So you want to learn more about people ...  
Step in for a journey to discover the potential, capabilities, strengths (and limitations) of this essential element in systems design!

Module 2

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(Sincere thanks to Prue Howard, Amanda Brain and Steve McKillup for their valuable contributions)
Physical ergonomics
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Introduction to the module

In the simplest terms your body works as a series of levers and winches, fuelled by your blood supply and activated by your nervous system.

Your bones make the solid structure your body requires to work. Where they join there is cartilage to provide a smooth moving surface and ligaments across the joint to stop excessive movement.

Muscle tendons attach on either side of a joint. The muscle contracts (shortens) or relaxes (lengthens) to move the joint. The muscles thus provide the mechanical movement. Blood carries energy (oxygen and nutrients) to, and removes waste from the muscles. Your heart pumps the blood around your body to supply the energy wherever it is needed. Nerves tell your muscles when and how much to contract and relax. This is the electrical component of the system. Nerves also give us information on what position our joints are in, and allow us to sense temperature, sight, sound, smell, and pressure.

Our brain is the control centre, which collects information (electrical messages) sent to it from the nerves and gives the message a meaning (similar to reading morse code). The brain also sends out electrical messages through the nerves to the body.

These systems have limitations. If demands placed on a person exceed their system’s capabilities, sub-optimum performance will result, for example, errors in perception and decision-making, fatigue, damage to structures (bones, muscles, ligaments), and/or lack of control over movement.

Objectives

On successfully completing this module you should be able to:

• describe the metabolic processes being carried out within the muscle and the support of the cardiovascular and respiratory systems in this function
• discuss the application of these principles in relation to humans doing work
• evaluate the effectiveness of equipment and work design in relation to biomechanics and anthropometrics and recommend optimal man-machine match
• select and apply appropriate tools for evaluating manual tasks in the workplace
• recommend appropriate design parameters to optimise productivity and safety in the users’ environment.

Human performance capacity

To move, your body needs energy. We obtain this energy from other animals and plants, which we eat and digest to provide small food molecules, which are absorbed into our bodies, broken down, and have the energy they contain extracted from them. It is important to understand the supply of energy for muscular movement, as well as the restrictions that sometimes occur on this supply under certain conditions, to grasp these basic concepts.
You may wish to consult a textbook or web resource that provides a fairly simplistic overview of muscle and work physiology. You need to leave this independent research with a good understanding of these basic concepts as they will be the foundation for understanding the human body performing work.

The most common source of energy used by human cells is the molecule glucose \((C_6H_{12}O_6)\) which can be broken down in several small stages, yielding energy along the way. Glucose is broken down to pyruvic acid, and pyruvic acid is then broken down to carbon dioxide and water.

**Activity 2–1**

(a) Now if you consider the concept that chemical bonds can be visualised as a store of energy, which of the molecules ATP, ADP and AMP will contain the greatest number of chemical bonds and therefore the greatest amount of stored energy? Sketch out your idea.

(b) Actually, you could rank the molecules in order on an “energy gradient” with the lowest at the bottom and the highest at the top. Draw your energy gradient here.

<table>
<thead>
<tr>
<th>Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>High energy</td>
</tr>
<tr>
<td>Low energy</td>
</tr>
</tbody>
</table>

How did you go? You can check your answers at the end of the module.

When energy is available from the breakdown of glucose (or other large molecules), it is stored by joining phosphates to ADP molecules to make ATP. The energy is stored in the extra phosphate-phosphate bond. When energy is needed by the cell (e.g. for muscular movement), ATP is broken down to ADP and phosphate, releasing the stored energy, as shown in Figure 2-1.
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Physical ergonomics

Figure 2–1: The ADP/ATP cycle

Before moving onto subsequent sections of this module you need to have grasped the following key areas:

- aerobic sources of ATP
- anaerobic sources of ATP
- comparing the aerobic and anaerobic energy systems
- interaction of anaerobic and aerobic energy sources
- recovery from work
- energy, work and power
- measuring an organism’s use of energy.

If you do not feel comfortable with these concepts you need to revisit the appropriate sections of your text and/or supplement your reading with other simple physiology texts.

Fitness assessment: The response of an individual to a certain amount of exercise

In order to assess the suitability of a person for a particular job, and to reduce the risk of an existing physiological condition being exacerbated by that job or by other conditions in the workplace, the fitness of employees is often assessed. The heart rate can be used as a measure of fitness. Fitness or cardiovascular fitness is a measure of the efficiency of the cardiovascular system—that is, the ability of your circulatory system and respiratory system to deliver oxygen and glucose to, and remove wastes such as carbon dioxide from your muscles.

The efficiency of your cardiovascular system can be improved by frequent exercise. Some of the changes that occur in response to frequent exercise are an increase in stroke volume (i.e. the capacity of your heart, or the amount of blood pumped each time your heart beats) which may result in a decrease in the resting cardiac rate.

In addition, frequent exercise also increases the ability of muscles to extract oxygen from the blood. Consequently, someone who is physically fit will show a smaller increase in heart rate in response to exercise and also have a faster return to the resting cardiac rate after exercise. Physical fitness therefore involves not only obvious...
muscular development, but also the ability of the cardiovascular system to adapt to sudden increases in demand.

The efficiency of the cardiovascular system decreases with age and can also be affected by disease (especially diseases of the heart and lungs). Consequently, tests which measure fitness can be extremely valuable in placing a person in an appropriate job in the workplace.

**Activity 2–2**

What kinds of test data might be useful? What type of test would be suitable for most workplaces and easy to administer?

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Did you find that the most commonly used tests of fitness are simple exercise tests? These provide a numerical estimation of a person’s cardiovascular fitness and are often surprising simple. For example, resting pulse rates (and often blood pressure) are measured and the person is then required to perform a set task such as a certain number of “step ups” (e.g. their right foot is placed on a chair or stair 18 inches (45 cms) high, they are asked to raise their body so that their left foot comes to rest by their right foot. This is repeated several times (e.g. five), allowing three seconds for each step up. Immediately upon completion of this exercise, their pulse rate is measured, together with the time taken for the pulse rate to return to the pre-exercise value). Persons with a fit and therefore relatively efficient cardiovascular system will generally have a lower resting pulse rate, a smaller increase in response to exercise, and a faster return to the pre-exercise level.

**Activity 2–3**

Think of any application of these types of tests which might be valuable in the workplace. Why can this be critical to the ongoing health of workers? Jot down your thoughts here.

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If you think laterally to each of the discipline areas of health and safety you will think of many examples. For example, did you consider the implications of various workers (with individual levels of fitness and general health) being exposed to hazardous substances and the variation in their response to those substances?

**Fatigue**

Fatigue is the inability to maintain a given intensity of exercise or work, and can also be thought of as the inability to maintain a certain level of power. The tendency to become fatigued is also related to cardiovascular fitness—if you are relatively unfit you are likely to show signs of fatigue earlier than a fitter person performing the same muscular work.

