Occupational Hygiene Training Association

# STUDENT MANUAL

# Ergonomics Essentials

**April 2009**

# CONTENTS

# CONTENTS (Cont'd)

# CONTENTS (Cont'd)

# CONTENTS (Cont'd)

# CONTENTS (Cont'd)

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## ABBREVIATIONS

| | |
|---|---|
| ASCC | Australian Safety & Compensation Council |
| BOHS | British Occupational Hygiene Society |
| BPM | Beats Per Minute |
| CCOS | Canadian Centre for Occupational Health & Safety |
| CEN | European Committee for Standardisation |
| CIE | International Commission on Illumination |
| COP | Code of Practice |
| CTD | Cumulative Trauma Disorder |
| dB | Decibels |
| EAV | Exposure Action Value |
| ELV | Exposure Limit Value |
| EMG | Electromyograph |
| EU | European Union |
| FMEA | Failure Mode and Effect Analysis |
| FTA | Fault Tree Analysis |
| HAVS | Hand Arm Vibration Syndrome |
| HAZOP | Hazard and Operability studies |
| HDM | Hypothetical-Deductive model |
| HSE | Health & Safety Executive (UK) |
| HTA | Hierarchical Task Analysis |
| IEA | International Ergonomics Association |
| ILO | International Labor Organisation |
| ISO | International Organisation for Standardisation |
| JND | Just Noticeable Difference |
| KPI | Key Performance Indicator |
| LTIFR | Lost Time Injury Frequency Rate |
| MAC | Manual Handling Assessment Charts |

| | |
|---|---|
| ManTRA | Manual Tasks Risk Analysis |
| MSD | Musculoskeletal Disorder |
| NIHD | Noise Induced Hearing Damage |
| NIHL | Noise Induced Hearing Loss |
| NIOSH | National Institute of Occupational Health & Safety (USA) |
| NIPTS | Noise Induced Permanent Threshold Shift |
| NPI | Negative Performance Indicator |
| OCD | Occupational Cervico-brachial Disease |
| OCRA | Occupational Repetitive Action |
| ODAM | Organisational Design and Management |
| OHS | Occupational Health and Safety |
| OOS | Occupational Overuse Syndrome |
| OSHA | Occupational Safety & Health Administration (USA) |
| OWAS | Ovako Working posture Analysis System |
| PHEI | Potential Human Error Identification |
| PMV | Predicted Mean Vote |
| PPD | Predicted Percentage Dissatisfied |
| PPE | Personal Protective Equipment |
| PPI | Positive Performance Indicator |
| QEC | Quick Exposure Check |
| r.m.s. | root mean square |
| REBA | Rapid Entire Body Assessment |
| RPE | Rating of Perceived Exertion |
| RSI | Repetitive Strain Injury |
| RULA | Rapid Upper Limb Assessment |
| SAE | Society of Automotive Engineers |
| TC | Technical Committee |
| TRM | Tables of Relative Merit |
| TTS | Temporary Threshold Shift |

| | |
|---|---|
| UK | United Kingdom |
| UL | Upper Limb |
| USA | United States of America |
| VDT | Visual Display Terminal |
| VDU | Video Display Unit |
| VDV | Vibration Dose Value |
| WBGT | Wet Bulb Globe Temperature |
| WBV | Whole Body Vibration |
| WHO | World Health Organisation |
| WRAC | Workplace Risk Identification and Control |
| WRMSD | Work-related Musculoskeletal Disorders |
| WRULD | Work-related Upper Limb Disorders |

# 1. COURSE OVERVIEW

## 1.1 INTRODUCTION

This Course has been developed so that it follows the international module syllabus W506 – Ergonomics Essentials published by the British Occupational Hygiene Society (BOHS), Faculty of Occupational Hygiene. The BOHS administers a number of such modules; further information on which can be obtained by visiting the BOHS website at www.bohs.org.

At the time of publication every care has been taken to ensure all topics covered in the BOHS syllabus for the subject (W506) have been included in this Student Manual. Providers of training courses should check the BOHS website for any changes in the course content.

The developers of this Student Manual take no responsibility for any material which appears in the current BOHS syllabus for Module W506 which is not covered in this manual.

## 1.2 AIM OF COURSE

To provide the student with a broad based introduction to ergonomics principles and their application in the design of work, equipment and the workplace. Specific consideration is given to musculoskeletal disorders, manual handling, ergonomic aspects of the environment, as well as to the social aspects and relevant international standards.

## 1.3 LEARNING OUTCOMES

On successful completion of this module the student will be able to:

- Describe and apply ergonomics principles to promote safety, health and productivity
- Outline the process of ergonomics risk assessments
- Explain the causes of upper limb disorders

- Examine workplace layout and equipment design according to ergonomics principles
- Identify environmental aspects of good ergonomic design

## 1.4 FORMAT OF MANUAL

This manual has been specifically designed to follow the syllabus for this course as published by the BOHS. Similarly, the material provided in this manual has been aligned with the presentations for each topic so students can follow the discussion on each topic.

It should be recognised that the format presented in this manual represents the views of the authors and does not imply any mandatory process or format that must be rigidly observed. Presenters using this manual may well choose to alter the teaching sequence or course material to suit their requirements. In this regard the case studies are provided as illustrative examples and alternate case studies relevant to a particular industry may be used if desired.

In the final outcome, the aim of this manual is to transmit the principles of ergonomics essentials to attendees and provide guidance as to how those principles should be applied.

# 2. OVERVIEW OF ERGONOMICS

This topic outlines general information about the domain of ergonomics, and provides an overview of human characteristics, capacities and the specific considerations for the human in a work system.

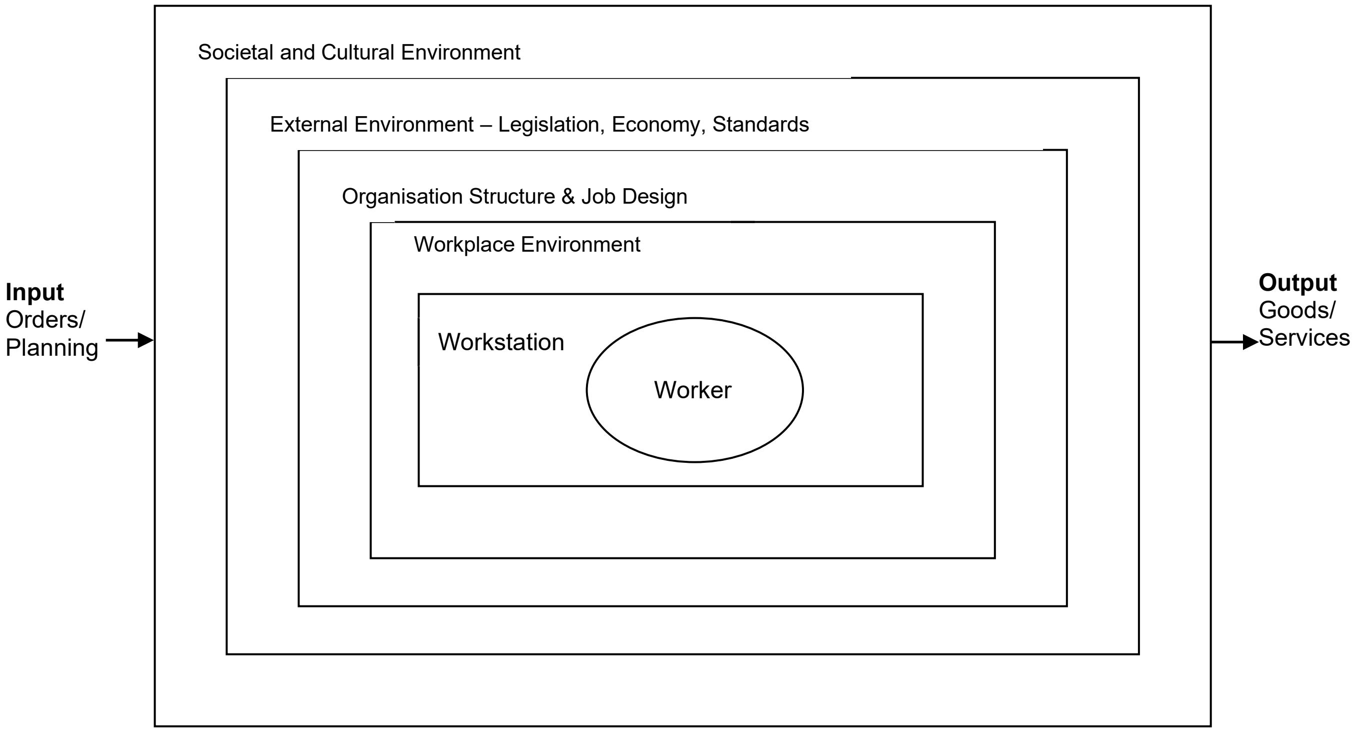
## 2.1 GENERAL PRINCIPLES

### 2.1.1 Definition

The word ‘ergonomics’ is derived from an Ancient Greek word meaning ‘rules’ or ‘study of work’. It is also referred to as ‘human factors (in design)’. Ergonomics is concerned with appropriate design for people - the design of systems, processes, equipment and environments so that tasks and activities required of them are within their limitations but also make the best use of their capabilities. Therefore the focus of the design is on the person or a group of people. This is often termed “user-centred design”.

Ergonomics is a science; it is a rigorous, user-centred approach to research and design. It is also a philosophy and a way of thinking. It is applied widely in areas such as aviation and other transport systems, sport, education, public facilities, the home, recreational equipment and facilities and in the workplace generally. In fact, the whole community benefits from ergonomics design. Ergonomics considers the whole work system, and the effects of the system on human and system performance (see Figure 2.1).

Ergonomics has three domain areas: Physical ergonomics, Cognitive ergonomics and Organisational ergonomics.




*Adapted from Stevenson (1999)*

***Figure 2.1 - Ergonomics: The Systematic Study of the Human at Work***

### 2.1.2 History of Ergonomics

Ergonomics in the United Kingdom arose out of World War 2 when scientists were asked to determine the capabilities of the soldier in order to maximise efficiency of the fighting man (Pheasant, 1991). In the United States, ergonomics arose out of psychology and cognitive function in the aviation industry and was termed 'human factors'. Today these terms are used interchangeably. Since the industrial revolution, work has turned away from its agricultural base to city-based work environments. Further changes have occurred in recent times with an increase of females in paid employment, an increasing age of workers, an internationalisation of the workforce and an increased trend to contract or outsource work. All of these changes have implications for design of equipment and work systems, and a role for ergonomics.

### 2.1.3 Scope of Ergonomics and Systems of Work

Ergonomists and designers take into account a wide range of human factors and consider biological, physical and psychological characteristics as well as the needs of people - how they see, hear, understand, make decisions and take action, (see Figure 2.2). They also consider individual differences including those that occur due to age, fitness/health, or disability and how these may alter people's responses and behaviours.

| | |
|---|---|
| Anatomy | |
| Anthropometry | Dimensions of the body (static and dynamic) |
| Biomechanics | Application of forces by gravity and muscles |
| Physiology | |
| Work physiology | Expenditure of energy |
| Environmental physiology | Effects on humans of the physical environment |
| Psychology | |
| Skill psychology | Information processing and decision-making |
| Occupational psychology | Training, motivation, individual differences, stress |

***Figure 2.2 - Human Characteristics and Capacities Considered in Ergonomics***

As there are many factors to be considered in ergonomics, a range of people are involved in its research and application. Specialist Ergonomists usually have university qualifications in ergonomics and related fields and can come from a range of disciplines such as physiology, psychology, engineering, physiotherapy, occupational therapy, medicine, industrial design, architecture, occupational health and safety (OHS), industrial relations and management. In order to address ergonomics issues at workplaces, Ergonomists interact and consult with designers, engineers, managers and the end users of any system, the workforce and individual workers.

### 2.1.4 Aims, Objectives and Benefits of Ergonomics

The overall aim of ergonomics is to promote efficiency and productivity and ensure that the capacities of the human in the system are not exceeded. The word ‘optimum’ is often used in ergonomics and refers to the balancing of the needs of people with real-life limitations such as the availability of solutions, their feasibility and costs. Successful solutions depend on solving the real, rather than the apparent problems. This in turn requires careful observation and analysis.

Ergonomics problems and solutions may not transfer exactly from one country, region or industry to another – they have a social context. Although the basic human characteristics are the same they take on local differences for a range of reasons – geographical, social, economic or historical. It can be described as ‘the way we do things around here’ and relates to the culture of a country, region, industry and/or company. Consequently, ergonomics issues should be identified and addressed locally because each set of circumstances is different. Importing solutions without reference to local issues and resources may fail.

In terms of cost benefits the advantage of ergonomics changes is that they will make the job faster, easier, safer and enhance productivity. It is important to assess the benefits in the short, medium and long term, as expensive equipment and process changes may take some time to take effect.

### 2.1.5 Fitting the Job to the Person and Person to the Job, Occupational Ergonomics

At work ergonomics is applied to the design of the workplace and tasks and to work organisation. It is often referred to as occupational ergonomics within the OHS community. As such it aims to promote health, efficiency and wellbeing in employees by designing for safe, satisfying and productive work.

Positive performance factors such as worker comfort, well being, efficiency and productivity are all considered in determining how to achieve an acceptable result. In this respect ergonomics is different from many other areas of OHS hazard management, where the primary aim is to reduce risks of injury or disease. Good ergonomics in the workplace should improve productivity and morale and decrease injuries, sick leave, staff turnover and absenteeism.

When analysing work and how it can be improved from an ergonomics point of view there are five elements that need to be addressed:

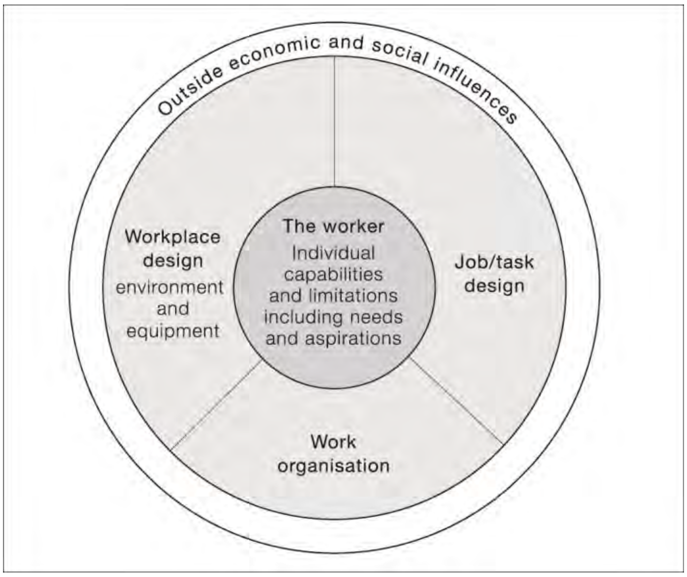
1. **The worker**: the human element of the workplace. Employees have a range of characteristics that need to be considered including physical and cognitive capacities; experience and skills; education and training; age; sex; personality; health; residual disabilities. An individual's personal needs and aspirations are also considered.

2. **Job/task design**: what the employee is required to do and what they actually do. It includes job content; work demands; restrictions and time requirements such as deadlines; individual's control over workload including decision latitude, working with other employees; and responsibilities of the job.

3. **Work environment**: the buildings, work areas and spaces; lighting, noise, the thermal environment.

4. **Equipment design**: the hardware of the workplace. It is part of ergonomics that most people recognise and includes electronic and mobile equipment, protective clothing, furniture and tools.

