# THE HUMAN SYSTEM

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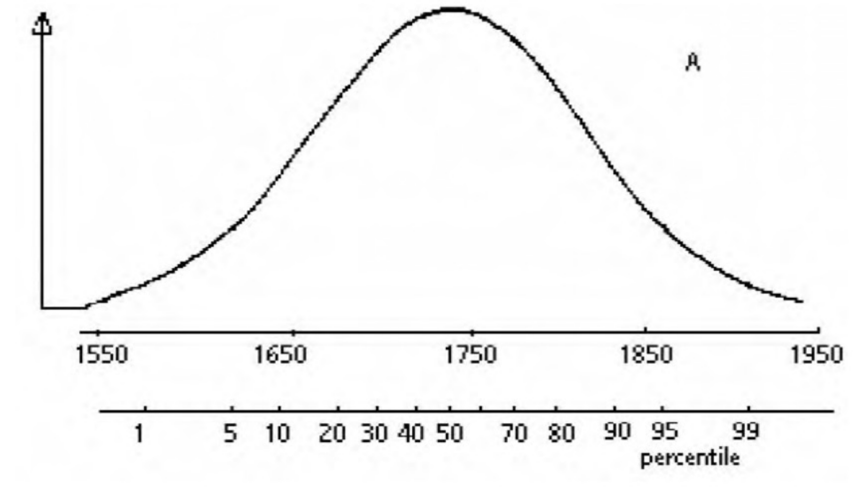
# ANTHROPOMETRY

- The study of body sizes and other associated characteristics is generally referred to as *anthropometry.*
- While the term typically refers to static space dimensions, such as length, width, and shape, other important anthropometric measurements include the weights
- Anthropometric measurements are essential when designing devices and/or systems to fit the users or employees.
- For example, almost everyone would expect doors in building to be well above 6 feet (1.83 m) tall, because we are well aware that many people exceed 6 feet in height. But how large should the diameter of a screwdriver handle be, if you want the human hand, including fingers and the thumb, to surround the circumference? Or suppose that you are designing eye-glasses and you want the hinges outboard of the glass frames to be slightly smaller than the width of the human head just above the ears. What size do you need? Clearly, people who design products for the human body need to know something about the wide variety of body sizes.

# PREDICTING THE STATURE OF PEOPLE

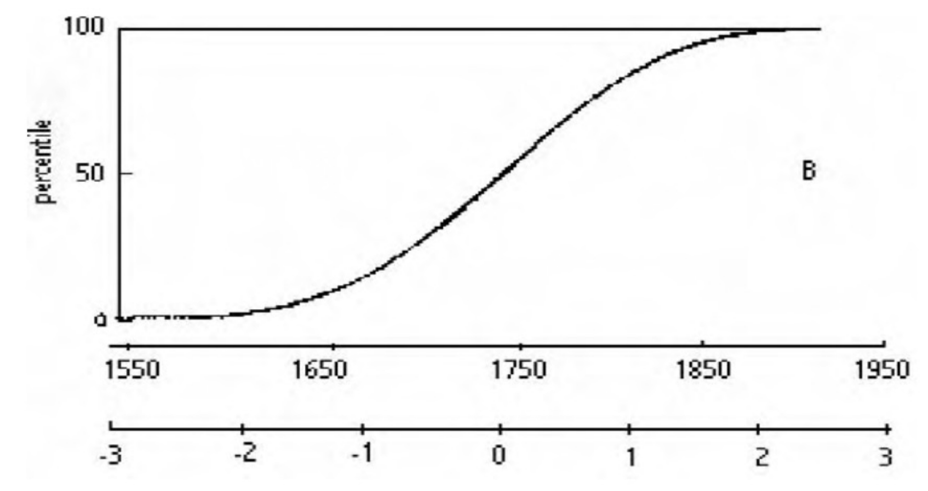
- People from a specified population vary in height from person to person following a normal distribution.
- The latter figure shows a bell-shaped curve obtained when the stature of British men (in millimeters) was plotted versus the relative frequency of each height for the population. Below that bell curve is a percentile scale, ranging from the first percentile to 99th percentile. These two points correspond to heights of approximately 1,575 mm and 1,900 mm. The median (50th percentile height) is about 1,743 mm.



# PREDICTING THE STATURE OF PEOPLE

The Figure shows the cumulative normal function for the various heights. Here, the lower line in this figure represents the *z*-values of standardized normal variation or standard deviations. The tail of the normal distribution to the right of a *z* score of 1.96 has an area of 2.5%. Accordingly, a range of *z*-values between -1.96 and +1.96 describes a 95% confidence interval around the mean.

For the data shown, 95% of the population falls in the interval from 1,600 to 1,889 mm. The range from $z = -1.64$ to $z = +1.64$ corresponds to the middle 90% of the population, and sizes ranging from 1,629 mm to 1,855 mm.



# Ethnic differences

- Designers often use such data to fit their designs to selected populations. This approach is especially likely to be useful when designers have some control over the subpopulations. For example, in military settings, pilot candidates who are unusually tall or short can be screened out.
- One major complicating issue is that anthropometric measurements show consistent variation between members of different ethnic groups, between genders, and over time.
- NASA and other organizations have attempted to document ethnic and other differences in stature data. Much of the information they have assembled shows that human stature has been increasing world- wide since the mid-1800s.
- The average heights of military personnel world- wide have shown dramatic increases from about 1,715 mm during the early part of this century to 1,775 mm (or slightly more) in 1980. That increase represents a rate of growth in the human stature of about 1 mm a year.
- Although the accuracy of some of the older records may be debatable, nearly all countries with records going back very far have shown a continual upward trend in stature. Many people attribute this worldwide change to better diets. Those data also tend to show ethnic differences.

# Anthropometric design

- **Example**:  if a seat height is to be decided and for economic or other reasons it is not possible to provide any adjustability, e.g. Seats in public places or in public transport, then the most important dimension is popliteal height which is the vertical distance from the sole of the foot to the crook of the knee.
- This distance is important to the sitter because if the seat is a little higher than his or her popliteal height then the foot cannot be comfortably placed on the ground and there may be discomfort due to the pressure on the underside of the thigh resting on the seat. For this reason, it is generally recommended that the popliteal height of the smaller members of the population is used to determine seat heights.
- There are two primary types of dimensions:
    1. **Static dimension**: taken when the body is in a fixed (static) position (Shoulder height).
    2. **Dynamic dimensions**: taken under conditions in which the body is engaged in some physical activity where dimension vary with time, such as practical limit of arm reach.

# Anthropometric design

- **Principles in the application of anthropometric data:**
  1. **<u>Design for extreme individual (Maximum or Minimum)</u>**:
     - Designing for the maximum population value is the appropriate strategy if a given maximum value of some design feature should accommodate all people.
     - Heights of doorways - Sizes of escape hatches - Strength of supporting devices
     - Designing for the minimum population value is the appropriate strategy if a given minimum value of some design feature has to accommodate all people.
     - The distance of a control button from the operator - The force required to operate the control.

# Anthropometric design

2. **<u>Designing for adjustable range</u>**:
   - Using a range from the 5th percentile female to 95th percentile male will result in accommodating 95 percent of a 50/50 male/female population, not 90 percent, because of the overlap between male and female body dimensions. An adjustable range is the preferred method of design, but of course, it is not always possible.

3. **<u>Designing for the average</u>**:
   - In this principle, the design of products is formed based on people who have an average size. Meanwhile, people who have large or extreme sizes, they will be made with their designs.

# Anthropometric design

- **Types of Variability in Anthropometric Data**
  - Sex differences
  - Ethnic difference
  - The secular trend (generations variation)
  - Ageing

# PREDICTING THE SEGMENT MASS OF THE HUMAN BODY

- Human physical activities normally involve movement. The larger the mass of the body part that is moved, the greater the forces needed to move it. For this and other reasons it is often useful to be able to predict the mass of different segments of the body.
- Some of the work at NASA provides an empirical basis for predicting those mass magnitudes. They made traditional body mass measurements and then ran statistical regression analyses in which they predicted the weight of the specific body segments as a function of the person's overall body weight ($W$).
- The size of different body parts is strongly related to a person's height.
- Taller people tend to have longer arms and vice versa, though this is not always the case.

# PREDICTING THE SEGMENT MASS OF THE HUMAN BODY

- Table 2.3 shows the regression equations developed by NASA, along with the standard error of the estimate, and the coefficient of determination. The masses and weight are recorded in kilograms. One caveat is that when the predicted weights for all the parts are added together, the sum is not exactly equal to the total weight of the human body. Fortunately, as can be easily verified by the reader, these differences are not very large.

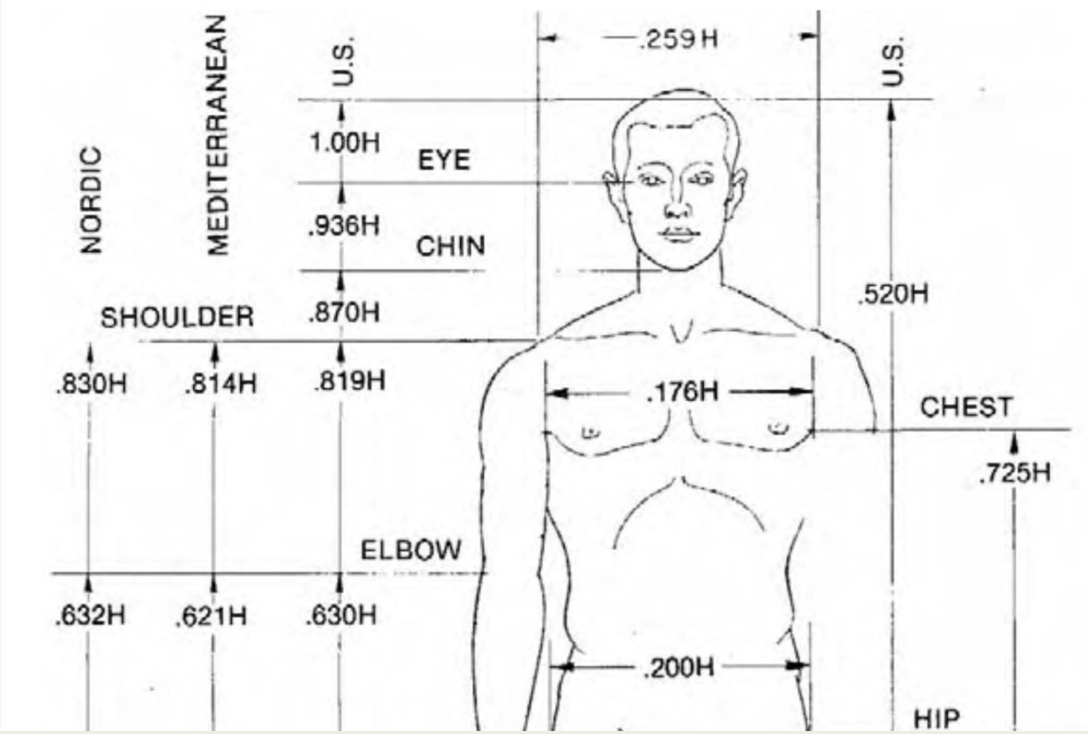
| Segment | Regression equation | Standard error of estimate | Coefficient of determination |
|---|---|---|---|
| Head and Neck | $0.0306W + 2.33$ | 0.60 | 0.726 |
| Head | $0.0306W + 2.46$ | 0.43 | 0.626 |
| Neck | $0.0146W + 0.60$ | 0.21 | 0.666 |
| Head, Neck & Torso | $0.5940W - 2.20$ | 2.01 | 0.949 |
| Neck and Torso | $0.5582W - 4.26$ | 1.72 | 0.958 |
| Total Arm | $0.0505W + 0.01$ | 0.35 | 0.829 |
| Upper Arm | $0.0274W - 0.01$ | 0.19 | 0.826 |
| Forearm | $0.0189W - 0.16$ | 0.15 | 0.783 |
| Hand | $0.0055W + 0.07$ | 0.07 | 0.605 |
| Total Leg | $0.1582W + 0.05$ | 1.02 | 0.847 |
| Thigh | $0.1159W - 1.02$ | 0.71 | 0.859 |
| Shank | $0.0375W + 0.38$ | 0.33 | 0.763 |
| Foot | $0.0069W + 0.47$ | 0.11 | 0.552 |

# PREDICTING THE SEGMENT MASS OF THE HUMAN BODY

| Age | Females | Males |
|---|---|---|
| Years | Height (cm) | Height (cm) |
| 1 | 74 | 75 |
| 5 | 110 | 111 |
| 10 | 138 | 138 |
| 15 | 160 | 168 |
| 20 | 161 | 174 |
| 35 | 161 | 174 |
| 40 | 160 | 174 |
| 50 | 159 | 173 |
| 60 | 158 | 172 |
| 70 | 157 | 171 |
| 80 | 156 | 170 |
| 90 | 155 | 169 |

# PREDICTING THE SEGMENT MASS OF THE HUMAN BODY

- Approximate dimensions of body segments for Swedish, Mediterranean, and US males as a proportion of height (H)



# PREDICTING THE SEGMENT MASS OF THE HUMAN BODY

- Selected Correlations of Body Measurements of Adult Females and Males—Data Above the Diagonal are for Females and Below the Diagonal are for Males.

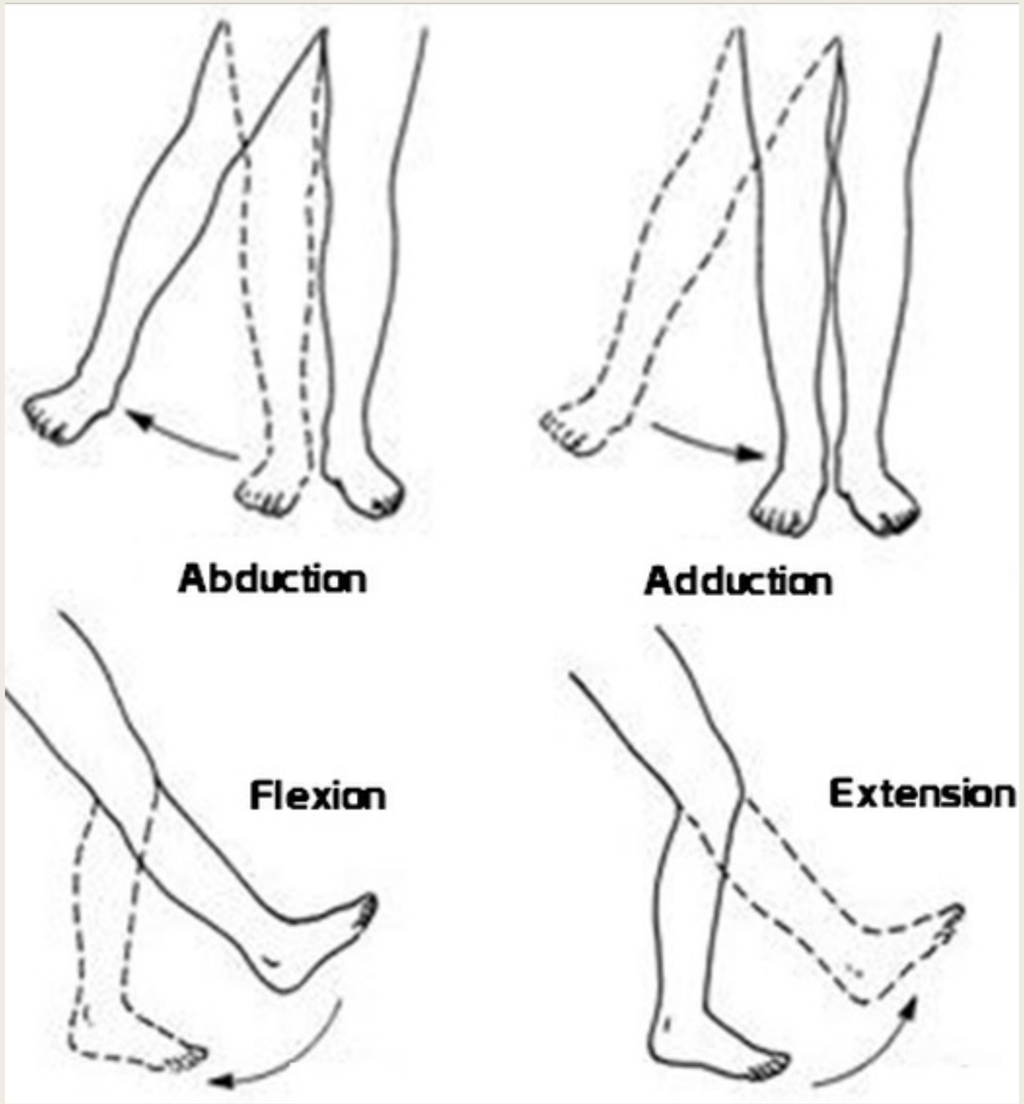
| Characteristic | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| A. Age | — | +.22 | +.05 | −.02 | +.04 | +.23 | +.10 |
| B. Weight | +.11 | — | +.53 | +.46 | +.50 | +.82 | +.40 |
| C. Stature | −0.03 | +.52 | — | +.93 | +.91 | +.28 | +.33 |
| D. Chest Height | −.03 | +.48 | +.98 | — | +.90 | +.22 | +.28 |
| E. Waist Height | −.03 | +.42 | +.92 | +.93 | — | +.24 | +.31 |
| F. Waist Circumference | +.26 | +.86 | +.22 | +.21 | +.14 | — | +.28 |
| G. Head Circumference | +.11 | +.41 | +.29 | +.25 | +.23 | +.31 | — |

# PREDICTING THE SEGMENT MASS OF THE HUMAN BODY

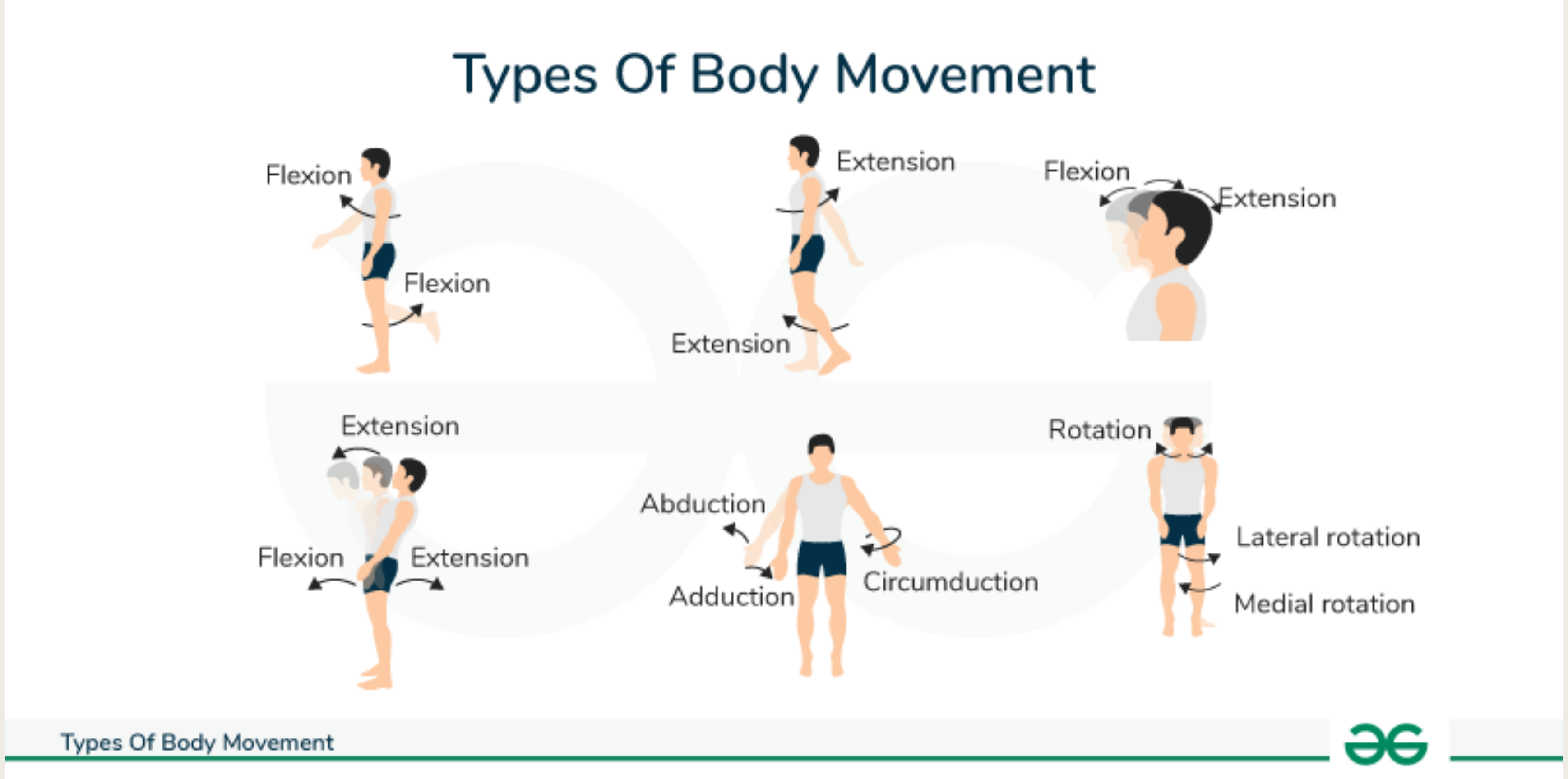
- Other factors are correlated with body segment differences.
- Examples include a general tendency for older people to weigh more, for taller people to be heavier, for heavier people to have larger waists, etc.
- More importantly, these numbers provide a starting point for thinking quantitatively about design problems. For example, a designer wondering how long to make a seat belt could make an initial estimate using the correlation in Table (slide 14) and some knowledge of how heavy prospective customers might be. This would probably be easier than finding a representative sample of heavy people and measuring the circumference of their waists.

# BODY MOVEMENT

- Movements around a joint can be measured in different planes. Flexing and extending movements are distinguished from each other, as are abductions (movements away from the body) and adductions (movements towards the body).



# BODY MOVEMENT



# BODY MOVEMENT

- Next table provides mobility data for joint movements, based on a sample of 200 people. The numbers in the table compare 5th, 50th, and 95th percentile males to females.
- Statistically significant differences between 50th percentile females and 50th percentile males are also shown.
- Movements are normally measured in the frontal, sagittal, and transverse planes. The frontal plane can be visualized as a vertical slice through the standing human body that separates the front of the body from the rear of the body. The sagittal plane is a vertical slice that separates the right and left halves of the body. The transverse plane is a horizontal slice separating the upper and lower parts of the human body. Other systems have been proposed

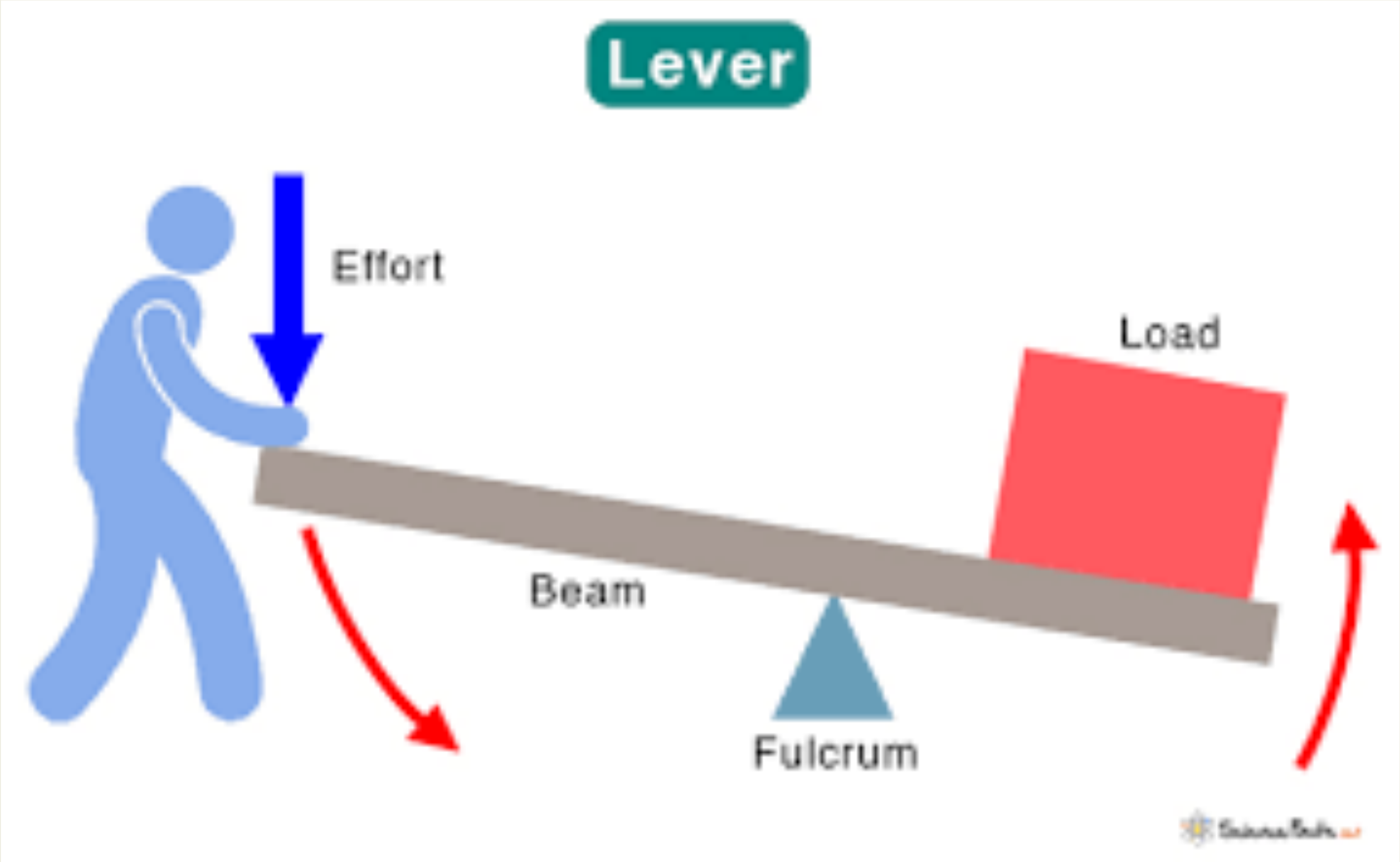
# BODY MOVEMENT

| Joint | Movement | 50th percentile female (male) | Significant difference | 5th percentile female (male) | 95th percentile female (male) |
|---|---|---|---|---|---|
| Ankle | Flexion | 23.0 (29.0) | −6.0 | 13.0 (18.0) | 33.0 (34.0) |
| | Extension | 41.0 (35.5) | +5.5 | 30.5 (21.0) | 51.5 (51.5) |
| | Adduction | 23.5 (25.0) | Not signif. | 13.0 (15.0) | 34.0 (38.0) |
| | Abduction | 24.0 (19.0) | +5.0 | 11.5 (11.0) | 36.5 (30.0) |
| Knee | Standing flex. | 113.5 (103.5) | +10.0 | 99.5 (87.0) | 127.5 (122.0) |
| | Prone flexion | 130.0 (117.0) | +13.0 | 116.0 (99.5) | 144.0 (130.0) |
| | Medial rotation | 31.5 (23.0) | +8.5 | 18.5 (14.5) | 44.5 (35.0) |
| | Lateral rotation | 43.5 (33.5) | +10.0 | 28.5 (21.0) | 58.5 (48.0) |
| Hip | Medial rotation | 32.0 (28.0) | +4.0 | 20.5 (18.0) | 42.5 (43.0) |
| | Lateral rotation | 33.0 (26.5) | +6.5 | 20.5 (18.0) | 45.5 (37.0) |
| Wrist | Flexion | 71.5 (67.5) | +4.0 | 53.5 (51.5) | 89.5 (85.0) |
| | Extension | 72.0 (62.0) | +10.0 | 52.5 (47.0) | 87.5 (76.0) |
| | Abduction | 28.0 (30.5) | −2.5 | 19.0 (22.0) | 37.0 (40.0) |
| | Adduction | 26.5 (22.0) | +4.5 | 16.5 (14.0) | 36.5 (30.0) |
| Fore | Supination | 108.5 (107.5) | Not signif. | 87.0 (86.0) | 130.0 (135.0) |
| Arm | Pronation | 81.0 (65.0) | +16.0 | 63.0 (42.5) | 99.0 (86.5) |
| Elbow | Flexion | 148.0 (138.0) | +10.0 | 135.5 (122.5) | 160.5 (150.5) |
| Shoulder | Adduction | 52.5 (50.5) | Not signif. | 37.5 (36.0) | 67.5 (63.0) |
| | Abduction | 122.5 (123.5) | Not signif. | 106.0 (106.0) | 139.0 (140.0) |
| | Medial rotation | 110.5 (95.0) | +15.5 | 94.0 (68.5) | 127.0 (114.0) |
| | Lateral rotation | 37.0 (31.5) | +5.5 | 19.5 (16.0) | 54.5 (46.0) |

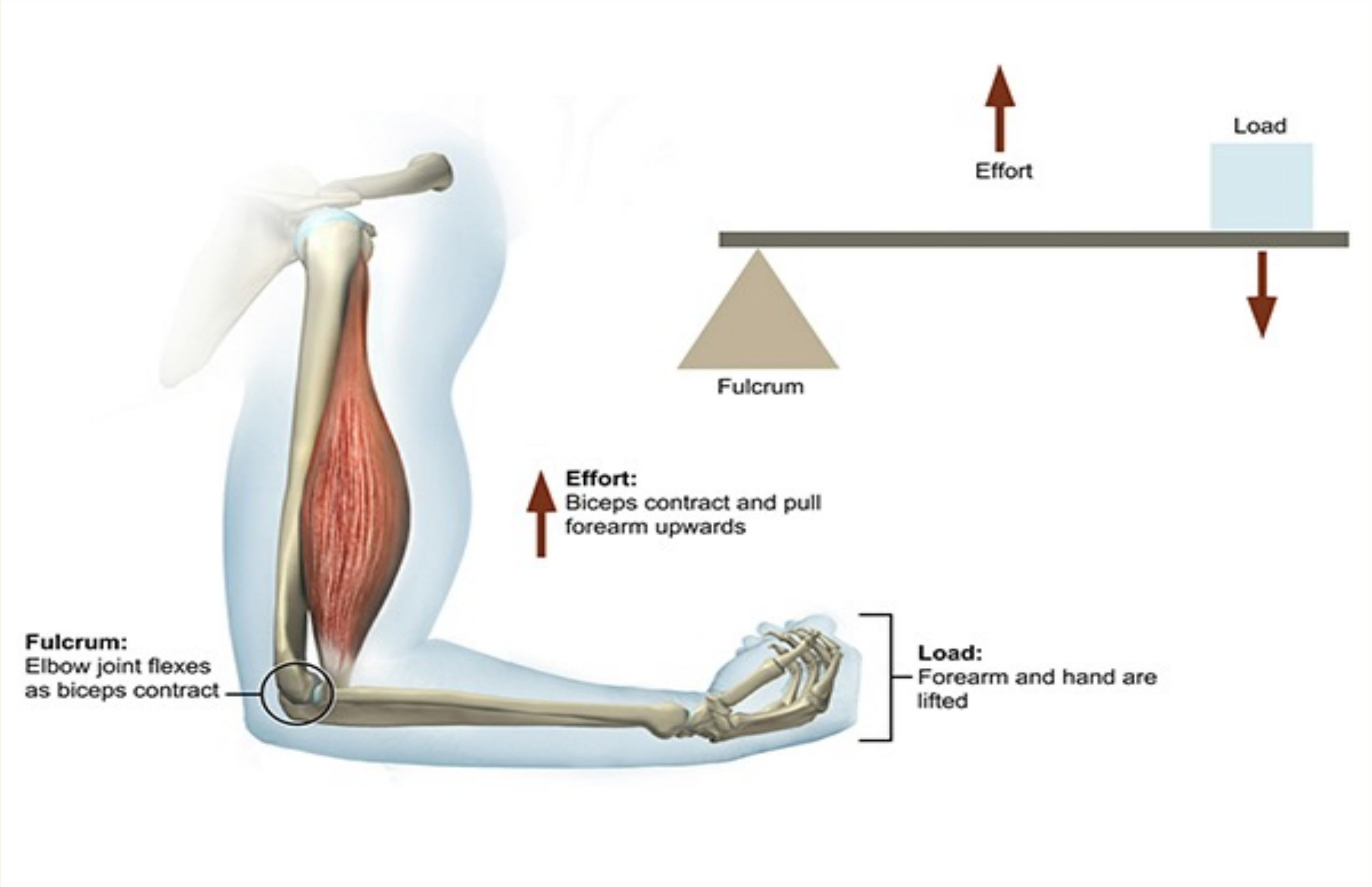
# THE MUSCULAR-SKELETAL SYSTEM AS LEVERS

- Ergonomists often develop models of the forces exerted within the human body when people perform tasks. These models provide fundamental insight as to how different product designs (i.e., hand tool designs), postures, and work methods might impact performance or cause injuries.
- In this modeling perspective, the skeleton is viewed as system of linked levers. Bones become links in the system, which are normally loaded in compression. Joints become fulcrums. Muscles and ligaments exert opposing tension forces around each joint or fulcrum, resulting in moments or torques at each joint and compressive loads on the bones.
- The modeling of the human body as linked levers lends itself to describing the body with stick diagrams. These figures can be drawn quickly and to scale. The most important joints can be shown so that movements can be illustrated easily and appropriate forces and torques can be incorporated to provide a biomechanical analysis.

# THE MUSCULAR-SKELETAL SYSTEM AS LEVERS

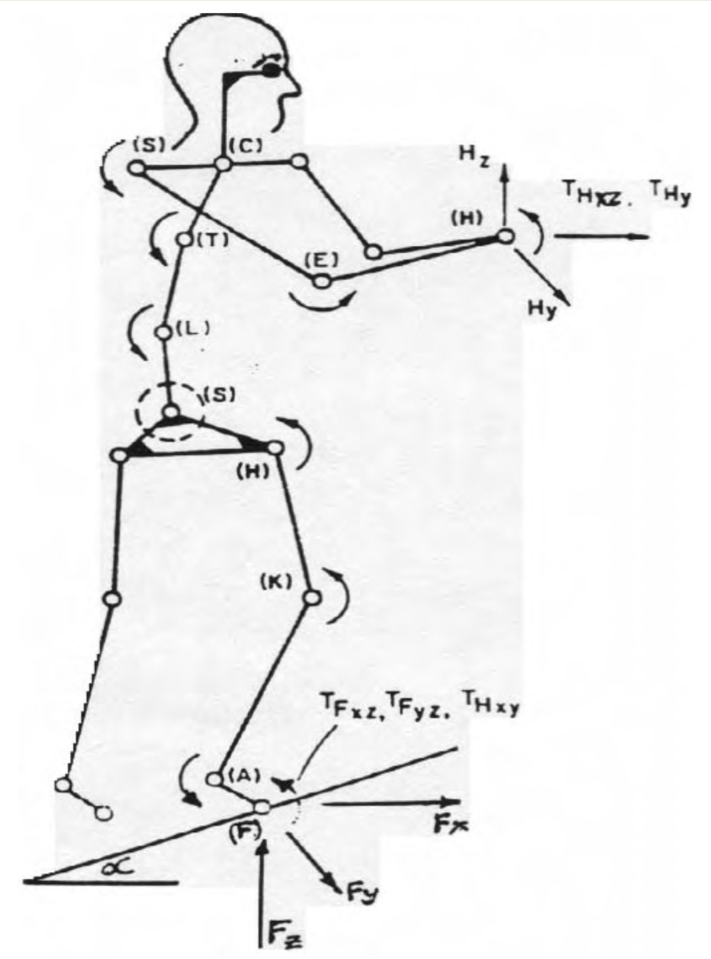


# THE MUSCULAR-SKELETAL SYSTEM AS LEVERS



# THE MUSCULAR-SKELETAL SYSTEM AS LEVERS

- Next figure is an illustration of a stick- person with ankle, knee, and hip joints in the legs.
- The figure also depicts the spinal column, in simplified form, with four joints separating lumbar, thoracic, and cervical regions. Shoulder joints, elbows, and wrists make up the hands and arms.
- This stick-person has resultant forces at the left foot and hands in the three mutually exclusive axial directions denoted as *Fx*, *Fy*, and *Fz*. The torques shown in the three mutually perpendicular planes are *Txy*, *Tyz*, and *Txz*. This leads to analysis of a free-body diagram, where all of the forces in the same axial direction and all of the torques in the same plane must sum to zero.

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# BODY MOVEMENT

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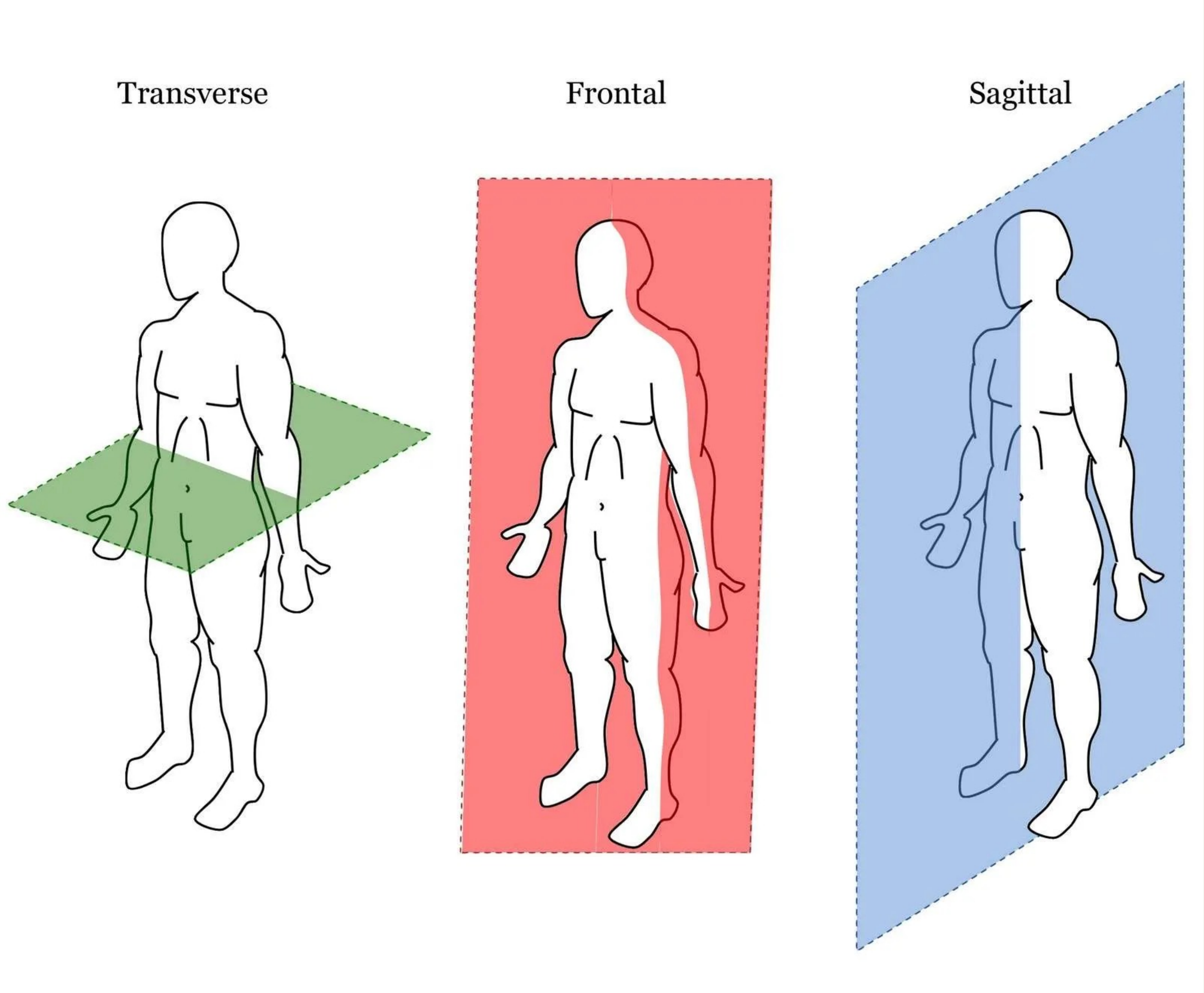


# Understanding the three types of levers in the body

- First up, all levers fall into one of three types of lever.
- The main difference is what order the different parts come in.
- Every lever has three parts to every lever:
    1. the effort,
    2. the fulcrum,
    3. the load.
- The position of these three parts varies in all three levers.

# Understanding the three types of levers in the body

- **Class 1 Levers:**
- A Class 1 lever has the **fulcrum** placed between the **effort** and **load**. The movement of the load is in the opposite direction of the movement of the effort. This is the most common lever configuration. The effort in a class 1 lever is in one direction, and the load moves in the opposite direction. Note that the length of the effort arm can be greater than, equal to or less than the length of the load arm in a class 1 lever.
- Picture a see-saw

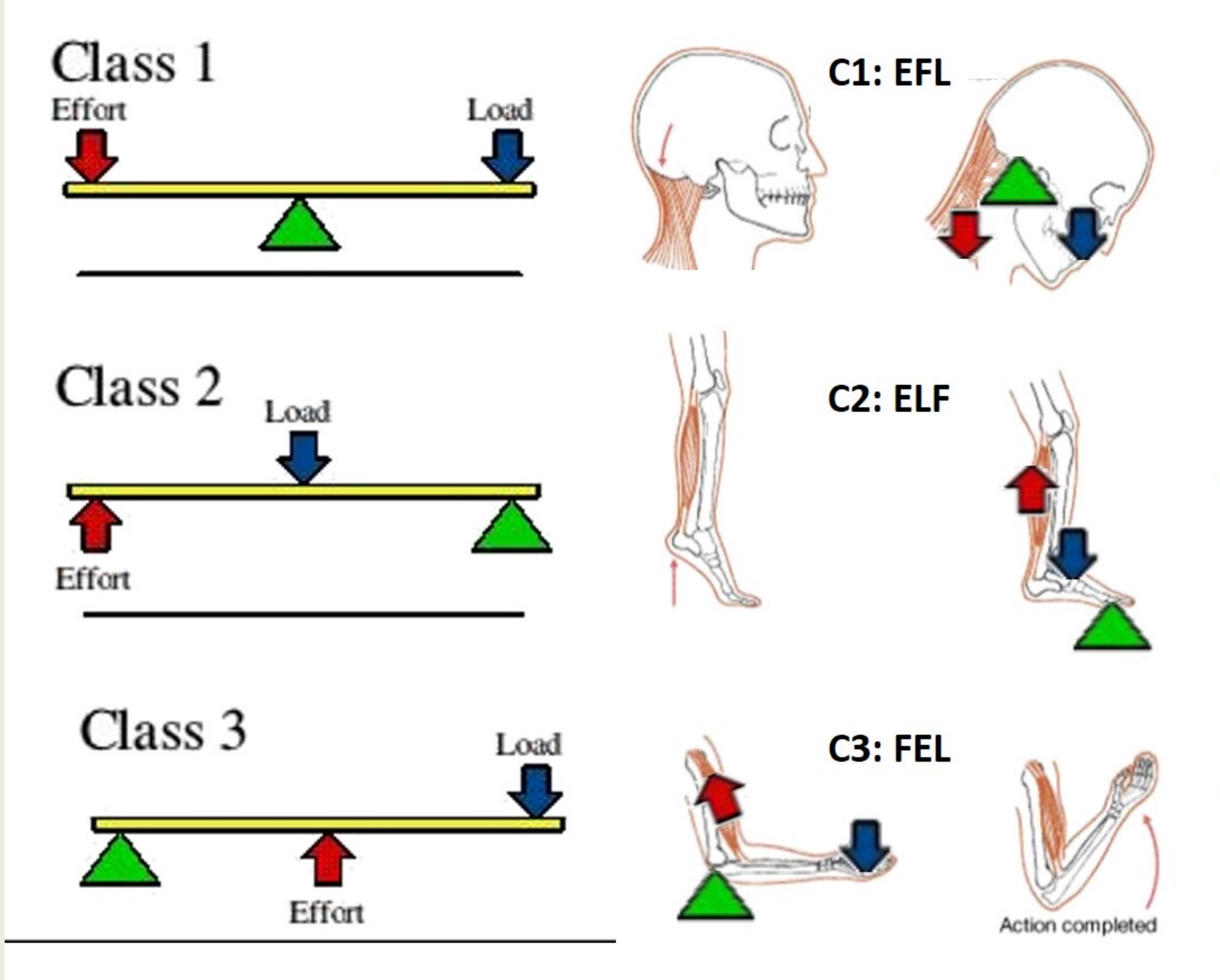
# Understanding the three types of levers in the body

- **Class 2 Levers:**
- A Class 2 lever has the **load** between the **effort** and the **fulcrum**. In this type of lever, the movement of the load is in the opposite direction as that of the effort. Note that the length of the effort arm goes all the way to the fulcrum and is always greater than the length of the load arm in a class 2 lever.
- Picture a wheel-barrow

# Understanding the three types of levers in the body

- **Class 3 Levers:**
- A Class 3 lever has the **effort** between the **load** and the **fulcrum**. Both the effort and load are in the same direction. Note that the length of the load arm goes all the way to the fulcrum and is always greater than the length of the effort arm in a Class 3 lever.
- Picture a fishing rod

# Understanding the three types of levers in the body



# THE MUSCULAR-SKELETAL SYSTEM AS LEVERS

Examples of the human body as three types of levers. At the top is a first class lever. A second class lever is shown in the middle and a third class lever at the bottom