There are several causes of fatigue during exercise, and these are listed below:

- The inability to supply ATP, that is, if ATP cannot be supplied at the rate needed by your muscles, ATP stores will decline and eventually there will be insufficient energy to maintain a given level of exercise;
- The inability to supply glycogen—as exercise continues, glycogen will be used up, fatigue will occur once the glycogen supply is depleted;
- The inability to supply glucose—blood glucose levels are maintained by breaking down glycogen stored in the liver, but during prolonged exercise blood glucose levels can be depleted, again leading to fatigue;
- Oxygen depletion can lead to fatigue because inadequate oxygen levels can reduce the aerobic breakdown of glucose, hence slowing the rate at which ATP can be supplied to muscle tissue.
- Accumulation of metabolites such as lactic acid (although this used to be the most widely accepted reason for fatigue there is not a great deal of evidence that the accumulation of lactic acid commonly prevents muscle functioning and hence results in fatigue); and an
- Increase in body temperature—exercise generates heat and excess production of heat can result in a rise in body temperature, which will impair the ability of your muscles to maintain a certain level of power.

**Activity 2–4**

You have a worker on “night shift” shovelling coal. Identify and discuss what factors you would need to consider in designing jobs, tasks and equipment for this worker.

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Hopefully, in your answer you considered methods of work, work posture, work rates, tool design, work-rest cycles and exercise training. Did you also note the design of shifts (considering circadian rhythms), availability of meals, design of tasks to prevent under stimulation of the worker? Congratulations if you added in any of the second list of factors, top marks! We will be discussing these factors further.

**Muscular work**

Recall your reading of muscle physiology in the basic physiology text you researched we will enhance these concepts further by discussing the relationship between nerves and muscles.

**The relationship between nerves and muscles**

Put extremely simply, if a nerve message or nerve impulse (you may have previously had this described as an *action potential* in other programs or courses) is sent via a nerve to a muscle, it spreads across the membrane of the muscle cell. As the action potential spreads, the filaments within the cell “pull together” and the cell shortens.

**Figure 2–2: The relationship between a nerve and the muscle cell**

![Diagram](image)

**Excitation coupling**

How does the action potential spreading across the muscle cell result in pulling together of the muscle filaments? The following is a very simplified explanation:

This process is called *excitation coupling* or *excitation-contraction coupling*, and is the events which occur as an action potential spreads over the muscle cell and causes contraction. To understand excitation-contraction coupling, you need to understand the detailed structure of a muscle cell, including that of the thick and thin filaments.
There are nine events in the process:

1. The action potential travels over the surface of the muscle cell, and also down the \textit{T tubules} which run “inside” the cell.

\textbf{Figure 2–3: The muscle cell, T tubules and the sarcoplasmic reticulum}

2. The action potential running through the T tubules causes calcium ions (\(\text{Ca}^{++}\)) to be released from a structure called the \textit{sarcoplasmic reticulum} which surrounds every muscle fibre (see the simplified diagram above). The calcium is released from the sarcoplasmic reticulum into the spaces between the actin and myosin filaments.

3. The thick filaments (which are made of many myosin molecules) have a very specific structure. Myosin molecules have an “head” and a longer “tail”.

\textbf{Figure 2–4: A simplified diagram of a myosin molecule}

4. If ATP is available, one molecule attaches to the myosin head.

5. When there is no action potential occurring in the muscle cell, the heads of the myosin do not attach to the thin (actin) filaments and the muscle is relaxed and can even be stretched.

6. When an action potential does occur, resulting in \(\text{Ca}^{++}\) flooding between the actin and myosin filaments, the myosin heads bind to the thin filaments and break down the ATP to ADP and phosphate.

7. The energy released by the breakdown of the ATP is stored briefly by the myosin molecules. These then bend, pulling the thin filaments inwards. This results in the muscle cell getting shorter.
8. The head then detaches and picks up another ATP. If there is still calcium present, the whole process is repeated and the muscle gets even shorter.

9. The process continues until the muscle cell cannot get any shorter (when it is fully contracted). When the action potentials stop, the calcium is rapidly returned to the sarcoplasmic reticulum (by a process requiring energy, called active transport) and the cycle of attachment, bending and releasing stops. The muscle cell can then be easily stretched back to its original length.

Figure 2–5: Contraction, initiated by the movement of part of the myosin molecules

Activity 2–5

Prepare a description of the structure and function of skeletal muscles. Describe your model to a co-worker. What questions did they have? What are the answers?

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Did you find the above activity difficult?

If you did, then perhaps it is time to consult a supplementary physiology reference book. Muscular physiology can be difficult to understand, however, if you can get past the terminology and think about the integrated relationship between nerves and muscles, it becomes a lot easier to understand.

If you didn’t find the exercise difficult, great work, keep going with the next topic!
Strength and endurance
As discussed previously, work capacity is limited to the ability of the cardiovascular system to transport fuel and oxygen to muscles. Strength and muscular endurance may also limit the ability to do work. The ability of people to perform work in relation to strength and endurance can vary considerably. The level of individual strength and endurance is not fixed but dynamic. The type of work we perform, our genetic makeup, body dimensions, physical training and motivation can all affect the level at a given time. We will further discuss some important factors associated with strength and endurance.

Strength and warm-up
The rate of a chemical reaction depends upon temperature, so small increases in muscle temperature may lead to increased reaction rates between actin and myosin as well as the supply of ATP. Consequently, many athletes attempt to “warm up” their muscles before a race or event by mild exercise (by stretching, etc.).

Strength: Variations in gender and age
There are differences between males and females in terms of strength and physical performance, but these are far less than used to be thought.

Generally, males have a greater proportion of muscle and less fat, plus an oxygen consumption, which is about 20% higher than females. Nevertheless, exercise programs, especially endurance training, can reduce, equalise, or even reverse these differences. It appears that social factors are important as well—for example, both males and females from lower socio-economic groups tend to have a greater ratio of fat to muscle compared to those in higher socio-economic groups.

Individual muscle fibres in males have a larger cross-sectional area than those in females. Therefore there are more muscle elements (the actin and myosin strands) per cell, which makes the fibres and therefore the muscle larger and stronger—consequently they are able to develop greater tension. One of the causes of this difference is that the hormone testosterone stimulates muscle hypertrophy by increasing the cross-sectional area of muscle cells and fibres.

One of the most marked increases in muscle strength occurs in males when they reach puberty and levels of testosterone increase greatly in the bloodstream, resulting in an increase in the number of actin and myosin elements in muscle cells.

As we get older, the systems which deliver oxygen to muscles, remove metabolic wastes and maintain body temperature gradually become less efficient. Our joints become stiffer and muscle mass declines. Peak physical performance is achieved at approximately 30 years of age and declines slowly after that. Exercise doesn’t slow down the processes associated with ageing—instead it just allows a person to perform at a better (or their “best”) level possible, considering the declining performance of the system with age.
Heart rate as a measure of workload

An increase in heart rate is one of the most important ways in which the delivery of oxygen to your muscles can be increased during exercise—this was discussed in the previous module under “fitness assessment”. Cardiac output is the amount of blood pumped by your heart in a given time, usually per minute. As cardiac output increases, so does the amount of oxygen delivered to muscles (as does the carbon dioxide removed). A resting heart rate of 70 beats per minute may increase to 180 beats per minute (which is virtually the maximum value possible) during exercise. At the same time, however, heart rate can be affected by other factors, including emotional state (you will surely have noticed that your heart rate increases when you are stressed—like before an exam!). Therefore, heart rate is not necessarily a direct function of oxygen consumption or workload.

Activity 2–6

Describe the various factors that may affect muscle strength. What indications do these factors have for your work situation?

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Your answer should have included pre placement issues and the design of jobs, tasks and equipment. If you identified others as well give yourself a pat on the back.