5. **Work organisation**: the broader context of the organisation and the work and how this affects individuals. It includes patterns of work; peaks and troughs in workload, shiftwork; consultation; inefficiencies or organisational difficulties; rest and work breaks; teamwork; how the work is organised and why; the workplace culture; as well as the broader economic and social influences.




(Source: McPhee – *reproduced with permission*)

***Figure 2.3 – The Five Elements to Consider in Ergonomic Analysis of Work***

To design better jobs we need to know about the work and how it will be done. We also need to know about the people who will do the work and their capabilities and limitations. Not only do we need to consider physical and cognitive aspects but we also need to take into account individual aspirations and needs - the social component. As work changes over time reviews and modifications are constantly required if systems and people are to work harmoniously and efficiently. No matter how well the workplace is designed it can be undermined by poor job design and work organisation.

### 2.1.6 Systems of Work: Seeing the Whole Picture

As most people realise, disorders arising from work can have a number of causes and they are not always obvious. Organisations are complex and people are too. For instance we now know that physical disorders may not arise purely from physical stresses.

In order to understand these issues we need to examine the work and its organisation more broadly and understand how various work factors may interact with each other and how personal factors might change the impact of work factors.

In occupational ergonomics, the physical design aspects of work or the ‘hardware’ may be only part of the problem and therefore part of the solution. In some cases it may be a small part. Other factors influence the development of a problem including work organisation and task design, job content, work demands and control over workload, support and training. Usually these aspects require ergonomics to be integrated into the broader work systems.

Therefore to determine if an optimum solution has been achieved the people who will perform the work (the ‘who’), the nature of the tasks (the ‘what’) and the context in which they are done (the ‘where’, ‘when’ and the ‘how’) need to be considered.

### 2.1.7 Human Characteristics, Capabilities and Limitations

As outlined above, the human characteristics and capabilities Ergonomists consider are the physical and cognitive capacities of the human at work. These capacities are affected by personal characteristics such as gender, age, pre-existing injury or disability and work organisation factors such as shift work, intensive work cycles and issues such as low morale. We will examine these factors throughout this course.

### 2.1.8 Human Error

‘Human error’ is a term often used to describe the cause of an accident. Human error has been defined as an inappropriate or undesirable human decision or behaviour that reduces, or has the potential for reducing effectiveness, safety, or system performance. Ergonomics applied to system design will make the system ‘error tolerant’ by considering the cognitive capacity of the human to make decisions in a number of situations. Human error is an unintentional act and is distinguished from a pre-mediated violation of rules and/or procedures by an individual.

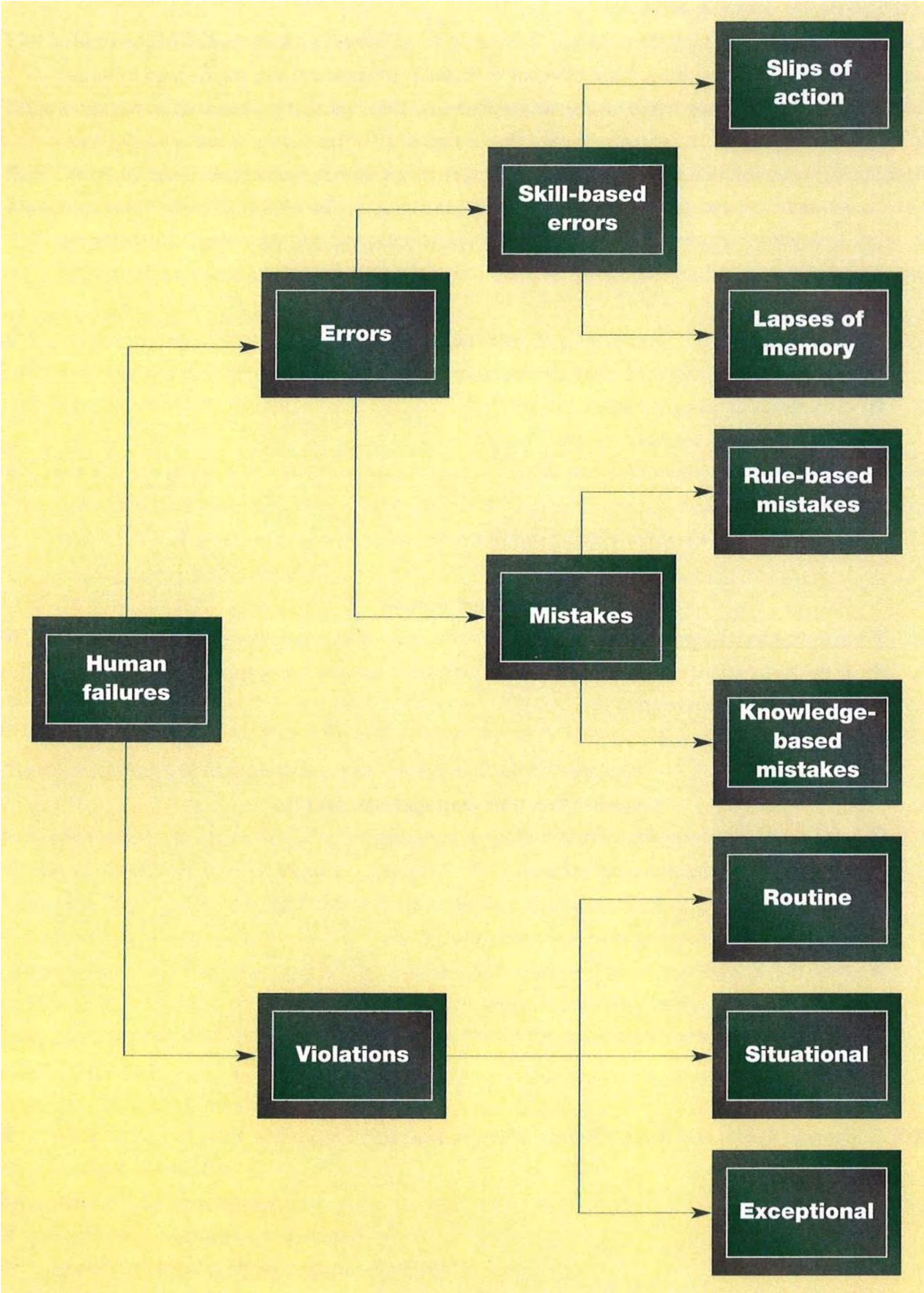
Conversely then, ‘human error’ ascribed to accident causation is really indicative of poor design. The ‘failure’ that results from this can be immediate or delayed. (HSE, 2007, p.10.)

In order to make systems ‘error tolerant’, we need to understand why and how people make errors so that we can design the system appropriately.

**Active** failures are usually made by operators at the front line. These failures have immediate consequences.

**Latent** failures are made by personnel removed from the ‘front lint’, for example designers and managers. Latent failures are system failures and include poor design of plant, processes and/or procedures (eg: communication, roles, responsibilities, training). These types of failures typically pose a greater risk to health and safety. (HSE, 2007.)

A useful diagram to illustrate the types of human error and violations (Human Failure) can be found in the HSE book: ‘Reducing Error and Influencing Behaviour’, and has been reproduced below.




(Source: HSE, 2007 – *reproduced with permission)*

***Figure 2.4 – Causes of Human Failure***

From this model, it can be seen that human error falls into two main categories, Skill-based errors (slips and lapses) and Mistakes (either rule or knowledge-based).

**a) Skill-Based Errors**

i) Slips – these types of errors are ones in which the action taken is not as intended and include:

- Performing an action too soon or too late (eg: selecting a button during timed process)
- Leaving out a step or steps in a process
- Performing the action in the wrong direction (eg: turning steering wheel the wrong way when reversing)
- Performing the correct function, but with the incorrect object (eg: using incorrect control lever)
- Carrying out the wrong check on the right item (eg: checking a dial for wrong value)

ii) Lapses – these types of errors are ones in which the action is not taken because the operator forgets or loses their place in the process, or forgets what they had meant to do. Often these errors are due to distractions and interruptions, and lack of systems to monitor work process (eg: checklist).

**b) Mistakes**

This is a complex form of human error, when an incorrect action is taken under the misapprehension that it is the correct action. These human errors are related to information processing in planning and action, assessing information and making intentions and judging consequences.

i) Rule-based – humans tend to rely on past rules or familiar procedures and will use these in new situations (eg: driving to previous set speed although the speed limit has changed).

ii) Knowledge-based – using past knowledge/analogies to determine planning or problem solving in a new situation, and coming to the incorrect conclusion or action (eg: applying cold climate clothing PPE principles to working in hot climates).

Errors can also be made through inexperience and inadequate training.

**c) What Causes Errors?**

An individual may be susceptible to making an error due to the influence of numerous organisational and individual factors.

Organisational factors include:

- Inadequate or inappropriate work layout
- Poor physical environment eg noise, heat, humidity, poor lighting or visual distractions
- Inadequate design of equipment including poor ergonomics
- Poor supervision

Individual factors include:

- Inadequate training
- Inexperience on a task
- Poor knowledge of a task
- Inadequate skill level
- Low motivation
- Attitude and emotional state
- Perceptual disabilities
- Stress levels
- Poor physical condition
- Social factors

**d) Avoiding Errors**

There are three basic ways to decrease human errors:

1. Improve the training received by an individual on a particular task so errors are minimised
2. Reduce the likelihood of a human error by:
   - Improving the work design and work layout - make improvements that will accommodate human limitations and reduce error provocative situations
   - Ensuring early detection of errors and early remedial action eg: installing safeguards and early feedback devices that will alert the individual that an error has occurred and ensure that remedial action is well practiced
3. Reduce the impact of a human error by ensuring that the impact is minimised when things do go wrong

### 2.1.9 Teamwork

Teamwork is often used in organisations and understanding the types of teams and the mechanism by which they operate is essential when understanding work systems. (See also Section 7.2.)

A work team is a collection of individuals who are required to work together to complete a goal or set of tasks. This type of teamwork can reduce worker alienation that can occur in some work places.

Work teams can either be:

1. *Self-managed* – the team is given a goal to be achieved. It then determines how the work will be conducted to achieve the goal.
2. *Integrated* – a supervisor oversees the work of the team in achieving the goal. This type of teamwork often occurs in mining where the supervisor oversees the work of a crew.

**a) Types of Teams**

There are four main types of work teams:

1. *Involved teams* – usually involved in providing recommendations or making decisions regarding a particular problem eg safety committees and quality circles.
2. *Production teams* –usually involved in providing goods and services eg manufacturing or mining teams.
3. *Project teams* – usually provide information in the form of reports and/or plans eg: research teams or a panel of experts in a particular field.
4. *Active teams* – can provide a variety of functions eg sporting teams scoring goals and medical groups performing a successful operation.

**b) Benefits and Drawbacks of Teams**

Some benefits of teamwork include:

- Increased problem solving skills
- Improved performance of employees
- Potential increase in lateral thinking and innovative ideas derived from multiple perspectives in brainstorming
- Increased output of the organisation
- Opportunities for managers to direct their attention to more long term strategic goals, rather than rudimentary supervisory functions

Common drawbacks of working in teams include:

- Some individuals may not pull their weight in the team
- Some individuals may have difficulty keeping up and may put themselves and others at risk of injury or overload

- Some team members may not agree on a particular course of action, creating a stalemate
- Conflict and competition may arise within the group

If teamwork is to be effective team members must have the necessary skills to operate within the team, including both good communication and negotiating skills. The team must have clear goals to fulfil, be committed to completing these goals and have appropriate management support.

### 2.1.10 Ageing

One of the biggest features in industry today is that of the rapidly ageing workforce. Ilmarinen (2006) found that the proportion of 50 to 64-year-olds in the workforce will be double in size compared to workers younger than 25 years (35% versus 17%) in the EU15 (the first 15 European countries to join the union) by the year 2025**.** Additionally his findings illustrate that some countries will experience this by 2010, and that the situation will last for decades to come.

An ageing workforce does have advantages. Older workers tend to be more consistent, careful and conscientious as evidenced by the following: they have no more work absences than other workers, they have fewer accidents and are less inclined to leave their jobs (see section below). They usually have extensive work and life experience which can be used to advantage in most jobs. However, increasing age brings some limitations including some reduced physical and cognitive capacity. The main limitations include:

- Vision and hearing acuity which decrease with increasing age
- Decreased ability to concentrate for long periods on difficult tasks especially in noisy or difficult work environments
- Lowered ability to focus and divide attention and to suppress irrelevant information

- Slower rates of information processing, recalling from memory, speech processing and language production
- Cumulative musculoskeletal wear and tear (sprains and strains) and decreasing physiological capacities leading to a decreased work ability (this appears to be greater in those who have worked in physically demanding jobs)
- Other health problems such as cardiovascular disease, diabetes and digestive disorders

The design of tasks and work organisation need to take these factors into account. Strategies to accommodate older workers might include:

- The reduction of physically heavy work as age increases
- The use of corrective spectacles especially where the tasks are computer based
- Allowing time to learn new tasks and understand new technology
- Designing training programs to assist older workers adapt to new methods and systems. The programs should be based on what older workers already know, 'learn by doing' methods. Using older trainers may help overcome difficulties

Generally older workers have considerable knowledge and experience to contribute that is important in decision-making.

They are usually keen to give information and offer suggestions and opinions and they respond well to consultative and participatory processes. These factors need to be considered systematically during job reviews and in long-term planning.

Evidence concerning the influence of age on the shift-working population is not conclusive but it is generally accepted that the ability to tolerate shiftwork declines after 45 years (Harma, 1996).

In summary, a review of the literature regarding occupational accidents showed that:

1. Older workers do not have more accidents at work than younger workers.
2. In an Australian study, the greatest number of traumatic work-related deaths occurred in the age range 20–54 years (about three-quarters); a smaller number of deaths occurred in individuals aged less than 20 years (6%) and those over 65 years (5%).
3. Older workers generally require longer periods of recuperation from injury due to age-associated physiological changes.
4. Factors that can influence recovery time from injury include the type of workplace hazard exposure, socio-economic factors and possible changes in reporting of minor workplace accidents (older workers may tend not to report minor injuries).
5. Older workers may be at risk of particular types of accidents, specifically sprains and strains of joints such as the shoulder, knee, ankle or back. However, information on exposure to work hazards, taking age into account, is not available.

### 2.1.11 The Role of the Ergonomist

The role of the Ergonomist is a significant and important one; they have a valuable role to play in assisting industry design appropriate work systems, equipment and human:machine interfaces to promote productivity, efficiency and worker comfort and satisfaction.

Throughout this course we will examine the principles of ergonomics theory, methods and techniques. The course will not turn you into an Ergonomist, but help you see workplace issues with ergonomics in mind and know when a specialist Ergonomist is needed.

## 2.2 BIOLOGICAL ERGONOMICS

### 2.2.1 Body Systems

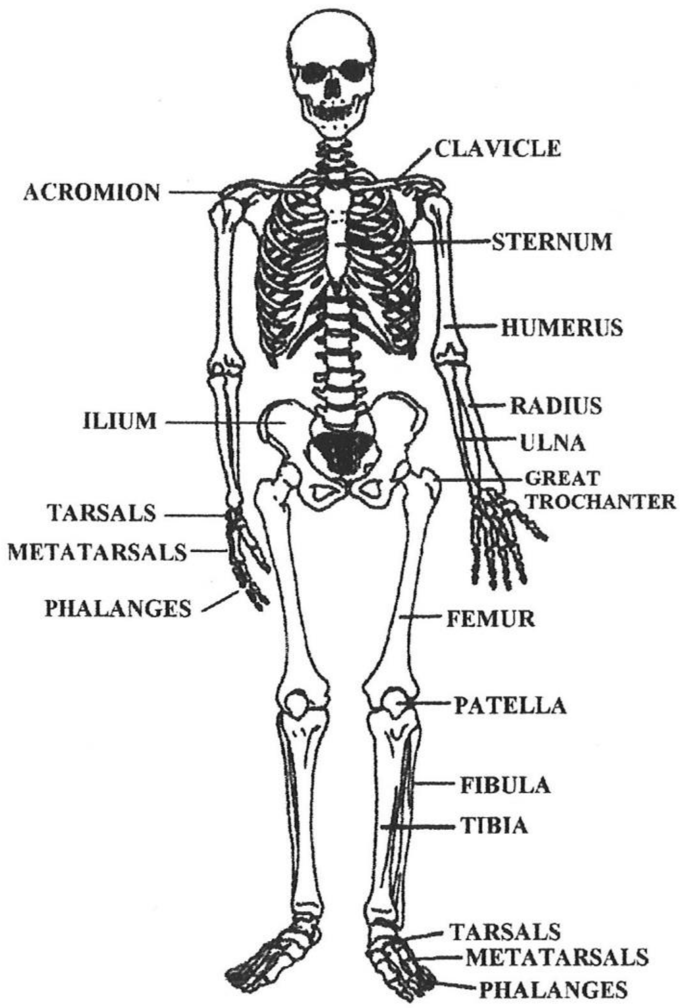
Simply put, the human body is a complex system of framework (skeleton), moving parts (bones, joints, muscles, ligaments and tendons), energy conversion system (metabolism and physiology), movement control system (nervous system), feedback and decision-making system (senses and brain). From an ergonomics perspective, we need to understand how these systems work, what they are capable of and requirements for optimum function before we can effectively design work systems, equipment and interfaces which rely on their capacity. We will briefly examine these systems in this section.

### 2.2.2 The Musculoskeletal System

#### a) Anatomy

The human skeleton performs four main functions, it protects vital organs (brain, heart, lungs); allows movements through its joints; provides framework for upright stature; and contributes to red blood cell production. From an ergonomics perspective, it is the range of movement and types of movements at the joints which are important. These determine the direction and limit of human movements such as reach, important for workstation design.

The skeleton needs ligaments, tendons and muscles to become functional, and together these structures are termed the 'musculoskeletal system' and will be the focus of our discussion in this section, as this system is the functional system of human movement.

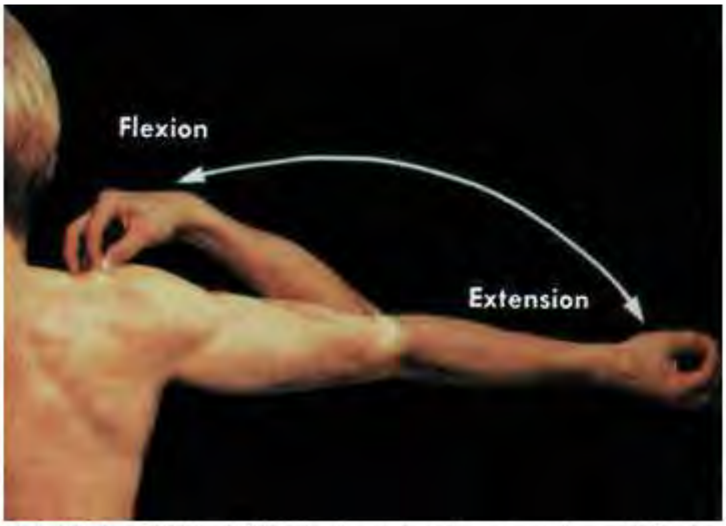



(Source: Stevenson, 1999 – *reproduced with permission)*

***Figure 2.5 – Front View of Human Skelton***

**b) Joints**

The human skeleton has three main types of joints, synovial joints, hinge joints and ball and socket joints. Each type of joint allows certain movements. Synovial joints can be found in the hands and feet; hinge joints allow movement in one plane only and are found in the elbows and knees (although the forearm can rotate around its long axis due to the movement of bones in the wrist); while the shoulder and hip are ball and socket joints which allow movement in 3 dimensions (though with limits!).



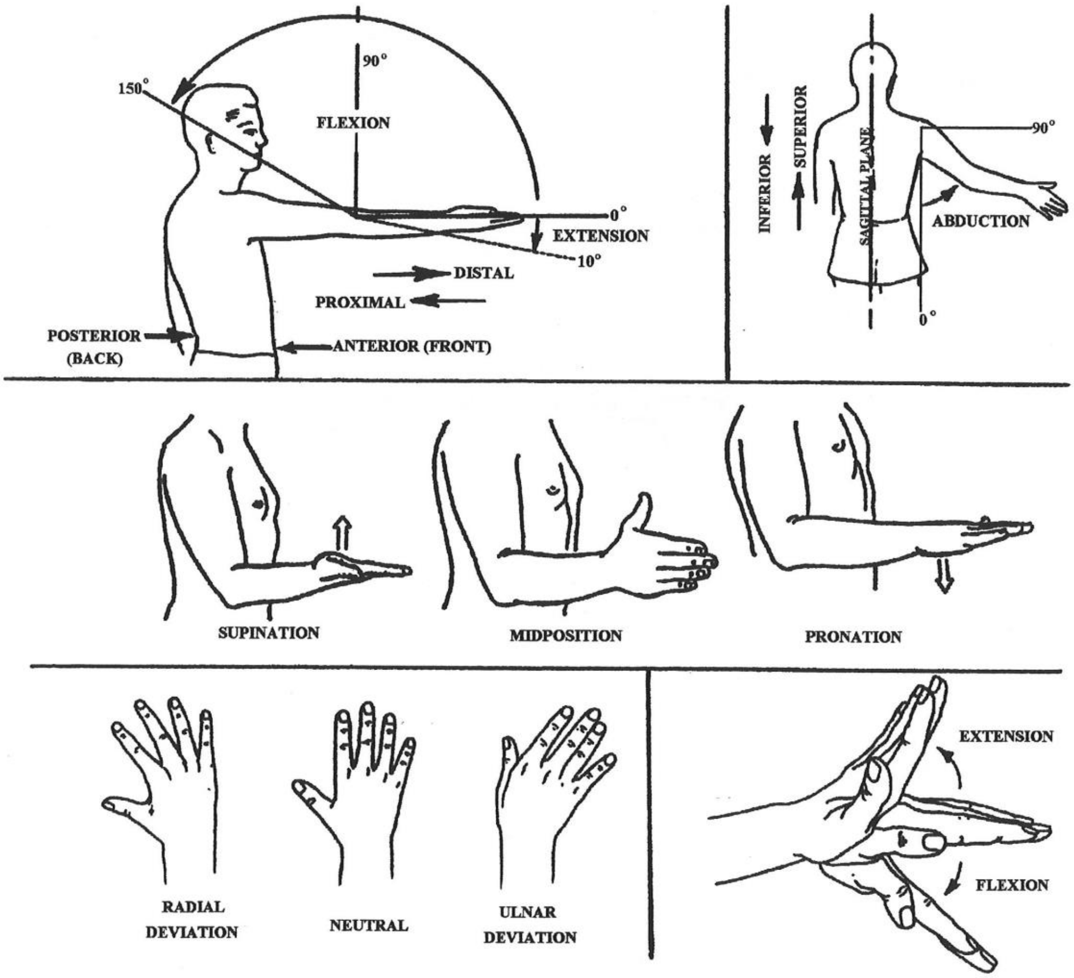



(Source: Mosby's Medical Encyclopedia)

***Figure 2.6 – Examples of "Hinge" Joints, Elbow & Knee***

**c) Muscle**

The muscles produce movement, enable posture and contribute to maintaining body temperature through heat production. Muscles are attached to bone via tendons, and are of two main fibre types: fast twitch or slow twitch. Postural muscles are slow twitch while dynamic muscle is fast twitch. Postural muscles are able to more efficiently sustain a contraction.



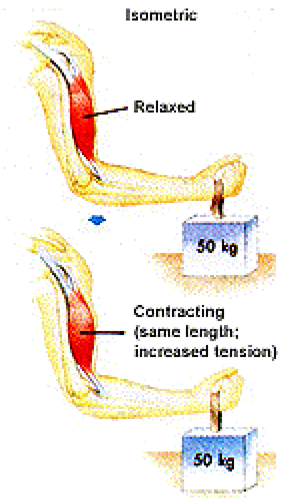

(Source: Stevenson, 1999 – *reproduced with permission)*

***Figure 2.7 – Hand & Arm Movements and Associated Terminology***

Essentially, muscles require oxygen to work efficiently. If they are starved of oxygen, for example by prolonged contraction to sustain a static posture, the muscle will use energy within itself for fuel and form lactic acid which leads to rapid muscle fatigue. This type of contraction is termed an 'anaerobic' contraction (without oxygen). An 'aerobic' contraction provides adequate supply of oxygen and nutrients to the muscle to work efficiently. Aerobic contractions allow time for muscles to contract and relax to access optimum oxygen, and continue to work.

The muscle contraction is the development of tension in a muscle. However when the muscle 'contracts' it does not always shorten. Contraction may be static (no movement) or active (movement). These states are further categorised as:

1. *Isometric (static)* - the muscle builds up tension but the length remains unchanged. Static muscle work is the most energy efficient but is also the most tiring. Compression of blood vessels and nerves stops nutrients and wastes from muscle activity from being dispersed eg when attempting to lift an immovable object or when an object is held stationary.
2. *Concentric (active)* - muscle fibres contract to shorten the muscle eg: the biceps muscle bends the elbow and overcomes the resistance of the weight of the arm, the source of the resistance being inertia and the force of gravity.
3. *Eccentric (active)* - allows for controlled lengthening of the muscle(s) against gravity eg: thigh muscles controlling knee movements while going down stairs.






(Source: Mosby's Medical Encyclopedia)

***Figure 2.8 – Isometric Muscle Contraction. Muscle length remains unchanged, tension increased.***

### 2.2.3 Posture and Movement

The science of human movement is known as kinesiology and describes motions of the body segments, as well as identifying the muscle actions responsible for the movements.

Posture provides the basis for movement and refers to the angular relationships of the body parts and the distribution of their masses. These elements influence the stability of postures, the loads on the muscles and joints, and how long different body positions can be maintained before fatigue sets in.

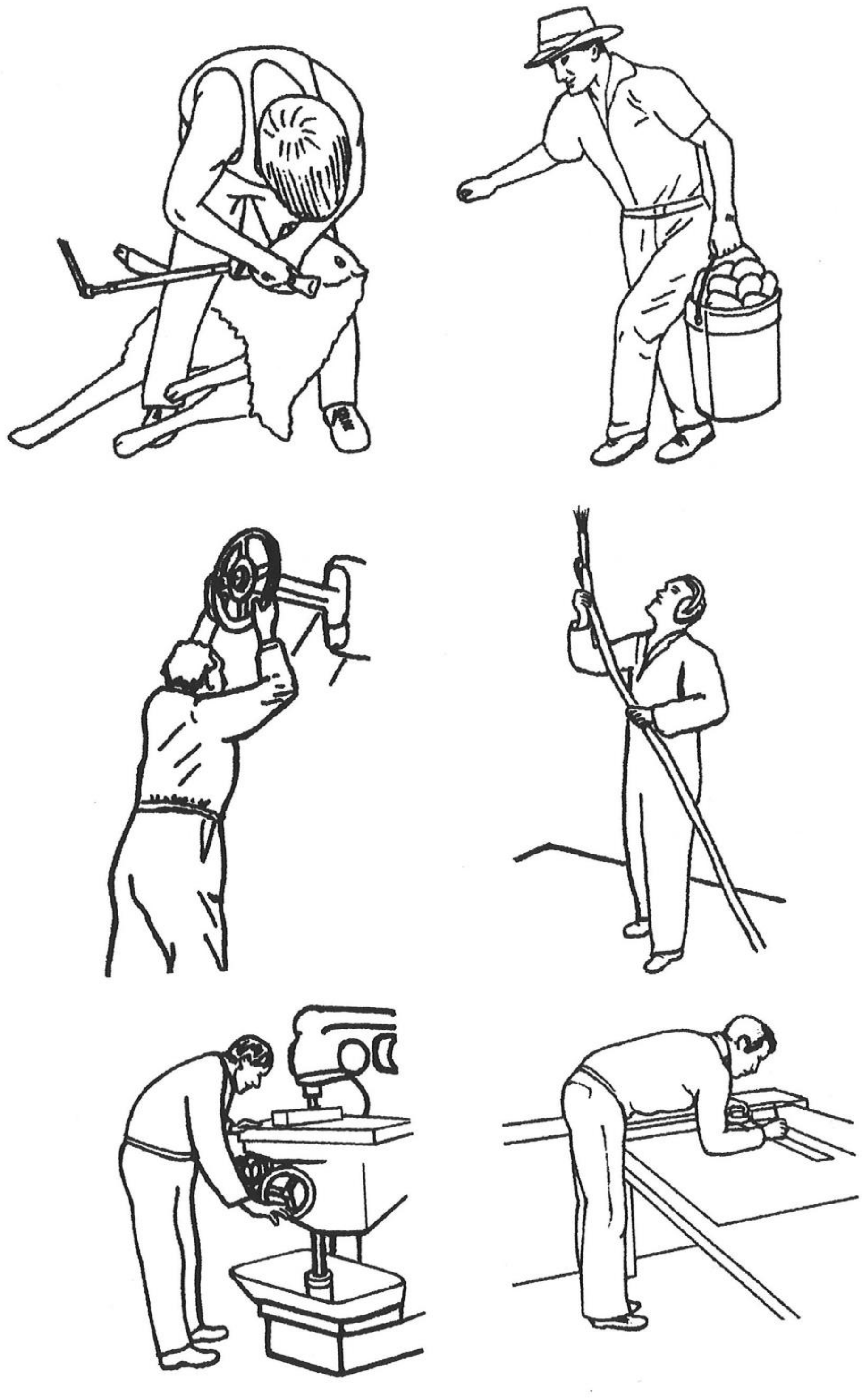
Movement and posture is fundamental to human existence. People have evolved through the activity and postures imposed by their living conditions and their need to feed, clothe and look after themselves. As a result, human physical performance is optimum when postures and movements are dynamic and varied.

In general the human body moves and works most efficiently when joints are in the neutral (mid) range and the muscles are around mid length pulling at right angles to the bone. However, movement of joints through their full range each day is necessary to keep the body supple and the joints and muscles working efficiently.

#### a) Static and Dynamic Postures

The information about muscle contraction is important for ergonomics, as any action/movements in the work process which does not allow the muscle to work aerobically should be avoided. Static muscle work is common in postural muscles of the neck, shoulders, back and buttocks. These stabilise the trunk allowing for more accurate and efficient movement of the limbs. The positioning of the body for optimum movement occurs naturally where the environment allows.

Both types of active muscle work (concentric and eccentric) use more energy but are less tiring than static muscle work.



(Source: Stevenson, 1999 – *reproduced with permission)*

***Figure 2.9 – Examples of Static Muscle Loading in Work Tasks***

### b) Balance and Movement Control

Balance is the ability to maintain equilibrium in different positions. This changes with the size of the base of support such as the feet, the buttocks in sitting or the whole body in lying and the height of the centre of gravity. Balance is maintained in standing and sitting by continually making minor corrections of position. In general we maintain stable postures by static balancing and unstable postures by dynamic balancing such as in walking.

As the position of a person's limbs changes sensors in the muscles, tendons and joints relay this information to the brain. This allows a person to know where different parts of their body are in space even when they cannot see them. This feedback mechanism is known as proprioception.

Both the muscle and joint sensors as well as those located in the ear (semicircular canals) are essential for balance and co-ordinated movement.

## 2.2.4 Biomechanics

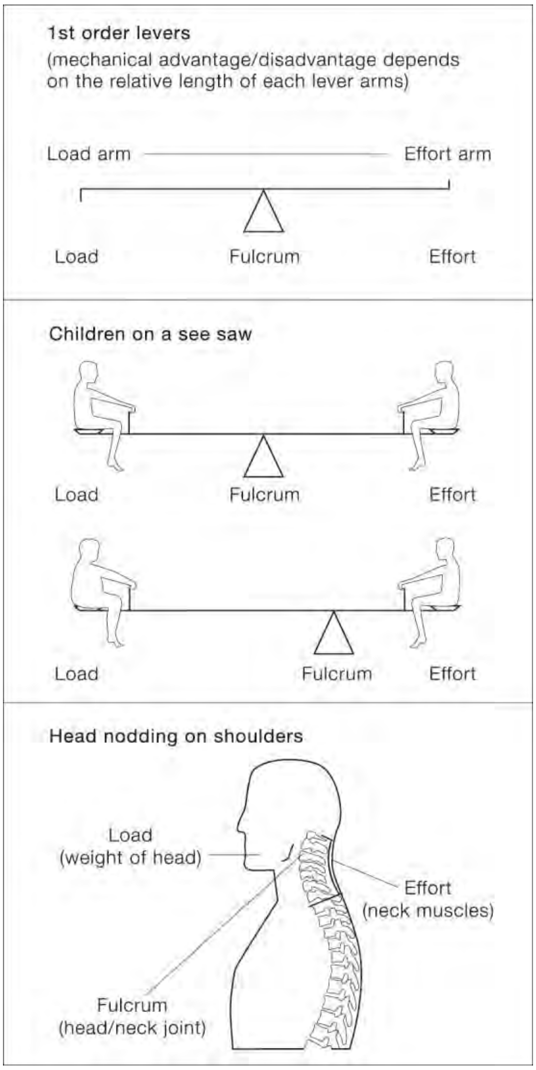
The interaction of human movement and posture is called biomechanics and describes the levers and arches of the skeleton, and the forces applied to them by the muscles and gravity.

### a) Levers in the Body

A muscle seldom acts alone; most muscle action involves the complex integration of muscle activity to produce whole movements. Most movements employ lever action, the bones acting as levers and the muscles applying force about a fulcrum (joints).

Three types of lever action are employed:

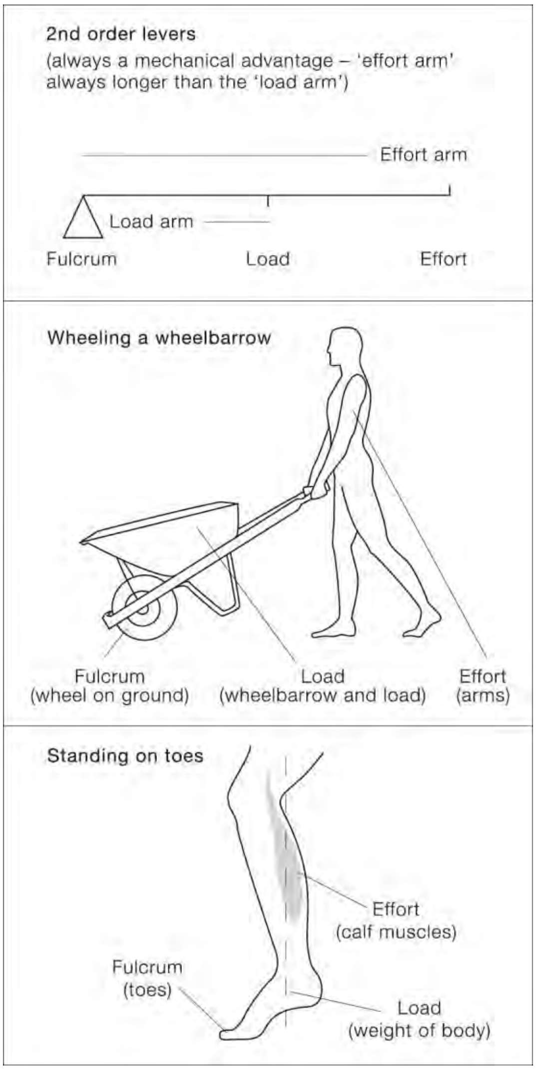
1. *First order lever* - mechanical advantage is determined by the length of the lever on either side of the fulcrum eg: the see-saw and nodding of the head.




(Source: McPhee, 2005 – *reproduced with permission)*

***Figure 2.10 – First Order Lever***

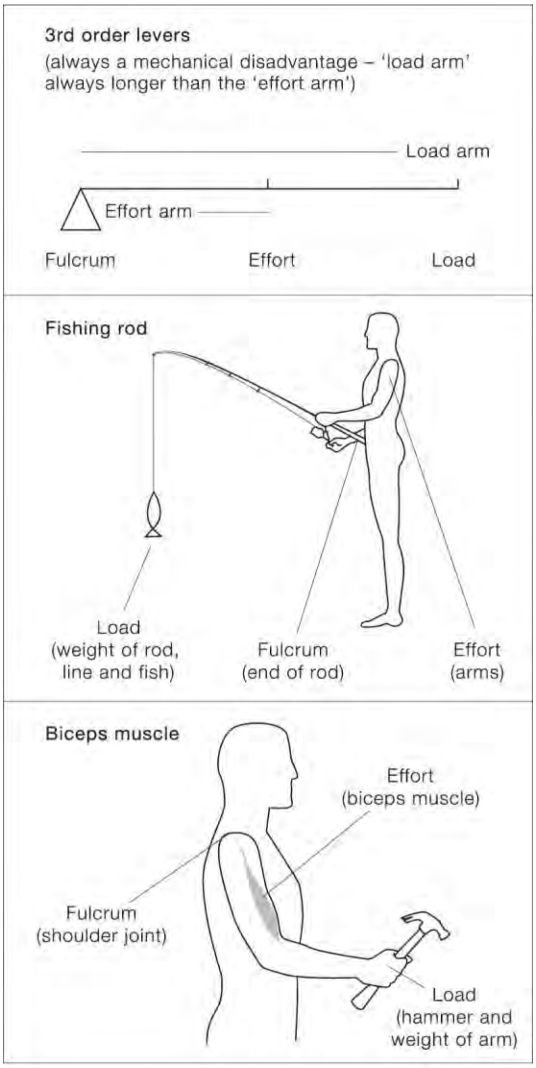
2. *Second order lever -* a relatively small force (the pull of the arms or the calf muscles respectively) acting through a large distance lifts a large weight through a short distance. This always imparts a mechanical advantage eg: a wheelbarrow or in tip toeing.




(Source: McPhee, 2005 – *reproduced with permission)*

***Figure 2.11 – Second Order Lever***

3. *Third order lever*- a relatively large force (in this case the muscles of the upper arm) acting through a short distance lifts a smaller weight through a large distance. This always leads to a mechanical disadvantage eg pulling up a fishing rod the lower end of which is supported against the thigh or in lifting an object by bending the elbow.




(Source: McPhee, 2005 – *reproduced with permission)*

***Figure 2.12 – Third Order Lever***

Most levers in the body are third order and as a result the body is very inefficient at generating force. The human body usually works at a large mechanical disadvantage and considerable energy is required to achieve modest output.

However, third order levers give humans some special advantages. These are speed, range and precision of movement.

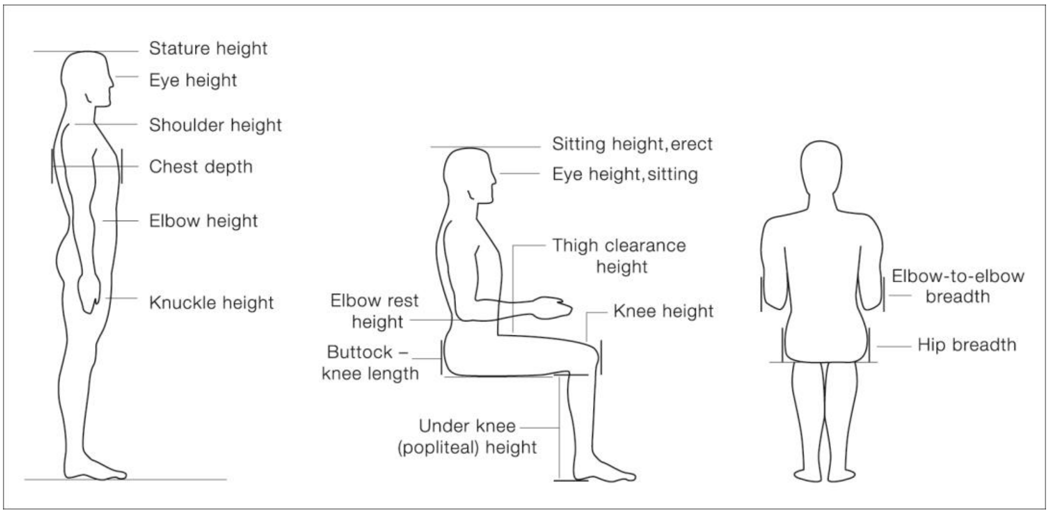
As a general ergonomics principle, work should never be designed so that it requires strength and precision at the same time. This can place intolerable stresses on muscles and joints especially if it is required for repeated or extended periods during the working day.

### 2.2.5 Anthropometry

From an ergonomics viewpoint, appropriate design needs to cater for the range of humans at work. To do this, Ergonomists utilise anthropometric data. Anthropometry refers to the dimensions of the human body and how these are measured. It covers the size of people; their height and circumference; their weight and percentage body fat; the length and range of movement of their limbs, head and trunk; and their muscle strength.

Measurements of large numbers of people are needed in any given population to determine ranges, averages and percentiles. Children of different ages, male and female adults and older people all may be included in the population sample depending on how the data may be used.

Measurements are made in two different ways – referred to as static and dynamic anthropometry. The most common measurements are made with the body in rigid standardised positions and this is static anthropometry. Dimensions are linear and are made relative to the body surface eg standing height, length of leg, head circumference. Measurements are standardised using the same methods and postures on different individuals but they allow comparisons between individuals and between population groups. They provide information on the size differences of individuals but they are not functional measurements (that is they are static length measurements).

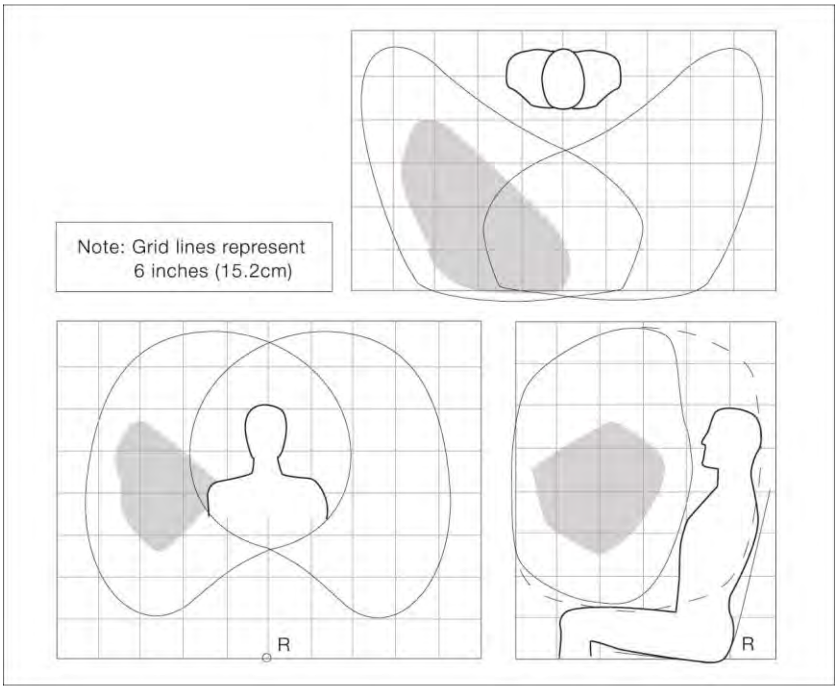



(Source: McPhee, 2005 – *reproduced with permission)*

***Figure 2.13 – Static Anthropometric Body Measurements***

**a) Dynamic Anthropometry**

Dynamic or functional anthropometry, in which dimensions are measured with the body in various working positions, is more complex and difficult to perform but it has important applications in the workplace. Measurements are three-dimensional and describe such things as space envelopes in driving cabs, arcs and ranges of movements for the optimum use of controls, and safety clearances.




(Source: McPhee, 2005 – *reproduced with permission)*

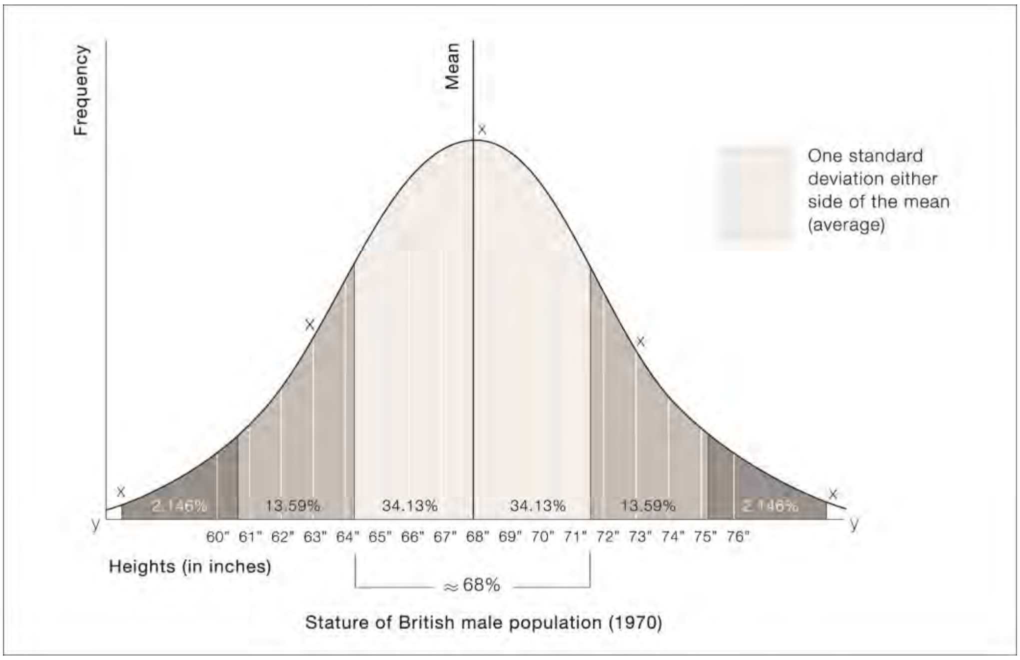
***Figure 2.14 – Space Envelope Depicting Hand Movements and Hand Grasps in 3 Dimensional Space Showing the Optimum for Different Manipulations***

**b) Using Anthropometric Information**

In workplace and equipment design, ranges of dimensions are often specified to allow for the short and the tall, the fat and the thin and those who may be differently proportioned to the average. Ranges can include extremes at either end such the 5th percentile in height represents people who are in the shortest 5%, while the 95th percentile represents the tallest 5%.

Often a design needs to suit the majority of the population as far as possible while not accommodating everyone in the extremes of range eg seats in a bus or an aeroplane suit 90% of the population adequately but may be very comfortable for very short or tall or obese people.
In these cases static dimensions are used as a guide eg: average (mean) height of the travelling population.

In most dimensions the middle 68% of the population can be accommodated relatively easily with little or no adjustment required.




(Source: McPhee, 2005 – *reproduced with permission)*

***Figure 2.15 – Curve of Normal Distribution showing Range of Height for British Men. One Standard Deviation From the Mean Represents Almost 68% of Men With a Range of Approximately 7 inches (180 mm)***

Ninety-five percent of the population can be accommodated with some flexibility in design or by using adjustments eg desks and chairs. It may be very difficult to achieve a fit for very tall/short or big/small people above 97.5th percentile or below 2.5th percentile.

If it is possible to use equipment lower/higher/wider/narrower than the optimum, variation is limited to one direction - it has a one-way tolerance eg: the height of a door for a tall person, the height of shelf for a small person.

Some design is concerned with static dimensions such as body height (stature), leg length or shoulder width. For instance, thigh length governs the optimum depth of a seat for a particular person while lower leg length dictates the height of the seat.

Where dimensions may not be critical, one dimension, usually stature, may be used as an approximation of other dimensions such as leg length and shoulder width. Using commercially available data tables other static dimensions can be derived. However, this method must be used with care as there are many exceptions to the rule and all the data that are readily available in this form are from the USA or Europe.

**Factors that Affect Body Size**

- A*ge* - there is an increase in dimensions from birth to age 20 in males and to age 17 in females with a decline after 60 years
- *Sex* - men generally are physically larger except in hip breadth and thigh circumference than women. Men’s arms and legs are longer than women’s absolutely and relatively in standing and sitting
- *Ethnicity* – statistical variations occur in size, proportions and body builds between people of Asian, Caucasian and African racial backgrounds as well as within each of these groups eg between nationality groups such as Scandinavian and Mediterranean people
- *Fitness and health* – the presence or absence of disease, nutrition and physical fitness can significantly affect height and size

- *Occupation* - workers in active jobs may tend to be physically larger than those in sedentary work. This may be due a self-selection process but is also related to age, diet, health and activity. However sedentary workers tend to have more body fat due to inactivity
- *Posture and body position* - differences in measurements occur between rigid and slumped postures, and dynamic and static measurements. The rigid, static measurements may provide a starting point for design but the dynamic or more functional postures are more likely to reflect the true situation

(Source: BP International – *reproduced with permission)*

***Figure 2.16 – Static Anthropometry of Seated Operator***

### 2.2.6 Applying Work Physiology: Body Metabolism, Work Capacity and Fatigue

While the musculoskeletal system has capacities and limitations, the Ergonomist also needs to consider the physiological capacity of the human: strength, work capacity, and the result of exceeding these capacities, fatigue.

#### a) Strength

Strength is affected by a number of factors,

- Gender: While some women are stronger than some men on average men are one third to one half stronger than women. This is due to body size, muscle mass (40 - 45% of body weight in men and 25 - 25% in women), the distribution and percentage of fat, and muscle bulk in the shoulders, abdomen, hips and legs

- Age: Muscle strength peaks are reached in men at about 20 years old and in women a few years earlier. Maximal cardiac efficiency and muscle strength decrease significantly with age. In both sexes maximal aerobic power reaches a peak at the age of 18-20 years followed by a gradual decline

  At the age of 65 the mean value of aerobic power is about 70% of what it is for a 25-year-old. The mean value of aerobic power for a 65-year-old man is roughly the same as a 25-year-old woman. The strength of a 65-year-old individual is, on average, 75-80% of that attained at the age of 20-30 years when medical conditions are not a limiting factor. The rate of decline in muscle strength with age is in both sexes greater in the leg and trunk muscles (big muscle groups) than in the strength of the arm muscles. The decline in muscle strength with age is due to a decline in muscle mass

- Training: Muscle strength can be enhanced through training. In a work situation, the training must be highly specific to the movements required by the task, or the training may be ineffective

**b) Work Capacity**

The capacity of an individual to undertake physical work can be measured directly by examining the individual's maximal oxygen uptake (ability to take in oxygen in the blood via the lungs), or indirectly by measuring heart rate. Heart rate is a reliable measure of workload and is easily measured in the workplace (as opposed to the oxygen uptake which is measured with special equipment in a laboratory setting).

To maintain a work level all day for a fit, young and healthy person, 25-30% of the maximal aerobic power (oxygen uptake) is usually acceptable. Maximal aerobic power varies markedly between individuals and the important thing is that individuals are measured against their own basic cardio-vascular capacity. However for all people the heavier the work rate the shorter the work periods should be.

Maximal heart rate can be roughly estimated as 220 beats per minute (bpm) minus the individual's age. For instance for a 40 year old person the maximum heart rate could be expected to be about 180 beats per minute (220-40 bpm).

In most people a heart rate of about 120-130 beats per minute corresponds to a workload of 50 per cent of the individual's maximal oxygen uptake. These figures would need to be modified for older, less fit or dehydrated workers.

An average heart rate of 110 beats/min for moderate levels of work is generally an acceptable physiological limit for an 8-hr working day for a 20 to 30 year old person. Exceeding these limits, even slightly for some people, may lead to fatigue (tiredness) and general lack of coordination, which may result in errors and injuries.

Environmental factors such as temperature, humidity, air velocity, (see Section 6.3 Thermal Environment) noise, vibration and dust need to be considered carefully as these may effect the performance of individuals doing strenuous work. They may decrease the person's alertness, concentration or physical capacity for work thereby increasing the risks of errors and injuries.

**c) Endurance**

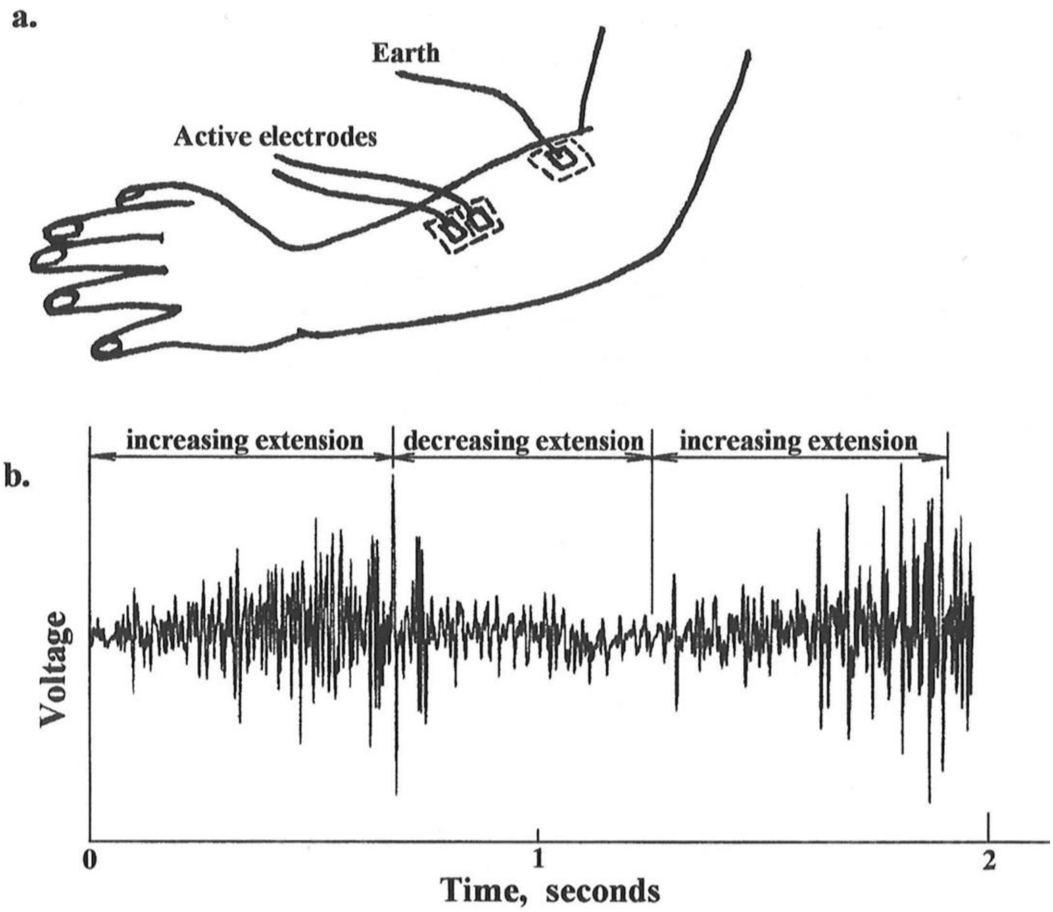
Efficiency of muscular contraction is necessary to enhance endurance and work capacity. To facilitate this, work tasks should:

- Eliminate unnecessary movements
- Use muscles according to their correct function
- Make use of body weight and momentum and of gravity
- Maintain balance
- Vary movements
- Vary position and posture
- Employ postures allowing maximum torque
- Use accessory supports for counterthrust or stability
- Provide opportunity for training and practice

Endurance of a given muscular performance varies with the nature and intensity of exertion, the size and structure of the muscles involved, and practice in the task. As noted previously in this section, static effort can be endured for much shorter periods than exertion involving movement. Endurance fails sooner when either rate of work or load is increased, or when degree of contraction of muscles approaches maximum levels. Postural muscles have greater endurance than faster moving muscles, which are designed more for speed of contraction; most muscles have variable amounts of red or pale fibres depending on their main function, movement or support of posture (with red fibres needed for strength and pale fibres for endurance).

Practice increases power and endurance, due largely to better coordination and elimination of unnecessary contraction: the same end is achieved with less effort. Training enhances the speed, strength and stamina of muscle contraction. However, motivation is also of great importance in any activity requiring endurance of muscular effort.

In prolonged static or repetitive muscular exertion, the maintenance of constant speed and load requires a progressive increase in muscle activity ie: more contraction for the same output, both in the muscle group mainly involved and in recruitment of other muscles.




(Source: Stevenson, 1999 – *reproduced with permission)*

***Figure 2.17 – Example of Progressive Firing of Muscle Fibres (a) Indicates placement of electrodes to measure wrist extension activity; (b) Typical raw EMG signal during repetitive wrist extension. Note: Increase in signal over time***

### d) Physical Fatigue

If particular movements are carried out continuously it is reasonable to expect all the muscles to tire, both those executing the movement and those stabilising or enhancing the movement. Stabilising (static muscle work) is more fatiguing than muscle contractions that cause movement (active muscle work).

As fatigue can lead to strain the effect of unchanging postures and static muscle work can be equally as damaging as highly repetitive movements. Muscles may tire and become sore to touch and move. Points of weakness such as the muscle/tendon/bone junction at the knee, shoulder or elbow or the tendons over the ankle or the wrist suffer damage and lead to pain.

Dynamic physical work can also lead to problems if it is excessive for the particular individual. Movements in the outer range of the muscle or the joint, heavy lifting, pushing, or pulling (forces that are too high), movements that are prolonged (duration of activity) or repetitive can lead to strain and fatigue and eventually injury. In this respect younger and older, trained and untrained individuals, as well as men and women can vary widely in their capacities. Health and nutrition, previous injuries, lifestyles and natural abilities also play a part in contributing to a person's capabilities to undertake a specific task.

## 2.3 PSYCHOLOGY AT WORK

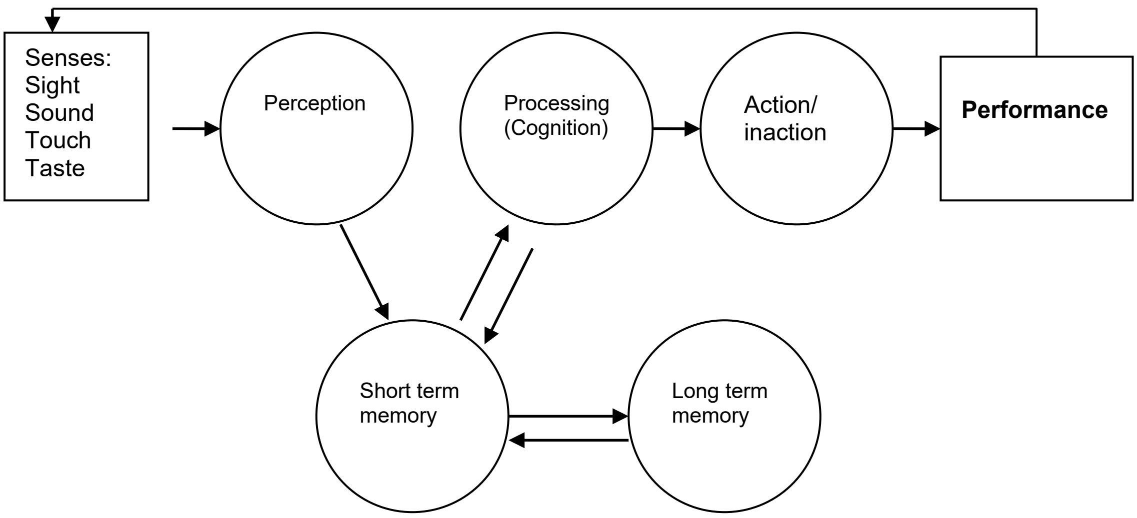
When people work, their output is determined by both their physical and cognitive capacity. Cognitive capacity/behaviour in turn, is affected by intrinsic personal characteristics such as age, experience, training, personality and motivation; as well as extrinsic factors such as work organisation (shift patterns, work loads, morale, etc) and environmental factors which may act as a distracter to the task at hand (eg: excessive noise, poor lighting, etc). Cognitive ergonomics deals with the process of perception, cognition (processing) and action (decision/output).

We will now examine the concepts of perception, motivation, memory, risk perception, work stress and work organisation factors.

### 2.3.1 Perception and Cognition

Human perception begins with our senses – sight, sound, taste, touch. The information is processed and action taken. Should the information be incompatible with our senses, perception can be altered.

Outlined below is a conceptual drawing of the pathway of human information processing and output/performance. Memory is discussed in the following section.




(Source: UOW - *Adapted from Stevenson, 1999, p.14.7*)

***Figure 2.18 – Pathway of Human Information Processing and Performance. (Note the use and interaction of short and long term memory which is detailed further in Figure 2.19)***

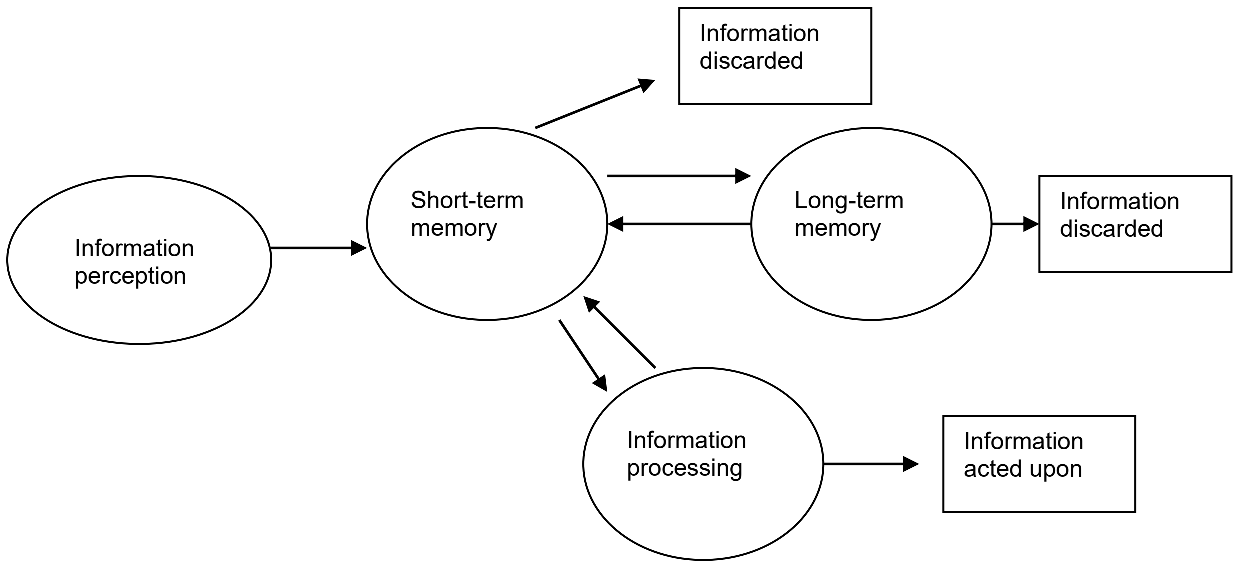
From an ergonomics perspective, we need to ensure that information is presented to the person at work in the most compatible way so that it can be efficiently processed. This can be achieved in three ways:

1. Not overloading the human with information
2. Not providing too little information or stimulus
3. Not presenting the information too quickly

### 2.3.2 Memory

Human memory is divided into short and long term components. We are all aware of the vagaries of short term memory! In fact short term memory has a limited capacity – we are able to hold 5 -9 small items in this repository. For the information to move into long term memory, it has to be made more meaningful, otherwise the information is discarded and new information will take its place.

As outlined in the figure below, the pathway of information passes firstly through the short term memory where it is processed, and then either discarded or progressed into long term memory. The pathway to long term memory is not one way, however, as we need information stored in the long term memory, it is called up into the short term memory and processed. A schematic diagram below shows the movement of information into short and long term memory, then either acted upon or discarded.




(Source: UOW - Adapted from Stevenson, 1999, p.14.7)

***Figure 2.19 – Information Processing in the Short and Long Term Memory***

### 2.3.3 Decision-making

Once we perceive information, we make a decision to act upon it. A useful model of this decision-making process has been put forward by an Occupational Psychologist, Wickens (2000), who outlines 3 features of decision-making as follows:

***Features of Decision-making***

- *Uncertainty*:
  If a decision has a degree of uncertainty and that uncertainty outcome is disagreeable, unpleasant, or a cost to us, we view the decision as risky.

- *Familiarity and Expertise*:
  Making decisions when the outcomes are known and familiar, is an easy and quick decision. When the outcomes are not known, and cues not familiar, the decision is much more difficult.

  There is an effect of expertise and training in this type of decision-making, whereby an 'expert' will make a more rapid decision than a 'novice' – though as Wickens points out, accuracy is not guaranteed just because the decision is being made by an expert.

- *Time*:
  People may make more 'risky' decisions if that decision is a 'one-off', such as property purchase, or if the decision can be made, acted upon, and then have additional information before another decision step is taken. An example of this second type would be deciding to treat a serious illness with an unknown outcome. The decision can be taken to deliver initial treatment, have further tests, review decision, elect to proceed, etc.

  Conversely, if time is limited, time pressure can have a significant influence on decision-making.

## 2.3.4 Perception of Risk

Kahneman and Tversky (1984) postulate that humans prefer to make gains rather than losses when making decisions. So, if the consequences of taking a risk are acceptable, this will affect our perception of that risk – that is, by lowering it.

This can be seen in situations where short term gains lead to acceptance and lower perception of risk, for example, driving too fast, not wearing personal protective equipment, or partaking in alcohol and other drugs. In other words, if risk taking is seen to have rewards, then risks seem more acceptable.

In addition to this phenomenon, humans have an inherent view of life that 'things should be fair', and 'what goes around, comes around', so that should a worker take risks at work and be injured, he or she may be seen to 'get what they deserved' and this then lowers the outrage that someone has been injured while working, and this in turn, lowers the perception of risk.

This tendency can be seen in our daily lives. Most of us drive a car, even though thousands of accidents occur every week and fatalities are not uncommon. Experience on the task of driving leads us to perceive a relatively low level of risk, and past experiences reinforce the "it won't happen to me" way of thinking (unless you have experienced an accident!) In the workplace this thinking is even more pronounced.

Each time you drive, there is a small risk for each trip. Over a lifetime this risk increases with the increased exposure. Over a lifetime of driving, the risk of accident is calculated to be 30-50% and is dependent upon age, gender, geographic location, trip frequency and duration, drugs/alcohol, etc (Evans, 1991). Risk is difficult to measure in these situations.

Real risk is determined by the magnitude of loss if a mishap occurs (severity) and the probability that the accident or loss will actually happen (frequency). Humans' perception of risk is generally much lower than actual risk.

Evidence of this in the workplace is the low levels or reluctance to wear personal protective equipment, or to follow safe work procedures which take longer than other methods and in the eyes of the worker provide the same results.

Sandman et al (1994) investigated factors influencing perceived risk, and found that lower risk is perceived when

- Exposure is voluntary
- Hazard is familiar
- Hazard is forgettable
- Hazard is cumulative
- Collective statistics are presented
- Hazard is understood
- Hazard is controllable
- Hazard affects everyone
- Hazard is preventable
- Hazard is consequential

The following factors were found to increase risk perception:

- Exposure is mandatory
- Hazard is unusual
- Hazard is memorable
- Hazard is catastrophic
- Individual statistics are presented
- Hazard is unknown
- Hazard is uncontrollable
- Hazard effects vulnerable people
- Hazard is only reducible, and cannot be eliminated
- Hazard is inconsequential

From looking at these factors, we can see that the more we know about risk the less threatening it appears, and that personalising experiences leads to increased perceptions of risk as people can identify with personal stories, and these affect them emotionally. Typically, the hazards we choose to be exposed to are perceived as less risky than those we are forced to go through.

For example, skiing, driving, working are usually seen as less risk than earthquakes, pollution, and exposure to certain food additives. If you are in a situation where you are feeling 'trapped', for example, unable to leave a job due to factors such as income for repayments, etc you are more likely to perceive high levels of risk than those who feel they are free to leave their job.

Balancing this process of risk perception, there is a concept of Risk Compensation, that is, that people will adjust behaviours to compensate for changes in perceived risk. This controversial area of research states that the lower the risk perception, the more and greater the risks that will be taken. This could be seen by workers wearing PPE feeling safer, and therefore behave more recklessly. Scott Geller, well known writer on human behaviour and safety, believes that risk compensation is a real phenomenon (eg: Geller 2001).

To investigate this, Geller ran a study with go-carts. Subjects were told to drive go-carts quickly but only at a speed they felt comfortable with. The 56 subjects were either buckled up or unbuckled in the first of 2 phases of driving trials. They then switched conditions for half the subjects so that there was no longer a seat belt for those previously buckled up and available for the group who previously did not have a seat belt. He found that people did feel less safe the 2nd time around when no belt was available BUT no change in driving speeds occurred despite the unease that people felt. Later a study by Jansson (1994) showed in a real situation that habitual "hard-core" non users of seat belts drove much more hazardously when asked to wear seat-belts.

It is Geller's contention that the implications for this is that some people will take extra risks when wearing PPE or some safeguards have been put in place. Also some will only follow safe practices when supervised. Worse still, some people may exercise their freedom by deliberately doing unsafe things.

Accordingly, interventions should focus on lowering the level of risk people are willing to tolerate.

The implications of risk compensation is that OHS excellence cannot be achieved through top-down rules and enforcement; some people will only follow rules when they are supervised, and others may like to 'make a stand' and deliberately not follow the rules because they feel too controlled.

### 2.3.5 Signal Detection Theory

Humans learn about their world by detecting changes within it. Effective operation of a process or work system requires signals to the operator informing them of the state of the system and indicating when action is required of the operator. This topic is relevant to the design of displays on equipment and should be considered with the work design and control design section.

On a simple level, the operator needs to be able to detect whether or not a signal is present. Should there be a serious overheating within a production line, for example, the operator should easily be able to detect and understand the problem in order to make a decision and deal with the issue with an appropriate response. This concept is known as signal detection – that is the signal is present or it is not.

The workplace, however, is not usually this straight forward. A control room may have multiple displays: meters, readouts, visual and auditory alarms etc.

This processing of information can be applied readily to the control room, and also judgement tasks such as reading an x-ray to view a fracture (which require careful professional judgement based on knowledge and experience). The signal detection model was developed by Green and Swets, in 1966.

To schematically represent this, a 2 by 2 Matrix is used as shown below. The operator determines whether or not a signal is present, and as a result of these choices, the categories of response are 'hit', 'false alarm', 'miss' or 'correct rejection.' In the ideal world, with clear signals, all the responses would be a 'hit'. However, given that the signal is not always clear and/or not always detected, the conventional method of considering the likelihood of each outcome is to consider the probability. For example if 100 signals were present, there would be 25 hits, and 75 misses, or a 25% chance of getting the right outcome.

| | | Condition | |
|---|---|---|---|
| | | **Signal IS Present** | **Signal IS Absent** |
| **Operator's Response** | **Signal Is Present** | **HIT** | **FALSE ALARM** |
| | **Signal Is Absent** | **MISS** | **CORRECT REJECTION** |

***Figure 2.20 – Signal Detection Theory***

The probability of outcome is affected by the response bias of the operator – more misses or more false alarms. This can be due to the individual or the circumstances. For example, if the outcome of missing a signal is very serious (as in medical diagnosis from a scan), then the operator is more likely to say a signal is present ('false alarm'); or if an operator is fearful of shutting down a process line due to the costs, they are more likely to 'miss' the signal.

Incorrect outcomes can also be due to the signal itself – not obvious (see section on vision and hearing), 'drowned out' by other 'noise' in the environment such as other alarms, screens, lights, etc.; or a result of inadequate training or skill of the operator.

These are known as operator 'sensitivity' and can be improved to promote correct outcomes/response decisions.

Three main strategies can be implemented to overcome this sensitivity:

1. Reducing the unnecessary 'noise' in the environment – distractors, excessive information.
2. Increasing the strength of the signal itself, eg: using audio and visual cues.
3. Presenting relevant information simply and with good design.

### 2.3.6 Vigilance

Many work environments require ongoing monitoring of equipment and/or process. This watching over of operations is termed 'vigilance' and of course in many workplaces can be carried out over various shifts, and with the operator working different shift patterns.

While performing the vigilance task, the worker detects signals over a period of their shift and the signals are sporadic and unpredictable. For example, monitoring coal mining process, x-raying luggage at an airport, or checking for faults in manufacturing process. The operator is required to sustain an adequate level of vigilance – the vigilance level. Research has demonstrated that this vigilance level declines sharply during the first 30 minutes of the task, and this decline is known as vigilance decrement.

**a) Types of Vigilance Tasks**

Vigilance can be considered in a number of ways. It can be a task which is a

- ‘Free response’ whereby the event occurs indiscriminately and non-events are not defined (eg: gas plant monitor where the process is continuously monitored)
- ‘Inspection’ task where events occur at regular times
- ‘Successive’ task in which the operator must remember a standard and compare data with that standard (eg: fruit grading)
- ‘Simultaneous’ in which the operator would have the different grades of fruit in front of them and be able to make direct comparisons each time
- ‘Sensory’ in which the signal requiring detection is a change in visual or auditory levels
- ‘Cognitive’ in which the change will be in cognitive demand, such as proof reading a document

These different vigilance demands result in different outcomes for the vigilance task. Despite a great deal of laboratory experiments on vigilance, there is limited reliable cross-over to the workplace due to the complexity of task demands. However, there are a number of strategies that organisations can put in place to enhance vigilance performance, and these are outlined below (after Chengalur et al., 2004, p.282).

Promote signal detection by:

- Provide good training and ensure familiarity with the signals
- Use simultaneous presentation of signals (eg: auditory and visual)
- Ensure the signal ‘stands out’ from background noise
- Make the signal dynamic

- Provide 2 operators for monitoring; allow them to communicate freely
- Provide 10 minutes of rest or alternate activity for every 30 minutes of monitoring
- Provide feedback for action taken as result of the signal
- Install 'artificial signals' that require a response, and provide feedback on these
- Provide refresher training
- Vary the environmental stimulation inversely to the task stimulation
- Avoid overloading or underloading the signal detection and action taken
- Not using artificial signals that do not require a response
- Require operator to report all signals, even those in doubt

**b) Improvement Strategies**

Devising goals to be met by employees and rewarding them for meeting these goals are one way in which employers can motivate employees. In order for motivational strategies to succeed in the workplace employers must recognise that each employee will have different individual needs and goals. Thus types of organisational rewards that motivate one employee to perform well may not necessarily motivate all employees eg: monetary, or time off in-lieu.

Employees must be included in the decision-making process regarding goal setting and have the ability to provide comment on the types of rewards that are proposed by management.

The organisation needs to ensure that:

- Goals to be achieved contain an element of challenge for the employee

- Goals are attainable
- Feedback mechanisms are in place so that employees are provided with information regarding their performance
- Any organisational rewards offered are linked to objective employee performance achievements and that these rewards are individualised.
- Group goals do not have unwanted outcomes such as peer pressure that leads to overloading of slower or physically weaker workers

### 2.3.7 Motivation and Behaviour

Motivation in the workplace refers to as an individual's intention or willingness to perform a task to achieve a goal or reward that will satisfy them. Each individual experiences differing amounts and types of motivation and considers different rewards or incentives as being attractive.

Some individuals are intrinsically motivated ie: performing and completing a task and the resulting feeling of accomplishment is its own reward. Others are extrinsically motivated and prefer their rewards to come from external sources in the form of bonuses, promotions and/or praise.

### 2.3.8 Work 'Stress' – Causes, Preventative and Protective Measures

Individuals can experience stress when demands exceed their ability to cope. These demands can be personal or work-related or both. Stress can have negative effects on an individual's work performance, health and wellbeing. It can occur in the workplace when individuals experience:

- A lack of control over workloads or overly demanding workloads and schedules
- A lack of social support in the workplace, either through supervisors or peers
- A lack of clear direction from supervisors or management

- A lack of information regarding the individual's role in the organisation
- A lack of career opportunities or job security
- Conflict with other individuals within or external to the organisation
- Physical work environment problems with extremes in temperature, noise, vibration or exposure to hazardous substances
- Violence or aggression from fellow employees or clients or as the result of events such as armed hold-ups

**a) The Signs of Stress**

Individuals who are experiencing stress may have psychological symptoms such as increased feelings of anxiety, depression, aggression or confusion. They may have physical symptoms such as increased blood pressure, heart rate and muscle tension and headaches. They may also be prone to habits such as smoking or drinking alcohol, show signs of irritability, perform poorly at work and have a high rate of absenteeism.

**b) Overcoming Occupational Stress**

Identifying the real causes of stress amongst individuals may take time and may need mediation skills to resolve (such as counselling). In some cases discussions and a general willingness to listen will be all that is required. In general solutions to the problem of occupational stress can involve both alterations to the work environment itself and/or attempts to improve an individual's ability to manage stressful situations.
Stress management training can be beneficial and may include development of coping techniques to deal with stress such as muscle relaxation, meditation and time management skills.

Organisations should try to identify why individuals may be feeling stressed. They should then structure an appropriate response that will address the stressor or stressors – stress related problems could have several causes. All interventions should be developed in consultation with the individual involved, trialled and then evaluated.

### 2.3.9 Work Organisation – Shift Work and Overtime

Work organisation refers to the broader context in which the work is done – the culture and the way the workplace functions as a whole. It encompasses management styles, organisation of work groups, responsibilities and accountabilities. It is influenced by the type of industry or business in which it operates; its history and culture; peaks and troughs in demand for services or products; whether or not there is shiftwork, extended hours or flexitime; and profitability. The extent and type of trade union involvement and the need to meet externally determined standards also influence how a workplace is organised and managed.

Ultimately work organisation affects all parts of the workplace and probably has the greatest influence on ergonomics, occupational health and safety (OHS) practices and the development of high quality, satisfying work. Given this the application of ergonomics in the workplace needs to be understood in an organisational and social context.

#### a) Flexible Work Hours

The traditional 9am to 5pm eight-hour-day is no longer the primary work schedule available to many employees. With the introduction of flexible work schedules many individuals have the opportunity to use flexitime arrangements, time-in-lieu, 4-day weeks and other such arrangements.

There can be benefits for both the organisation and the individual in using flexible work schedules.

| BENEFITS OF FLEXIBLE WORK SCHEDULES | |
|---|---|
| *For the Organisation:* | The opportunity to extend services and operating times |
| | Increased attractiveness of working conditions for potential employees |
| *For the Individual*: | The opportunity to balance the demands of private and working lives |

Any changes in the pattern of work in an organisation should be developed in consultation with employees.

**b) Peaks and Troughs in Workloads**

One major source of excessive work demands on individuals is the seasonal or cyclical nature of some types of work. Mining, manufacturing and service industries all have problems balancing increased workloads and worker capacity from time to time. Where these peaks and troughs can be anticipated they can be planned for and adjustments can be made. Where they are unexpected careful scheduling is needed. Excessive overtime and unpaid extended work hours can be harmful to health, safety and productivity. These workloads need to be managed at an acceptable level.

**c) Shiftwork and Extended Hours**

Shiftwork involves working outside what are considered to be 'normal' working hours, generally between 7am and 6pm. As a rule of thumb the 40-hour week (comprising five 8-hour workdays with two days break) is the 'gold standard'. The more work hours deviate from this regular pattern the more strategies may be needed to overcome the effects of excessive fatigue and sleep disturbances. An increasing number of workers are performing shiftwork and many suffer adverse effects from it.

**d) Problems Associated with Shiftwork**

Most of the health and safety problems associated with shiftwork arise from the working of irregular hours, often at times that are in conflict with the individual's internal biological rhythms. The body's circadian rhythm is normally set for activity during the daytime and for rest and relaxation at night. Disruptions to the body's circadian rhythm are most evident when an individual is required to work night shifts (between 11pm and 6am) and many people experience sleep problems during the day.

During a night shift, an individual's circadian rhythm is at a low and, when combined with fatigue, performance is generally reduced. Poor performance can affect both safety and productivity on the job.

Health-related problems that have been associated with working irregular hours include gastrointestinal problems resulting from irregular diet and eating habits, an increased risk of stomach ulcers, cardiovascular problems and nervous complaints. Shiftwork also imposes restrictions on social and home life.

Individual differences can play a factor in a worker's adjustment to shiftwork and for a few individuals working irregular hours poses few if any problems.

**e) Minimising OHS Problems**

It is important to minimise any OHS problems that are associated with shiftwork by:

- Reducing consecutive night shifts where possible, with a maximum of three 8-hour or two 12-hour night shifts a week
- Rapidly rotating shift rosters, with shift changes every two to three days. These are preferable to slow rotating rosters
- Forward rotating rosters (day-afternoon-night) are preferable to backward rotating rosters (night-afternoon-day) as they cause the least disruption to the body's circadian rhythm
- The adoption of compressed work weeks. These have benefited shift workers in some workplaces
- Identification of individual coping strategies. These lessen some of the adverse effects of shiftwork experienced by many workers. Examples of these strategies include physical exercise regimes prior to sleep periods

**f) Importance of Uninterrupted Sleep**

A problem for many shiftworkers, especially those with young families, is getting enough uninterrupted sleep during the day after working a night shift.

Shiftworkers should try and ensure that:

- Unwanted noise is controlled eg: unplugging the telephone and restricting noisy activities in the home such as vacuuming
- The bedroom is free from direct sunlight through the use of curtains or blinds
- Heavy foodstuffs and alcohol are avoided before sleep
- A regular sleep routine is established

**g) Advantages of Shiftwork**

For some individuals there are advantages to performing shiftwork as workers do not need to commute to work during peak travel times. Commuting time to and from work can be reduced and shift workers are able to pursue hobbies and other interests and undertake family commitments during daylight hours, although this may be at the expense of sleep.

**h) Compressed Work Weeks**

One alternative to the traditional shiftwork pattern is the adoption of compressed work weeks. These involve the use of a set block of shifts of increased length, usually of 10-12 hours duration, offset by a reduced number of work days and with blocks of three to four days rest.

Compressed work weeks can be useful to the individual as they contain shorter blocks of shifts, fewer successive night shifts, and increased blocks of free time including weekends.

Conversely, compressed work weeks involve additional working time per shift, possibly leading to fatigue that could affect performance.

Extended work hours may also adversely affect an individual's health and recovery may be prolonged for a worker after completing a block of 10 or 12-hour shifts.

The adoption of compressed work weeks has benefited shiftworkers in some industries through increasing their recreation time, improving the quality and duration of sleep and through improving their physical health and wellbeing. However, this is not always the case. Each workplace and workforce is unique and will require shift rosters that suit their particular requirements.

### 2.3.10 Rest and Work Breaks

Everybody needs to rest for some part of any 24-hour period. How much rest is needed and what form it takes varies widely between individuals and will depend on the intensity of activity in the preceding hours.

Sixteen hours in a 24-hour cycle is the normal period of wakefulness for humans. Beyond this point the body's processes increasingly promote sleep. If work is continued beyond 16 hours substantial performance impairment is observed particularly with respect to attention lapses.

The following is a guide to the average amount of sleep required by individuals. However, some people can do with less, others may need more:

- No less than 5.5 hrs sleep in each 24 hours
- No less than 49 hrs sleep in each week
- No less than 210 hrs sleep in each month ie: No less than an average 7.5 hrs sleep per day

Work by its nature is tiring. During a work day most people need to take regular rest breaks in order to complete eight hours of work without excessive fatigue and the increased risk of injury or illness.

**a) Work Pauses**

Work pauses are additional, spontaneous breaks not incorporated into the job structure but taken by all individuals in the course of a day. They are not the normal fixed breaks in a working day such as lunch but may be breaks between tasks or a change in routine. They are essential because they delay the onset of fatigue by allowing the body to recover from physical or mental work.

**b) Work Breaks**

If intensive physical and/or mental work constitutes a significant part of a person's workload during the day it may be necessary to for them to take breaks in addition to the normal lunch and personal breaks.

There is no easy way to determine how long breaks should be to ward off the effects of fatigue at work, even for someone who is undertaking specific tasks. Therefore many work systems now incorporate set breaks to allow for mental and physical recovery. These are usually about 5-10 minutes within each hour for moderately demanding work.

In general the length and type of break will depend on how hard the work is, the age and fitness of the worker and environmental conditions such as heat and humidity. Too short a break may lead to progressive or cumulative fatigue. (See also Fatigue in Section 2.2.6.)

Employees are usually best placed to determine for themselves when a break should be taken and how long it should be. However, workers often have to be encouraged to pause from work even when they are tired and they must be actively discouraged from accumulating breaks.

As work demands sometimes do not allow this to happen, care must be taken not to impose too demanding a work schedule with insufficient breaks. Consultation with employees who do the work should be undertaken before fixed work-rest schedules are finalised. Ongoing monitoring should be carried out to ensure that the breaks are appropriate. (See also Repetitive Work in Section 4.2.)

To estimate reasonable rest allowances in physical work it is necessary to examine the load and work rate against the number of hours the work is carried out during a work shift. There are guidelines on rest allowances for jobs such as heavy, physical work involving manual handling and work where safety is critical eg: airline pilots. However, care is needed when using these guidelines as risks arising from fatigue may be underestimated. As a general rule, the number and duration of rest allowances must increase as the load and/or the intensity of work increases.

Exercises may be useful in reducing the damaging effects of repetitive or sedentary tasks or work in fixed or awkward postures. However they need careful planning and supervision.

## 2.4 DEVELOPING AN ERGONOMICS STRATEGY AT WORK

### 2.4.1 Culture of an Organisation – Commitment and Decision-making

Organisations are systems and they are made up of sub-systems acting together to meet the objectives of the organisation. Systems are the structures that underlie complex situations. A system can be considered to be a set of interrelated and interdependent parts arranged so that it appears to be a unified whole. Organisations themselves are sub-systems within society. The design and management of organisations has a very powerful effect on the safety and health of people at work.

The size and complexity of an organisation is often baffling and intimidating for individuals within it. Understanding what constitutes a system, how it works and how and why decisions are made can help individuals become more active in the process of change and development.

**a) Managing Change**

In the developed world change is a feature of most workplaces. As a result ‘change management’ is a term commonly used to denote a special approach to the way changes are handled in an organisation. Change is difficult to manage because normal human responses are subject to personal and emotional influences as well as rational, logical ones.

No matter how good the technology, how wide the debate, how clear the arguments, individuals will not always agree with the experts about the benefits of change - whatever form they take. Responses will vary depending on the age, sex, education of the person and a range of other personal and social factors. What works well in one location for one group may not work in another. These issues need to be recognised as a barrier to change and managed. Therefore designers and decision-makers must take care not to impose change without adequate consultation or to transfer technology and systems from one workplace to another without a proper analysis of local requirements and limitations.

It is unreasonable and counter-productive to be too prescriptive in an approach to solutions for recognised and foreseeable problems. This tends to blunt imagination and discourage local, more appropriate solutions over the long-term. If general principles of good task and workplace design are understood and applied, and peoples’ local needs are given adequate consideration when planning the system, the basic mismatches and obvious problems can be avoided.

More specialist ergonomics input becomes necessary as the complexities of the systems increase and as the need to contain costs and to reduce errors and wastage becomes more critical. System reviews are essential to ensure that changes are working and to rectify outstanding problems.

Essential elements to successful change management are:

- Careful and iterative planning moving from generalised goals to more specific and concrete objectives
- Commitment to the change by the most senior managers
- Involvement of and participation by stakeholders (individuals or groups who will be affected by the change)
- Knowledge and communication including adequate feedback
- Incentives for individuals to change
- Support by managers and fellow workers

**b) Consultation and Feedback**

Consultation with workers is considered a necessary part of the organisation of work and is encompassed in some OHS legislation in Australia. It can be defined as the sharing of information and the exchange of views between employers, employees and their representatives. It includes worker participation in identifying and solving problems, in decision-making and in obtaining feedback from workers on the success of programs and interventions. It is an active and inclusive process and needs to be systematically practiced in order to gain the benefits.

Feedback and communication are necessary for effective worker participation. The process takes time and can be difficult to establish if workers are not used to making decisions and solving problems.

An essential component of a safety program is feedback to and from workers. Where there is a steady flow of information on progress, hurdles and developments workers respond better than when this information is absent.

Effective communication is central to all efficient management systems and in order to be effective it must be optimised. Too much information, particularly if it is of marginal value, bogs people down and they may opt out by ignoring all communications.

Too little information and employees can feel left out and resentful. Information that comes down through an organisation's hierarchy should be matched by information that goes up. Its impact will be related to its need-to-know qualities. (See also Risk Management, Section 3.2.)

### 2.4.2 Macro-ergonomics and Participatory Ergonomic Teams

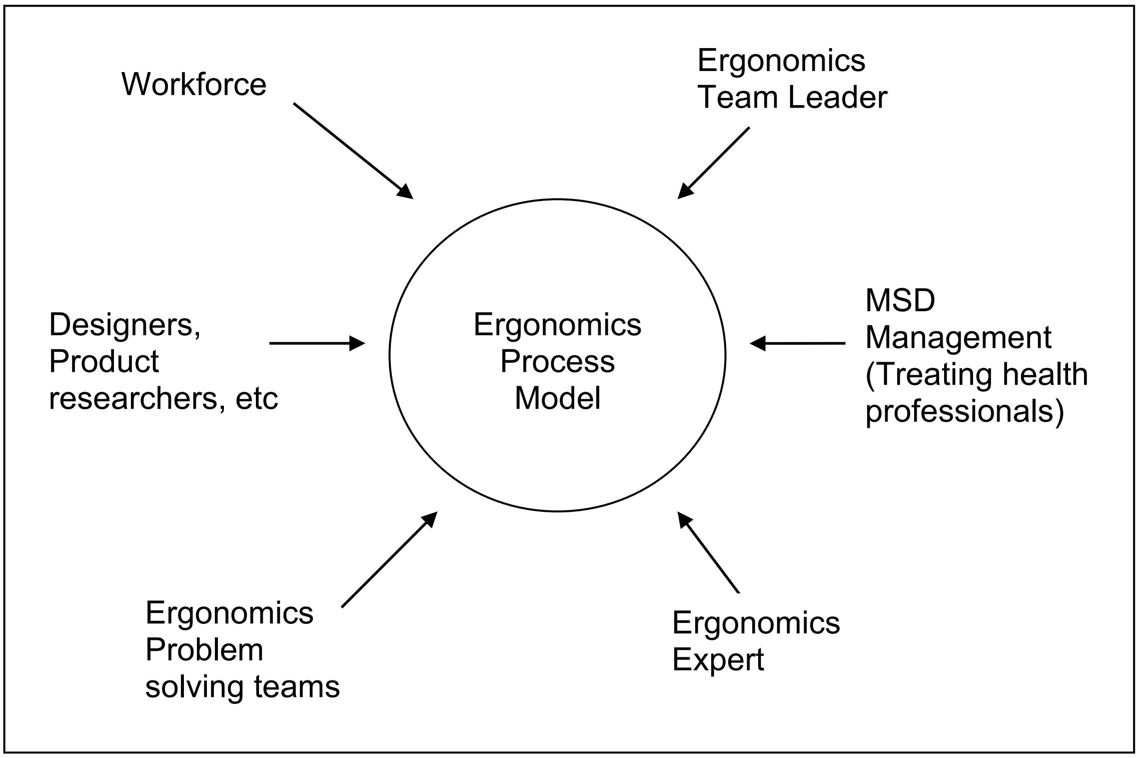
Solving ergonomics problems involves improvements at various levels within a system. Local ergonomics solutions (microergonomics) often cannot be properly implemented because of wider issues. To be effective today's systems require people to be involved in implementing changes including ergonomics solutions if they are to be really effective. This is also required by some occupational health and safety (OHS) legislation.

Systems ergonomics is also referred to as organisational design and management (ODAM) or macro ergonomics. It tries to examine the whole picture. It attempts to look at problems and issues in the perspective of the overall system so that it achieves effective and lasting change.

The macroergonomic approach allows an organisation to examine the root causes of ergonomic issues, rather than reacting to microergonomic problems, and as such is a comprehensive ergonomic method.

Participatory ergonomics teams can be formed within organisations to address macroergonomic issues. These teams are formed using employees from all levels and units of an organisation to address macro and micro ergonomics issues with the view to making good ergonomics part of the overall business strategy. This type of team demonstrates the organisation's commitment to the role of ergonomics within the business/organisation and requires effective systems, teamwork training and communication methods. Additionally, participatory ergonomics teams facilitate a process of continual improvement leading to strategic use of the teams within and across the business/organisation.

The diagram below shows a participatory ergonomics process model linking various key players and business units within an organisation.




(Source: UOW: Adapted from Kodak's Ergonomic Design for People at Work, 2004)

***Figure 2.21 – Participatory Ergonomics Process Model***

### 2.4.3 Ergonomics at the Design Stage

Design of equipment, workplaces and systems of work require design to ergonomic specifications as well as the production of the output. Ergonomics is about designing for the user population, but also to consider the potential population that may access the workplace. A good example of this is the consideration of wheelchair users when designing door widths and accommodating the needs of the ageing workforce given the foreseen increase in older workers in employment into the future. Workplaces, equipment and work environments that are designed for a greater range of people to use provide greater flexibility in terms of who can effectively operate in that environment. In other words, we need to design for the greatest percentage of the population, see Section 2.5.5.

However, even with the best design process, unforseen issues may arise. To overcome this, the process of trials, mock-ups or prototypes is undertaken in order to consult with the user group and make modifications based on the feedback.

This area will be addressed further in Section 3, Ergonomics Methods and Techniques.

### 2.4.4 Developing Ergonomics, Professional Ergonomists and Competence

The peak ergonomics body is the IEA (International Ergonomics Association). This association has on overarching aim of promoting the knowledge and practice of ergonomics through initiatives and cooperation of its federated societies around the world. The IEA lists its goals and objectives as:

- To develop more effective communication and collaboration with federated societies
- To advance the science and practice of ergonomics at an international level

- To enhance the contribution of the ergonomics discipline to global society

In order to fulfil these objectives, the "IEA establishes international contacts among those active in the field, cooperates with international organisations to facilitate the practical application of ergonomics in industry and other areas, and encourages scientific research by qualified persons in the field of study and practice." (IEA 2008)

The IEA has established a number of technical committees working on key ergonomics issues across the globe, and lists these as:

- Activity Theories for Work Analysis and Design
- Aerospace HFE
- Affective Product Design
- Aging
- Anthropometry
- Auditory Ergonomics
- Building and Construction
- Ergonomics for Children and Educational Environments
- Ergonomics in Design
- Gender and Work
- Healthcare Ergonomics
- Human Aspects of Advanced Manufacturing
- Human Reliability
- Musculoskeletal Disorders
- Organisational Design and Management
- Primary Industries
- Process Control
- Psychophysiology in Ergonomics
- Quality Management
- Safety & Health
- Slips, Trips and Falls

- Work With Computing Systems - WWCS

While the IEA does not act as an accrediting or licensing body, it does have a set of criteria and procedures for assessing and endorsing professional certifying bodies and programs around the world – the Criteria for IEA Endorsement, 2001. Additionally, the IEA has a series of competencies for Ergonomists and guidelines for accrediting tertiary education programs (within member societies/associations). A list of the guidelines and criteria is set out below:

- International Directory of Ergonomics Programs
- Core Competencies in Ergonomics: Introduction
- Summary of Core Competencies in Ergonomics
- Criteria for IEA Endorsement of Certifying Bodies
- Guidelines for Process of Endorsing a Certification Body
- Guidelines on Standards for Accreditation of Ergonomics Education Programs at Tertiary (University) Level
- IEA Code of Conduct for Ergonomists (COCE)

Each member organisation around the world has various methods of accrediting or certifying Ergonomists in their own country. For example, the USA, Canada and New Zealand have a certification process, Britain and Australia a Professional Affairs Board which analyse applications for Fellow of the Society and Certified Professional Ergonomist respectively.

A detailed description of the certification process and approaches can be found in “Fundamentals and Assessment Tools in Occupational Ergonomics” 2006, Chapter 1, by Jahns.

### 2.4.5 Seeing the Whole Picture

As most people realise disorders arising from work can have a number of causes and they are not always obvious. Organisations are complex and people are too. For instance we now know that physical disorders may not arise purely from physical stresses. Psychological and social factors can contribute to the development of symptoms in some individuals at particular times. In order to understand these issues we need to examine the work and its organisation more broadly and understand how various work factors may interact with each other and how personal factors might change the impact of work factors.

In occupational ergonomics, the physical design aspects of work or the 'hardware' may be only part of the problem and therefore part of the solution. In some cases it may be a small part. Other factors influence the development of a problem including work organisation and task design, job content, work demands and control over workload, support and training. Usually these aspects require ergonomics to be integrated into the broader work systems.

Therefore to determine if an optimum solution has been achieved the people who will perform the work (the 'who'), the nature of the tasks (the 'what') and the context in which they are done (the 'where', 'when' and the 'how') need to be considered.

# 3. ERGONOMICS METHODS & TECHNIQUES

This topic describes methods which can be used to facilitate good ergonomics practice; as well as methods to identify and investigate poor ergonomics practice and improve the work system and its elements to promote human comfort and productivity.

## 3.1 WORK DESIGN

### 3.1.1 Allocation of Functions

When designing an overall system or process, the design team need to decide on the best way to allocate system functions, jobs and tasks to human or automated components. To do this effectively, the design team needs to understand the capabilities of humans and machines and allocate components effectively. This process is known as sociotechnical allocations (Clegg et al., 2000), function allocation (Hollnagel, 1999), or allocation of system function (Chapanis, 1970); (cited Stanton et al, 2005).

Various methods for deciding on allocation of functions can be used. Stanton et al (2005) provide the work of Marsden and Kirby (2005, p 34-2), who discuss tables of relative merit (TRM) or Fitts list (after Fitts, 1951, who developed the list while designing automation of air-traffic control tasks), psychometric approaches, computational aids, and the hypothetical-deductive model (HDM) (Price, 1985). Following a review of the tools, Marsden (1991) states the HDM model is the most appropriate, and consists of the following 5 distinct stages:

| HDM Model Steps | Purpose |
|---|---|
| 1. Specification | System requirements outlined |
| 2. Identification | System functions identified and defined by describing the inputs and outputs of the system components |
| 3. Hypothesisation | Specialist design teams propose solutions |
| 4. Testing & Evaluation | Run experiments, gather data to analyse utility and function of system |
| 5. Optimisation of Design | Make improvements as a result of step 4 |

When designing systems, and deciding whether or not a function should be either automated or performed by a human, there are three possible function outcomes:

1. Functions that must be carried out by machines
2. Functions that must be carried out by humans
3. Functions that could be carried out by humans or machines, or a combination of both

For Ergonomists, this last category is the one of interest, as the capacities and limitations of the human in the system are of the paramount importance. A myriad of factors need to be considered, covering the spectrum of the 3 domains of ergonomics, physical, cognitive and organisational.

Marsden and Kirby (2005) have also developed their own model for analysing allocation of functions, and set out a series of procedures as follows:

1. Define the task under analysis
2. Conduct a Hierarchical Task Analysis (see next section for description).
3. Conduct stakeholder analysis for allocation of functions – satisfaction or dissatisfaction with the proposed changes
4. Consider human and computer capabilities – decide whether each final task should be allocated to human only (H), computer only (C), human and computer with human in control (H-C), or computer and human with computer in control (C-H)
5. Assess the impact of allocation of function on task performance and job satisfaction, (potential for error, cognitive load, cost, time taken, etc)

### a) ISO 6385, 2004: Ergonomic Principles in the Design of Work Systems

The International Standard (ISO) 6385, Ergonomic principles in the design of work systems, summarises all these approaches into the following phases, emphasising that the process of work system design is iterative and ongoing, ie: likely to have a number of designs as the process of analysis, synthesis, simulation and evaluation continually take place. The 6 phases outlined in the standard are:

1. Formulation of goals (requirements analysis).
   Identification of relevant ergonomic issues through studies, or statistics, focus groups etc.

2. Analysis and allocation of functions
   Determining the technical and human capabilities and limitations.

3. Design concept
   Carry out a hierarchical task analysis (see next section); conduct simulation, scale model mock-ups, user trials and interview/discussion.

4. Detailed design
   Design of work organisation; jobs; work tasks; work environment; equipment (hardware and software); and design of workspace/workstation.

5. Realisation, implementation and validation
   Planned, documented, staged introduction of new system with adequate and appropriate consultation/training with the user group; ensure system is ‘validated’ – ie that it is working well and does not cause any ergonomic issues for the users.

6. Evaluation

Review whole process (steps 1-6) to use as a learning experience for the organisation. Evaluation should include the 3 categories of worker health, safety and performance as outlined in the table below.

***Table 3.1 - Evaluation Techniques for System Design***

| Category for Evaluation | Suggested Evaluation Techniques |
|---|---|
| Worker Health & Well-being | Medical/physiological measures (eg: heart rate monitoring)<br>Subjective measures (eg: job satisfaction survey)<br>Psychological measures |
| Safety | Reliability measures<br>Errors<br>Unsafe behaviour<br>Near-misses<br>Accidents |
| Performance | Quality<br>Quantity<br>(Cost benefit analysis) |

(Source: UOW - Adapted from ISO 6385 2004)

### 3.1.2 Task Analysis

The first step in determining allocation of function is to undertake a Hierarchical Task Analysis (HTA). Firstly, specification of the system purpose is undertaken, identifying the tasks to be completed to fulfil system function/purpose. (This is a high level task analysis, and should not be confused with the task analysis undertaken by Ergonomists for reviewing job components by breaking the job into individual tasks.)

Each task/system component is identified along with the goal of that component. Subtasks are then determined and in turn these are broken down into smaller subtasks until they cannot be broken down further.

Plans can be

- Linear: do 1, then 2, then 3
- Non-linear: do 1, 2, 3 in any order
- Simultaneous (or concurrent): do 1, then 2 and 3 at the same time
- Branching (or choice): do 1, if Y is present, do 2 then, 3; if Y is not present, exit the system
- Cyclical: do 1, 2, 3 and repeat until Z is achieved
- Selection: do 1, then 2 or 3

Table 3.2 shows the different plan types with three notation conventions.

***Table 3.2 – Different Plan Types & Three Notation Conventions***

| Type of Plan | Types of Notation |
|---|---|
| *Linear*<br>Sequential plan | 1>2>3>4<br>1 then 2 then 3 then 4<br>Do in order |
| *Non-linear*<br>Non-sequential plan | 1/2/3/4<br>N/A<br>Do in any order |
| *Simultaneous*<br>Concurrent plan | 1 + 2 + 3 + 4<br>1 and 2 and 3 and 4<br>Do at the same time |
| *Branching*<br>Choice plan | X? Y>2 N>3<br>If X present then 2 else 3<br>Do when required |
| *Cyclical*<br>Repetitious plan | 1>2>3>4>1…<br>1 then 2 then 3 then 4 then repeat from 1 until<br>Repeat the following until |
| *Selection*<br>Exclusive plan | 1:2:3:4<br>1 or 2 or 3 or 4<br>Choose one of the following |

(Source: UOW – Adapted from Stanton, 2006, p.65)

A simple example could be making a cup of tea; a complex example, landing an aeroplane. Two examples are provided here - a research example from an HSE report into design of hospital rooms for bariatric patients. This task analysis was part of an experiment to determine functional space requirements (HSE 2007), and an example of supervision of an underground railway system.

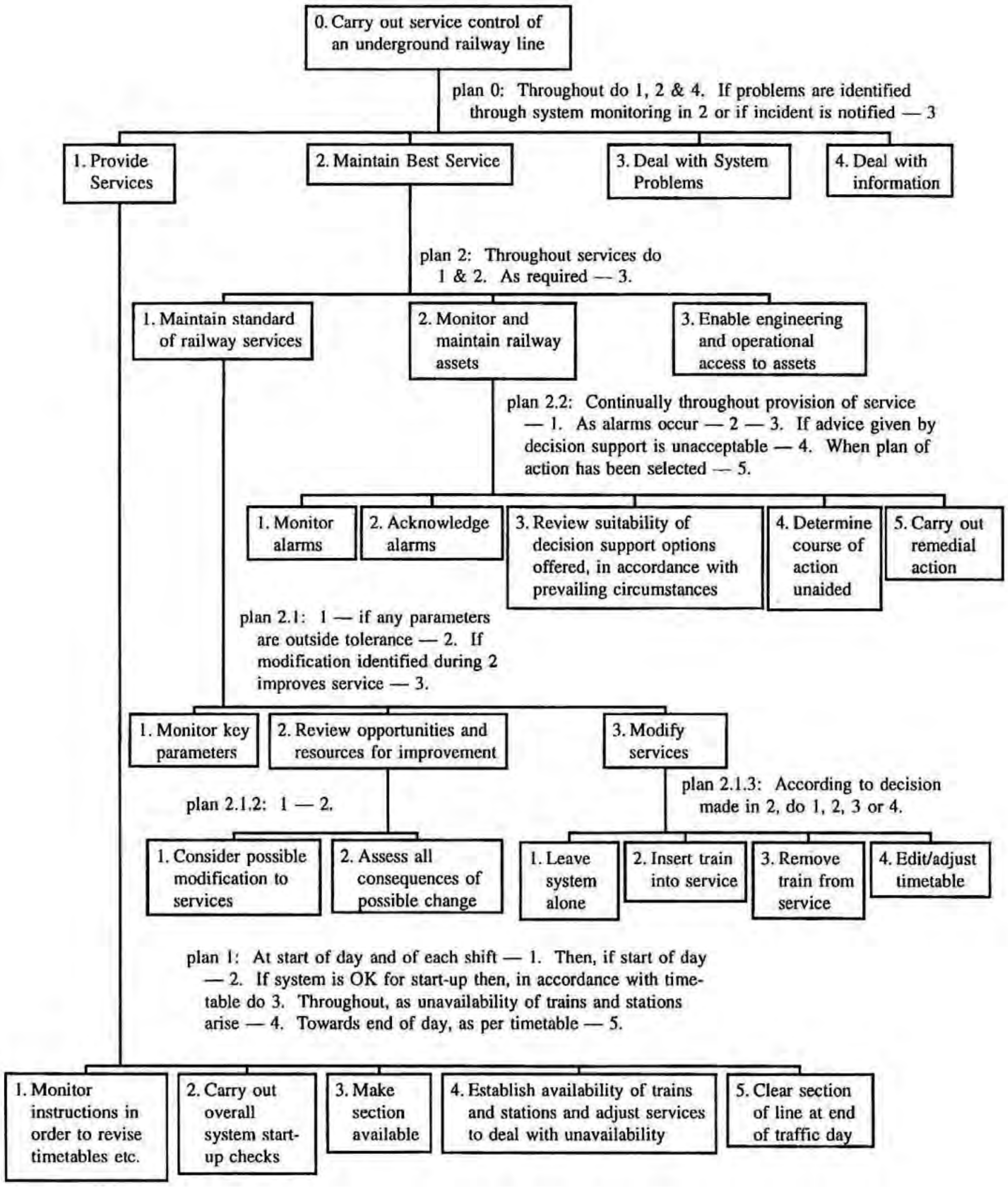
| Task 1: Transfer from chair to the Contoura 1080 bed using Likorall hoist and sling | |
|---|---|
| Start position: | Patient sitting in chair |
| Task: | Insert sling behind patient using sliding sheets |
| | Attach the sling to the hoist |
| | Lift the patient using the hoist |
| | