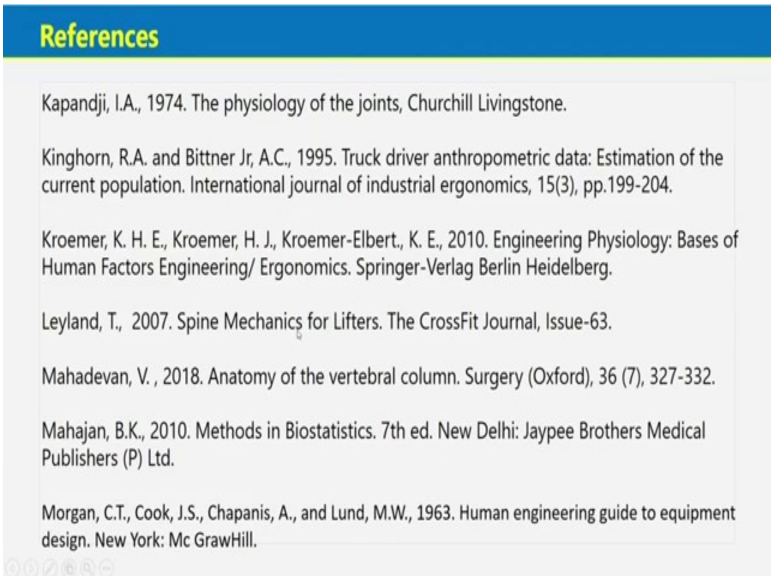

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So, students can go through, or they can explore all these references for further learning.

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## Useful online resources

| Sources | Webpage |
|---|---|
| International Ergonomics Association (IEA) | http://www.iea.cc/project/index.html |
| Human Factors and Ergonomics Society | https://www.hfes.org//Web/linksofinterest.html |
| Indian Society of Ergonomics (ISE) | http://www.ise.org.in/links.shtml |
| Ergonomics Lab for Assessing Physical Aspects of Design | https://ergonomics-iitg.vlabs.ac.in/ |
| Engineering Design -Ergonomics for beginners: Industrial design perspective | https://www.youtube.com/playlist?list=PLbMVogVj5nJREntlYvXAED0aobgAqruJ2 |
| Chartered Institute of Ergonomics & Human Factors | http://www.ergonomics.org.uk/ |
| Association of Canadian Ergonomists | https://www.ace-ergocanada.ca/resources/ |
| Ergonomics in Design | http://ergonomicsindesign.com/ |
| Foundation for Professional Ergonomics (FPE) | http://www.ergofoundation.org/ |
| Humanics Ergonomics | http://www.humanics-es.com/ |
| Ergonomics laboratory, Dept. of Design, IIT Guwahati | http://www.iitg.ac.in/erglab/ |

And here is the list of few useful resources, these are the web links. So, you can further explore.

Thank you.