Biomechanics

The study of biomechanics is the study of the mechanics of the structure and function of living organisms—how the structure of living things allows them to make movements. You are also likely to meet the term kinesiology, which means virtually the same thing, and is often used in North America instead of the term “biomechanics”. The foundation knowledge you need to take from this section is the lever action of muscles and bones, torque and compression.
Basic concepts of biomechanics

Bone joints

The bones of our bodies are attached to each other by joints (a joint is just the point of attachment between two bones). There are three types of joints in the human body—fibrous, cartilaginous and synovial joints. Fibrous joints are extremely inflexible joints where the bones are joined by many short fibres (Figure 2–6 (a)). Cartilaginous joints are more flexible because the bones are joined by cartilage (Figure 2–6 (b)), but synovial joints are extremely flexible because the bones are not directly joined together. Instead, they have a fluid-filled synovial capsule between them which allows the ends of the bones, which are covered by hard, shiny cartilage, to “roll” over each other (Figure 2–6 (c)) allowing a great deal of movement. Human biomechanics is mainly concerned with the movements of bones, which are joined by synovial joints—examples include elbows, knees, ankles, finger joints, wrist joints and so on.

Skeletal muscles—the muscles which produce most of the voluntary movements we make—are attached to bones. When the muscles contract, they attempt to move the bones to which they are attached. The type of movement, which occurs, depends on the location of the muscle and the type and extent of movement allowed by a particular joint. For many movements, the muscles and bones act as levers, and to understand these movements, it is important to understand how different types of levers are classified.

Figure 2–6: (a) A fibrous joint, (b) cartilaginous joint and (c) synovial joint
Levers

A lever is a rigid bar or rigid body, which can turn about a fixed point, the fulcrum, when a force is applied to it. The point where the force is applied is called the point of application and the point where there is resistance to that force is called the point of resistance. Each of these features is shown in Figure 2–7.

Figure 2–7: A simple lever, showing the fulcrum, point of application and point of resistance

There are three basic sorts of levers—first, second and third order (which are sometimes called first, second and third class levers).

First class levers

A first class lever has already been illustrated in Figure 2–7, but is repeated in Figure 2-8(a) together with a “skeletal” example. For a first class lever the fulcrum is between the point of application and the point of resistance to the force. One example is when you nod your head—your neck muscles supply the force, the fulcrum is the joint at the top of your spine, and the resistance is the weight of your head.

Second class levers

For a second class lever the point of resistance is between the fulcrum and the point of application of the force. One example of a second class lever is when you stand on tiptoe. The fulcrum is towards the front of your foot, the load is the weight of your body and the force is supplied by your calf muscle (see Figure 2-8 (b)).

Third class levers

For a third class lever the point of application is between the fulcrum and the point of resistance. An example has been used earlier in the package—picking up an object from your desk. The fulcrum is your elbow joint, the force is generated by your biceps brachii muscle and the resistance is the weight of the object in your hand (Figure 2-8 (c)).
Forces: Magnitude, direction and application point

We frequently use levers. You are likely to use some sort of lever type tools (and perhaps lever type door handles) every day and you have almost certainly noticed that short levers (such as short spanners, short crowbars or even short lever type handles) may be “harder” to use than longer ones. This is an example of how levers can be used to give a mechanical advantage—they can be used to move a resistance which is greater than the force applied. It is an important concept which will be discussed below.

For any lever system:

\[
\text{Effort (the force applied)} \times \text{Distance between the point of application and the fulcrum} = \text{Load (the resistance)} \times \text{Distance of the point of resistance to the fulcrum}
\]

Again, an example will make this clear.
Example 2–1

If two people who are the same weight sit on a seesaw (a class 1 lever) then the seesaw will balance provided they are each an equal distance from the fulcrum (see Figure 2–9 below). Each person exerts the same downward force (say 70 kilograms) and is the same distance from the fulcrum (say 1.0 metre). Consequently, the force × distance to the fulcrum will be equal \((70 \times 1.0 = 70)\).

Figure 2–9: Two persons of equal weight equidistant from the fulcrum

If, however, one person is lighter (say 50 kilograms) they can still balance the seesaw by sitting further out from the fulcrum. This is because they have created a mechanical advantage—their force of 50 kg is less than that of the person on the other side but their distance from the fulcrum has increased (in this case it will need to be 1.4 metres so that the product of the two is the same as before \((50 \times 1.4 = 70)\).

Figure 2–10: The use of increasing distance from the fulcrum to create a mechanical advantage

This is why levers are so useful—a small load over a long distance can be used to move or counterbalance a heavier load over a shorter distance and vice versa. It is especially important in our use of tools. (For example, a car jack allows us to progressively lift a 1000 kg car using a number of small movements where only 10–15 kilograms of force are used each time.)

Power levers and speed levers

The mechanical advantage of using a lever as discussed above is an example of a power lever—a small force applied further from the fulcrum can be used to balance or exert a greater force at a point closer to the fulcrum.
Figure 2–11: A power lever. A weak force applied at a relatively large distance from the fulcrum can be used to exert a stronger force closer to the fulcrum

A lever can also be used at a mechanical disadvantage, in which case it is called a \textit{speed lever}. If a strong force is applied close to the fulcrum it can not only move a lighter load which is further from the fulcrum, but it will be able to rapidly move the lighter load through a great distance.

Figure 2–12: A speed lever. A strong force applied over a relatively short distance close to the fulcrum can be used to exert a weaker force over a relatively greater distance further from the fulcrum

The principles discussed above also apply to the use of our muscles as levers. Muscles cross joints (the fulcrum) and contraction of muscles results in the movement of limbs. The distance from the fulcrum (joint) to the point where the end of the muscle is attached to the bone will determine the amount of force which can be moved by the muscle, and also the speed of movement. Figure 2–13 shows a muscle acting as (a) a power lever and (b) a speed lever.

Figure 2–13: A muscle acting (a) as a power lever and (b) as a speed lever

\textbf{Torques}

The concept of torque in relation to the use of levers or muscles and bones as levers has already been discussed conceptually in the section “Forces: Magnitude, direction and application point”, although the term \textit{torque} deliberately wasn’t used because it would have confused the explanation.
Torque is often defined as a moment of force. This sounds very confusing, but an example will help. If you apply a force of 50 kilograms on a lever 1.4 metres away from a fulcrum then you will generate a moment of force or torque of $50 \times 1.4 = 70 \text{ kg/metre}$ (this is one of the same examples used earlier when discussing seesaws). Depending on the resistance to that force, rotary movement (that is, circular movement around the fulcrum) may or may not occur. If the resistance is less than the torque, movement will occur—if resistance is greater, movement won’t occur. Extra torque can be applied by increasing the distance away from the fulcrum that the force is applied (as discussed earlier) or simply by increasing the force itself.

**Figure 2–14: Generation of a rotary torque**

![Figure 2–14: Generation of a rotary torque](image)

**Compression**

Often we use our muscles to compress an elastic object such as a spring. The force needed to compress a spring depends upon its resistance to compression. If the force applied exceeds that resistance, then the spring will be compressed and some of the energy required to do this work will be stored in the compressed spring as potential energy (discussed earlier in relation to work capacity). Potential energy will be released when the compressing force stops. Forces of compression are usually expressed as kilograms—for example, if the resistance to compression of a spring is 20 kilograms, it will only be compressed if the force acting on it is greater than this.

**FIGURE 9-1**

Range (in degrees) of rotation and movement of certain upper and lower extremities, based on a sample of 100 male college students. The three values (in degrees) given for each are the 5th percentile, the mean, and the 95th percentile. (Source: Houy, 1983, Table 1. Copyright by the Human Factors Society, Inc. and reproduced by permission.)
Activity 2–7

Consider the range of movements as presented by Sanders and McCormick above. List and describe workplace examples where these principles have been applied, for example, a postal worker responsible for sorting mail would perform work in which the range of movements involving shoulder adduction and abduction would be important. Jot your thoughts down here.

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Hopefully as engineers this task might not have been as difficult for you as some others. As you have more experience in evaluating ergonomics in the workplace you will become more aware of these types of movements. You should note the range of movements required for a job as part of your tools for assessing the workplace.

Your job is to transfer your learning from one context to another, that is, machines to people!

These concepts will of course be very familiar to you however have you ever considered them before in light of the human body rather than traditional engineering concepts? Revisit the concepts above again and consider the potential for integrating your knowledge of engineering with this new application, people!

Applied biomechanics

At the moment in this part of the module we will present a summarised consideration of applied biomechanical principles. There will be some terms you might not understand yet, for example, *anthropometry*, (which refers to studying the size, shape and weight of the human body), we will cover this area in detail later in this module.

Again, you will find the concepts presented in the next couple of sections very familiar but in a new context, people!
Posture and position

The forces generated to sustain a posture and position will vary according to leverage principles and mass of body parts.

For example an average male’s head, neck and upper body above L₂/S₁ weigh about 35.8% of his body mass. If I weigh 80 kg, the mass of my head, neck and upper body is about mass = 28 kg. The centre of mass is approximately 20 cm above L₂/S₁ (Chaffin & Anderson 1991). As the trunk is inclined the force required to be counteracted increases rapidly. For example, at 45° incline, the horizontal distance to be moved is 14 cm, and the work required to move the head, neck and upper body is 14 cm \times 28 \text{ kg}.

The counteracting force (erect spine muscle) is approximately 5 cm from the fulcrum (L₅/S₁), therefore must generate about 78.4 kg of force to hold the posture. The various forces also act on the disc to both compress and shear. If the person also rotates; forces are unevenly distributed across annulus fibres of the disc increasing strain on individual fibres. Rotation will also increase strain on ligaments.

Sustained exertions reduce blood flow to the muscle, and fatigue. This means postures that require significant forces to sustain will result in fatigue and increase injury risk.

Postures commonly seen in a work environment include:

- squatting
- standing
- kneeling
- stooping
- lying.

The position of limbs relative to the body will also vary:

- arms extended overhead
- wrist flexed
- knees bent to 90°.

A person’s anthropometry, the workspace design and task demands will determine posture. Likewise posture has an influence on ability to perform a task.

Different activities are more suited to different postures. The ability to stabilise unnecessary movement (e.g. arm when writing) and the ability to generate force (e.g. pushing using whole body and legs) tend to suit a particular posture.
Sitting and standing

The advantages of a sitting posture are:

- It provides stability required on tasks with high visual and motor control.
- Sitting is less energy consuming than standing.
- It places less stress on the lower extremity joints.
- It lowers hydrostatic pressure on the lower extremity circulation (Chaffin & Anderson 1991).

The disadvantages of a sitting posture are:

- There is increased pressure in the lumbar region of the spine due to flattening of the lumbar curve (max 4.5 kg, Code of Practice, Manual handling).
- There is reduced capacity to lift and to generate force.
- Sitting reduces reach distance.
- Sitting causes slackening/deconditioning of stomach and other muscles.

The advantages of standing are:

- There is increased ability to generate forces and capacity to lift.
- There is less pressure on spine and discs.
- There is greater reach range and ability to move whole body.
- Standing requires less leg clearance at workstations compared to sitting.

The disadvantages of a standing are:

- There is less stability.
- There is more energy consumption.
- There is more stress on lower extremities (legs and feet).

Ideal postures

Generally one of the aims of ergonomics is to design workplaces that allow persons to work in postures that require minimal force to sustain. Examples of “good” postures include:

- standing upright with one (1) foot on a step
- sitting with lumbar support and 110° incline backrest
- maintaining arms close to the side of the body.

Another aim is to provide postures that optimise ability to generate forces (e.g. pushing at waist level).

Manual handling activities are performed in a variety of postures. Chapter 9 in Mital, Nicholson and Ayoub describes manual handing capacities for lifting, pushing and pulling in unusual postures. Note: The postures discussed in this text may be “unusual” to researchers but are common in industrial handling situations.
Postures discussed include:

- sitting
- squatting
- one knee kneel
- two knee kneel.

Activity 2–8

What is the trade off between ideal position for vision/neck and ideal position for arms/hands?

Describe the effect on spine compulsive forces and lumbar of sitting compared to standing.
Explain why sustaining a forward incline posture places high “strain” on your back muscles (consider static loading and forces involved). Can you think of a workplace example when you have seen this occur?

Posture will be further discussed in assessing physical work demands. Tools such as OWAS, EWA and VIRA focus on critical postures as a method for identifying physically demanding work.

**Anthropometrics**

Natural postures and movements are the key to efficient work as they do not involve static effort. It is necessary, therefore, to consider the body size of the operator when designing workplaces. Anthropometry is “the science dealing with the size, shape and weight of the human body as a whole and of individual parts” (Horrigan, O’Sullivan & Whiting 1987, p. 8).

There are around thirty human body dimensions which are most frequently used for design purposes presented as tables. Body dimensions when measured across a population result in a typical “bell-shaped” curve of a normal distribution when shown in graph form, Figure 2–15 (Horrigan, O’Sullivan & Whiting 1987, p. 8).
Figure 2–15: Bell-shaped curve showing the normal distribution curve for heights of adult males (US adult civilians)

Most of the population are clustered around the mean or average. The distribution is then defined by its mean and its standard deviation. From these two values, any required percentile can be calculated. In the above example, fifty percent of adult males will be shorter than this average height of 173 cm, and this value is called the 50th percentile. At 185 cm, 95 percent of the population is shorter in stature; therefore this is called the 95th percentile. Since it is not usually possible to design workplaces for the very smallest and very biggest workers, normally a selection is made of a 90% or 95% confidence interval (Ci). If in the above example we chose 90% that would mean that the smallest 5% and largest 5% are excluded from consideration, that is anyone shorter than 162 cms and anyone taller than 185 cm would be excluded (Grandjean 1988, p. 28)

Fundamental fallacies about using anthropometric data

You should recall some fundamental fallacies about designing equipment and workspaces from Module 1:

- Design is satisfactory for the designer and therefore it should be satisfactory for everybody.
- Design is satisfactory for the average user and therefore it should be satisfactory for everybody.
- Human variability is too great to cope with and human adaptability is high.
- Ergonomics is expensive and appearance/performance is what counts.
- Ergonomics is common sense—no need for data.
Consider your own work environment. Note the different shapes and sizes of your colleagues.

Does your workplace allow for these differences? For example, can all personnel function comfortably and efficiently within the area (height of storage areas, height and width of workbenches, etc.)?

What problems might be encountered by those who don’t fit into what is termed “average”?

Figure 2–16 and Table 2–1 illustrate examples of static anthropometric data.

**Figure 2–16(a): Static anthropometric dimensions (standing)**
Adapted from Pheasant, in Grandjean 1988, p. 29

![Static anthropometric dimensions (standing)](image)

**Figure 2–16(b): Static anthropometric dimensions (sitting)**

![Static anthropometric dimensions (sitting)](image)
Table 2–1: Anthropometric data in mm of British adults aged 19–65 years
(Adapted from Pheasant, in Grandjean 1988, p. 32)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>5th 50th 95th SD</td>
<td>5th 50th 95th SD</td>
</tr>
<tr>
<td>1. Stature</td>
<td>1625 1740 1855 70</td>
<td>1505 1610 1710 62</td>
</tr>
<tr>
<td>2. Eye height</td>
<td>1515 1630 1745 69</td>
<td>1405 1505 1610 61</td>
</tr>
<tr>
<td>3. Shoulder height</td>
<td>1315 1425 1535 66</td>
<td>1215 1310 1405 58</td>
</tr>
<tr>
<td>4. Elbow height</td>
<td>1005 1090 1180 52</td>
<td>930 1005 1085 46</td>
</tr>
<tr>
<td>5. Hip height</td>
<td>840 920 1000 50</td>
<td>740 810 885 43</td>
</tr>
<tr>
<td>6. Knuckle height</td>
<td>690 755 825 41</td>
<td>660 720 780 36</td>
</tr>
<tr>
<td>7. Fingertip height</td>
<td>590 655 720 38</td>
<td>560 625 685 38</td>
</tr>
<tr>
<td>8. Sitting height</td>
<td>850 910 965 36</td>
<td>795 850 910 35</td>
</tr>
<tr>
<td>9. Sitting eye height</td>
<td>735 790 845 35</td>
<td>685 740 795 33</td>
</tr>
<tr>
<td>10. Sitting shoulder height</td>
<td>540 595 645 32</td>
<td>505 555 610 31</td>
</tr>
<tr>
<td>11. Sitting elbow height</td>
<td>195 245 295 31</td>
<td>185 235 280 29</td>
</tr>
<tr>
<td>12. Thigh thickness</td>
<td>135 160 185 15</td>
<td>125 155 180 17</td>
</tr>
<tr>
<td>13. Buttock-knee length</td>
<td>540 595 645 31</td>
<td>520 570 620 30</td>
</tr>
<tr>
<td>14. Buttock-popliteal length</td>
<td>440 495 550 32</td>
<td>435 480 530 30</td>
</tr>
<tr>
<td>15. Knee height</td>
<td>490 545 595 32</td>
<td>155 500 540 27</td>
</tr>
<tr>
<td>17. Shoulder breadth (bideltoid)</td>
<td>420 465 510 28</td>
<td>355 395 435 24</td>
</tr>
<tr>
<td>18. Shoulder breadth (biacromial)</td>
<td>365 400 430 20</td>
<td>325 355 295 18</td>
</tr>
<tr>
<td>19. Hip breadth</td>
<td>310 360 405 29</td>
<td>310 370 305 38</td>
</tr>
<tr>
<td>21. Abdominal depth</td>
<td>220 270 325 32</td>
<td>205 255 460 30</td>
</tr>
<tr>
<td>22. Shoulder-elbow length</td>
<td>330 365 395 20</td>
<td>300 330 760 17</td>
</tr>
<tr>
<td>23. Elbow-fingertip length</td>
<td>440 475 510 21</td>
<td>400 430 650 19</td>
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<tr>
<td>24. Upper limb length</td>
<td>720 780 840 36</td>
<td>655 705 190 32</td>
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<tr>
<td>25. Shoulder-grip length</td>
<td>610 665 715 32</td>
<td>555 600 150 29</td>
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<tr>
<td>26. Head length</td>
<td>180 195 205 8</td>
<td>165 180 190 7</td>
</tr>
<tr>
<td>27. Head breadth</td>
<td>145 155 165 6</td>
<td>135 145 150 6</td>
</tr>
<tr>
<td>28. Hand length</td>
<td>175 190 205 10</td>
<td>160 175 190 9</td>
</tr>
<tr>
<td>29. Hand breadth</td>
<td>80 85 95 5</td>
<td>70 75 85 4</td>
</tr>
<tr>
<td>30. Foot length</td>
<td>240 265 285 14</td>
<td>215 235 255 12</td>
</tr>
<tr>
<td>31. Foot breadth</td>
<td>85 95 110 6</td>
<td>80 90 100 6</td>
</tr>
<tr>
<td>32. Span</td>
<td>1655 1790 1925 83</td>
<td>1490 1605 1725 71</td>
</tr>
<tr>
<td>33. Elbow span</td>
<td>865 945 1020 47</td>
<td>780 850 920 43</td>
</tr>
<tr>
<td>34. Vertical grip reach (standing)</td>
<td>1925 2060 2190 80</td>
<td>1790 1905 2020 71</td>
</tr>
<tr>
<td>35. Vertical grip reach (sitting)</td>
<td>1145 1245 1340 60</td>
<td>1060 1150 1235 53</td>
</tr>
<tr>
<td>36. Forward grip reach</td>
<td>720 780 835 34</td>
<td>650 705 755 31</td>
</tr>
</tbody>
</table>
Human variation

You will have noticed in the previous exercise and from Pheasant’s dimension tables that humans are invariably “different”. It is therefore important to consider those differences in the design of a workplace.

This includes consideration of the following:

• ethnicity
• sex
• age
• secular trends
• occupations.

There are sometimes very dramatic variations that can be found between user populations. Many authors advocate that there are three basic approaches to using anthropometric data. Check the link and see if you can identify these three approaches. Some authors would argue an additional use (Horrigan, O’Sullivan & Whiting 1987, p. 9), that is, designing for the individual. When a workstation, piece of equipment or furnishing is to be used by one individual, the anthropometric data from that individual is collected and applied. An example of this would be a purpose-built kitchen for someone confined to a wheelchair. Of course designing for the individual would be the optimal way of applying anthropometric data, but this situation is actually very rare.

Using static anthropometric data

There are no set rules when applying static anthropometric data, but the following is a compilation of the general procedures that should be considered during the design process.

• Determine the body dimensions that are important to the design. For example, the sitting height would be important when considering the seat to roof height in a car.

• Define the target population. For example, who will use the car, which countries will the car be sold in?

• Determine the principle which should be applied. (For example, which principle would be used in designing the reach to the steering wheel, or to the controls on the centre panel?) Consider constraints including reach, clearance, posture and strength.

• Define criteria to be used as a priority, for example, safety, case of use, comfort, efficiency and performance (Straker 1990).

• Select the percentage of the population to be catered for. For example, is it vital, desirable or practical to cater for 90% or 95% of the population or just a specific age group or gender?

• Use appropriate anthropometric tables and extract relevant data, for example, male/female, British/Chinese, appropriate age.
• Take into account actual situation for use. For example, is it likely that the user will wear restrictive clothing which will reduce reach (thick jacket), or increase body size (safety helmet, shoes)? Add appropriate allowances.

• If possible, build a full scale mock-up of the environment and test practicality of design by a wide range of users.

To determine the height of an emergency exit, for example, the following would be considered.

(a) User population—anglo-saxon adult with hard hat and shoes

(b) Clearance required—tallest person to get through (safety priority)

(c) Criteria—95%ile male stature plus allowances

(d) Stature 95%ile male 1855 mm

Shoes 25 mm

Hard Hats 55 mm

Exit door 1935 mm

Using measurements from the 5th percentile to 95th percentile of a population characteristic would be expected to mean that 90 percent of the user population is accommodated. It has been found, however, that when the 5th and 95th percentile limits are applied using each of the 13 static dimensions of the body, 52 percent of the population would be excluded (Bittner 1974, cited in Sanders & McCormick 1993, p. 422). This occurs because the body parts of humans are not uniformly proportioned, for example, having a long torso does not guarantee that you have long legs.

The use of static anthropometric data tables alone in the design of equipment does not always mean that the optimal work situation will result.

Activity 2–9

(a) Calculate the clearance required for the emergency exit door of a night club in New York city. Would the fact that the night club was in Harlem change your answer?
(b) Calculate the clearance required for a door in an international conference centre in Kobe, Japan. Would this differ from the height required for a door in the Japanese family home?

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Seated work

From your discoveries you should have found that the general principles for good seat design are:

- promote lumbar lordosis,
- minimise disc pressure,
- minimise static loading of the back muscles,
- reduce postural fixity, and
- provide for easy adjustability.

Activity 2–10

For this activity you need to assess the usability of a car seat (front seat would be best).

Have the principles been incorporated into the design?
If not, what are the likely reasons for not incorporating the design features?

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What would you do to improve the design?

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How did your car seat measure up? Use the guide below to check your understanding of the features of a well designed vehicle seat (Chaffin & Anderson, 1991).

Seating design

Features of a well designed vehicle seat
In the seated position the force acting on your back is approximately 675N (67.5 kg), sitting with no lumbar support and backrest (vertical).

1. Providing 5 cm of lumbar support reduces the force to approximately 375N (approximately 55% decrease). Lumbar support is an essential feature on a seat. Adjustability is preferable to allow optimal lumbar support for individuals.
2. **Reclining the backrest** 10° from the vertical will further reduce forces to approximately 300N. 20° to vertical reduces force to approximately 200N. Reclining the backrest further results in little force reduction and an awkward driving position. Therefore ability to recline the backrest is a highly desirable feature in seats such as this.

3. **Lateral curving** of seats around the operator will provide support against lateral trunk movements. Too much curving will be unsuitable for wide-framed persons. Some lateral curving is desirable.

4. **Leg position** will also influence forces in the lower back. Cramped leg space results in increased pressure on the spine. Too large a space means people are sitting forward to reach the pedal and slouching. This results in no effective position lumbar support from the backrest. Adequate adjustability in forward/aft position is a **highly desired** feature.

5. **Arm rests** on seats will slightly reduce pressure on spine. High armrests may interfere with arm movement. They also pose problems for wide framed persons fitting into seats. Arm rests may also interfere with getting close to a desk or workstation. Well designed, fold away arm rests are a desirable feature if used appropriately.

6. **Seat height** is important for neck/eye position too. Car cabins are designed for particular head/eye height. Seat height will also affect arm/shoulder position to operate controls such as lever and steering wheels. Neck and shoulder pain is associated with too high or too low sitting relative to a workstation. Seat height will affect buttock and leg comfort. Adjustability in seat height is a **highly desirable** feature.

## Arrangement of components

The scope of this course does not allow for detailed discussion of all relevant areas of workplace design however the provided link highlights the most important principles.

### Activity 2–11

Sketch the interior of your car (no points for artistic talent). The driver’s seat should be the centre of your sketch include all displays, levers, controls (hand and foot). Apply the four basic principles of arranging components within a work space.
Identify which, if any, principles were considered in the design.

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Are there any recommendations you could make to the manufacturer to improve the design.

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If you went back to previous modules and included analysis of posture as well then you were on the right track. Did you think to move forward in your course to display design? Top marks if you did! I am sure that you are starting to appreciate the scope of ergonomic assessments and that each evaluation can only be approached holistically.

Hand tools

Important things to consider when looking at a tool:

• **Where and how** will the tool be used? A tool design suited for overhead use may be unsuitable for use in front of a person.

• **Who** will use the tool? The physical size of the hand of the operator will influence grip circumference.
• **Forces vs control** needs to perform the task. Fine control and high force by operator are incompatible. Use small finger controlled tools when fine control is required. Use whole hand power grips for higher force. Consider weight to tool and triggers or controls.

• Can a **movement or force be eliminated**. For example, pliers which “lock on” to reduce need to use force to sustain grip, scissors or shears which self-open to eliminate need to open, screw drivers with handles that allow handle to be turned freely in opposite direct to direction force required to eliminate need to reposition.

**Note:**
These designs must consider how they affect forces to perform a task. In the scissors/shears example the force to “cut” may increase significantly if design is poor.

The most effective way to evaluate a tool is to have ‘real’ operators trial it on the task it will be used for or a mock up of the task. Observe the application and consider:

• hand, wrist arm, position to operate
• handle compatibility with appropriate grip and size of users hands
• how the tool is activated or controlled and forces involved.

The provided link outlines a method to assess suitability of tools. Australian Standards also provide guidelines on design. You should initially scan these readings noting how you will assess hand tools in the workplace if required, listing any data which will need collection on your preliminary visit. Then revisit as required later.

Try this next activity from the operator’s viewpoint.

**Activity 2–12**

Find a hand tool used at your work or home (e.g. drill).

Try and use it in three planes, that is:

• overhead, upwards
• in front of you, vertically
• downwards.

Comment on the four (4) considerations previously outlined.

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Identify some design improvements for one of the positions (planes).

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Why would a sledge hammer have a thicker, heavier handle than a tack hammer?

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If you considered use (where and how), user (who) and the forces and control required, you are on track.

**Manual tasks**

The body and its parts have a limited range of movement. As previously discussed force-generating capacity depends on the length–strength relationship of muscles. Forces on the body structure vary depending on leverage and weight of external loads and internally generated forces.

This leads us to the most common reason for actions and movement: manual handling.

Manual handling is defined as “any activity requiring the use of force by a person to lift, lower, push, pull, carry or otherwise move hold or restrain any animate or inanimate object” (Manual Handling Code of Practice).
The Queensland Advisory Standard pushes this concept further, defining *Manual Tasks* as “those workplace activities requiring the use of force exerted by a person to grasp, manipulate, strike, throw, carry, move (lift, lower, push, pull), hold or restrain an object, load or body part” (DETIR 2000). This recent initiative more closely reflects the types of tasks causing problems in our workplaces.

**Activity 2–13**

Hold your text in your hand beside your shoulder for 15 seconds.

Now hold the text at arm’s length from your body for 15 seconds.

Explain why it feels heavier and harder to hold.

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Now lift the text from your waist to in front of you at arm’s length five (5) times in 15 seconds.

Why is it easier to lift five (5) times than to hold for 15 seconds?

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Put your text on the floor, lift it to a table five (5) times using a stoop lift, five (5) times using a semi-squat lift. What are the advantages of each style of lift? Consider balance, knees, back, fatigue etc.

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Assessing manual work

In Australia, the Code of Practice Manual Handling is the key legislative document on manual handling. Most states have a code of Practice Manual Handling in line with the National Code of Practice Manual Handling.

It follows a risk management model:

- identify
- assess
- control
- review.

It is a simple tool for screening manual handling activities to identify key risk factors.

Read your State’s or the National Code of Practice Manual Handling now. (The below example uses the Queensland Standard-see link). You can also access “Manual Handling Info Sheets” in the same website.

Activity 2–14

First look at the suggested process for assessing manual work on page 20 to 24 of “Manual Tasks 2000. Then choose a common activity at work and apply the various checklists found in Chapter 10 of the Standard. Readers outside of Queensland should substitute the guidance provided in their State.

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How is risk controlled? What are the suggested risk control options identified in the Manual Tasks 2000 Advisory Standard?

These tools can be used to identify the presence of risk factors. They do not, however, combine risk factors to indicate if demands (or risks) are unacceptable.

**Application of assessment tools**

There are a variety of tools that can be used for this purpose.

The approaches to assessing manual handling are:

- Biomechanical models which measure the forces on bones, cartilage, ligaments, and muscles.
- Physiological models which measure the responses of the cardiac and respiratory system.
- Psychophysical models which ask people to tell us what the nerves are telling our brain about effort and strain.
- Epidemiological methods which measure what damage can be seen or felt (pain) in a population of people with exposure to risk factors.

Revisit the link provided previously – Ergonomic Analysis Tools
How to conduct an assessment of manual handling

The following describes a practical process for analysing a manual task to identify the extent of risk and how it can be best controlled. It is not expected that engineers would necessarily conduct an evaluation of a current manual task however many of the tools allow the designer to check whether the parameters they have included in their design are adding risk to the work environment. It is also very useful for the designer to understand the work that a consulting ergonomist might be completing to assist them in their design work.

Step 1: Preparation
Preparation involves a basic walk through and task familiarisation, examination of injury statistics and talk with employees if a retrofit. Often at this stage it is worthwhile to look at the organisations Workplace Health and Safety Management System and how Manual Handling fits into the system.

Manual tasks 2000 identifies risk identification methods, including:

- analysis of workplace injury records
- consultation with employees
- direct observation.

Step 2: Basic task analysis
This is to identify what are the key task demands and the steps to perform the task. This step is crucial when planning a system. In the case of a retrofit it might be possible to do a video recording of the task is one tool that can make task analysis easier particularly for rapidly performed tasks.

Key things to note are:

- task duration
- cycle time (if repetitive)
- physical dimensions of space
- weights and forces involved.

Typically a diagram of the work layout and objects will be used to record dimensions and locations of objects, equipment, work layout and people etc.

The weight and forces can be measured using force gauges, scales etc.

Step 3: Identify key risk factors
This is to identify what are the key risk factors which require measurement.

The Manual Tasks Advisory Standard risk identification checklist Chapter 10 may be a useful guide.

Injury data and talking with the workforce are also useful. Employees usually will be able to identify what it is about a task that makes it difficult, particularly if you ask the right questions to prompt their ideas or opinions.
Step 4: Choose assessment tools appropriate to risk factors

Based on key risk factors identified, an appropriate tool or selection of tools is then applied.

We assess physical work in the field, using a selection of the below:

- body mapping and seven (7) point scale of discomfort or Nordic Musculoskeletal questionnaire.
- posture and joint position:
  - calculate forces on joints and muscles
  - Owasko Working Posture Analysis System (OWAS)
  - RULA—Rapid upper limb assessment
  - VIRA—Video recording analysis
- models:
  - 2D / 3D Mitchigan
  - NIOSH (1981 and 1991 models)
  - job stress index (JSI)
- use Snook tables 1991 and 1989
- use of Tables in Mital, Nicholson and Ayoub 1993 (based on JSI)
- measure heart rate
- observe breathing, sweating, control of movement (fatigue)
- measure physical dimensions of space (compare to anthropometric data) to determine posture and position effect
- MODAPS—Predetermined time and motion
- EMG—Electromylograph (muscle tension).

Physical tools used

- video
- still camera
- HR monitor
- force gauges, scales etc.
- metal tape measure
- stop watch
- checklists/scales etc.
- tools—heart rate monitor
  —lumbar motion monitor
  —pedometer.
Typically a combination of tools will be used, as no tool stands alone.
For example, to assess cargo loading in an aircraft the following tools were used:

- body mapping of discomfort
- Borge 15 pt Scale of Perceived Exertion
- heart rate and observation of breathing and sweating
- NIOSH 1991
- measurements of space to move—head clearance (vertical) and body clearance (horizontal)
- Video recording of activity
  - observation of posture and position.
  - cycle frequency.

Discussion with workers and professional observation and judgment also play an important role.

The skill in assessment lies in selecting the best “tools” to analyse a task and in interpreting the data. If an inappropriate tool is selected, a task may appear to have acceptable risk when in fact it places considerable strain on a particular system of a person’s body.

Depending on what activity we are assessing, different tools are suitable.

<table>
<thead>
<tr>
<th>Typical activities</th>
<th>Suitable tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole body manual lifting and lowering</td>
<td>– NIOSH, Snook, RPE, heart rate</td>
</tr>
<tr>
<td>repetitive upper limb handing</td>
<td>– RULA</td>
</tr>
<tr>
<td>static holding</td>
<td>– EMG, biomechanical, NORDIC</td>
</tr>
</tbody>
</table>

**Step 5: Interpret findings**

The information gathered should then be interpreted to determine what it means and where it is appropriate, and to make risk control recommendations. It is important to understand how the data from various sources is combined (e.g. pain in neck shoulder using NORDIC is consistent with posture of static overhead work with arms identified using RULA).

Another example is that a high effort report using RPE and low Heart Rate may indicate high static loading (rather than dynamic work) or psychological influences on reporting of effort.

Information from the task analysis can be applied to “models” or tables to determine if the task falls within the capability of a population or within anthropometric characteristics of clearance and reach of a population.
Note: If results of analysis are not consistent:
- workers opinions/comments.
- with “observer”, observation/judgement
- with injury data
- between tools considering each limitation and strengths.

The tool selection should be reassessed.

Activity 2–15

Identify what risk factors are likely to be critical and which tools you would use in the following situations to assess workloads:

- unloading a pallet of 3 cartons of wine at a bottleshop.

- bagging chickens—repetitively putting chickens into bags in chicken processing factory

- holding koalas on one (1) arm for up to three (3) hours at a time at a nature park.
Brief description of tools

Predetermined motion-time systems

Methods-time measurement is one such system. It requires the user to break down a job into its basic elemental motions (e.g. reach, position, release, disengage, grasp, eyefocus travel, turn apply pressure, body, left/foot motion, simultaneous motion etc).

The predetermined time to perform each elemental motion varies according to:

- type of terminal condition
- load being transported
- length (distance) of motion.

Basically what is done is a detailed task analysis to describe the basic elemental motions to perform the task. (e.g. grasp, move, position, release).

Each of the basic motions is then allocated a predetermined time that is required to perform the motion.

The actual task time is then compared to the predetermined time to determine if the actual time is adequate (actual cycle time too short meaning a risk of strain).

MODAPTS is a similar tool. This tool can only be used after specific training.

Nordic musculoskeletal questionnaire:

This tool is basically a systematic way of collecting data on an individual’s reported discomfort.

This tool is usually used to identify what areas of the body are being subjected to “strain”. A person self-reports pain and location (e.g. neck, shoulder, wrist pain) which indicates a need to look at posture, position and forces in these regions.

This tool is a psychophysical tool and therefore subject to over- or under-reporting with populations that have other influences acting on them (other than physical job demands) in their work environment (e.g. high stress, low morale, high motivation etc).

This is a useful data collection tool particularly when for those unfamiliar with characteristic injuries/problems in a job or industry. Knowing where people experience discomfort often cues sources of strain. It is worthwhile to ask specific questions on what activities are associated with the reported discomfort. It is an easy tool to use but data should be applied with care (i.e. most people will have experienced various aches and pain over a twelve (12) month period).
**Postural tools**

Postural tools are basically biomechanical tools. Postures that have been identified as creating high forces within the body are flagged.

Authors have identified key postures from the literature which are considered acceptable or unacceptable or have graded the risk of various postures.

Ovako Work Analysis Systems (OWAS), VIRA, RULA, Postural Targeting are all such tools. OWAS particularly focuses on the back, VIRA the neck/shoulders region and RULA the arm and wrist. EWA (Ergonomics Workplace Analysis) contains reference to postures of the neck, shoulders, elbow, wrist, hip-legs, back.

Postural targeting is a tool to describe and record a posture rather than give it a “risk” value. The AET is another tool which contains components on posture.

OWAS, RULA and EWA are very useful as field tools and are relatively simple to use after some initial practice and training. Video records are easier to analyse than on-the-job observations due to the ability to “still or pause” the picture.

OWAS is available on computer software from National Occupational Health and Safety Commission. This software includes training in coding.

**Psychophysical tables**

Snook has produced two sets of lifting tables determined by using the psychophysical model. The first in 1978 and the revised version in 1991. These tables are used to compare “actual” situations with those found acceptable using “rating of acceptable load”.

These tables separate males and females and include:

- lifting
- pushing
- pulling
- lowering
- carrying.

They describe the weights in relation to:

- width of object away from body
- vertical distance of lift
- location of lift
- frequency of lift
- percentage of population who can perform the lift.

For example, 75% of the female population can lift an 11 kg box 34 cm wide once every 9 seconds, 51 cm between floor and knuckle height.

These tables are useful for questions such as those in the Legal report (Brain) in the readings.
They are also useful in design situations. For example, how heavy can a box be loaded that is carried 4 m every minute? or How often can a 25 kg box be carried 8 m?

**NIOSH 1981 and NIOSH 1990**

The 1981 guide (Work practices guide for manual lifting) was intended to be used to assess the hazard of an overexertion injury for workers who perform two handed symmetrical lifting jobs.


This tool is basically a formula into which you plug data to get a value. This value is the ideal maximum weight for the job described. This acceptable weight is then compared to the actual weight.

These tools are a combination of physiological, biomechanical and psychophysical criteria. Basically to apply the tools you identify a key posture and measure:

- horizontal distance of load from centre of ankles
- vertical location of hands from the floor
- vertical distance of travel
- frequency of lift
- coupling
- angle of asymmetry (amount of twist).

The last two (2) are in the 1990 model only.

This data is then compared to tables to get values known as multipliers and these values are plugged into a formula. The result is called the Action Limit (1981) and Recommended Weight Limit (1990). The resulting “limit” is then compared to the actual weight of the object.

If the weight is below this limit it is considered acceptable for 99% of men and 75% of women (1981), 99% of men and 90% of women (1990).

Up to three (3) times these limits describes a range where there is risk, and some controls are required. Above three (3) times the limit is considered unacceptable and engineering controls are mandatory.

This tool is probably the most commonly applied tool. However, it poses a number of problems:

1. Most situations are not a simple lift.
2. Weight limits determined by this methods are very low.
Best lifting situations: Metric

\[
1991 \text{ RWC} = 230\left(\frac{25}{4\pi}\right)(1 - 0.003V - 75).82 + \frac{(4.5)}{0.1}
\]

\[
= 392\text{N} \div 39.2\text{ kg}
\]

\[
1981 \text{ AC} = 392\left(\frac{15}{4\pi}\right)(1 - 0.004|V - 75|)(0.7 + \frac{23}{F_{\text{max}}})\\\left(1.00\right)\left(1.00\right)
\]

\[
= 230\text{ N} = 23\text{ kg}
\]

Obviously the “limit” weights in normal lifting situations will be much smaller than those above due to measured factors. This means strict application of this tool in industry would eliminate all people-handling industries (nursing homes, hospitals etc.) and many heavy industries (mining etc.).

It is a useful tool to identify high-risk jobs and what factors are the key contributors. It can also be used to evaluate and measure the effectiveness of various controls. For example, which is more effective—putting the pallet in a pallet raiser or slowing the frequency of handling?

The 1981 version has greater acceptance than the 1990 version although both are being questioned by authors such as Marras.

This is a tool you must know if you intend to work in manual handling risk control.

**Job Stress Severity Index**

The Job Stress/Severity Index, a tool described in Mital, Nicholson and Ayoub is similar to the NIOSH models.

It identifies a number of critical elements as NIOSH 1981, 19991 plugs then into a formula to give a “risk score”. It is based on the same “original” research but is a slightly different model/formula. Mital, Nicholson and Ayoub (1993) have a variety of psychophysical tables in their text including lifting and handling in unusual postures. These tables are based on the JSI and can be used in a similar way to the Snook tables.

**Other**

The EWA (Ergonomics Workplace Analysis) and the AET are tools for general evaluation of work including sections on manual handling, lighting, noise, job design and other factors.

**Summary**

In this module we have discussed muscular work and the role of the cardiovascular and respiratory systems in providing the energy required. We’ve considered the design of the workplace, and equipment and the influence this will have on workers.

In the next modules we will look at ways of assessing the ability of people to do work and the suitability of design of equipment, tasks and jobs in facilitating that work.
Review questions

Review question 2–1
Sketch the process whereby glucose is broken down to carbon dioxide and water.

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Review question 2–2
What is one of the commonest chemical bonds used for energy storage in human cells?

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Review question 2–3
What is the difference between anaerobic and aerobic metabolism?

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Review question 2–4
What is oxygen debt?

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Review question 2–5
Briefly define “energy”, “work” and “power” in your own words.

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Review question 2–6
What possible problems are there in using direct and indirect measurements of energy use? Why might those problems be significant?

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Review question 2–7
List the possible causes of fatigue.

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Review question 2–8
List the unique properties of muscle cells.

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Review question 2–9
What is muscle strength?
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Review question 2–10
Outline the differences between the various types of muscle contraction.
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Review question 2–11
How can muscle strength be varied?
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Review question 2–12
Describe the various factors that may affect muscle strength. What indications do these factors have for your work situation?
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Review question 2–13
What are the three types of joint found in the human body? Briefly describe each type of joint.
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Review question 2–14
Write your definitions of the three basic types of lever:
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(b)
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(c)
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Review question 2–15

Sketch from memory:

(a) A power lever

(b) A speed lever

Now check your sketches against Figures 2–11 and 2–12.

Review question 2–16

What is torque?

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Review question 2–17

Describe compression in your own words.

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Review question 2–18

What factors would you consider to be of primary importance in the design of:

• workstations for children at school

• ambulance interiors

• hospital beds

• position of a fire hydrant in a spray painting workshop

• spare-part storage bins
• access to and from heavy mobile equipment (e.g. cranes).

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Review question 2–19

What would be the key things you would look at to determine which posture (sitting or standing or combination) is best for a job?

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What is the preferred height (sitting and standing) for fine work and heavy work?

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Why are they different?

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What is the reason work envelopes are important?

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Review question 2–20

Why does sitting increase forces on spine?

How can forces be reduced?

Answers to activities

Answer to Activity 2-1(a)

Answer to Activity 2-1(b)
References


Straker, L 1990, Personal communication.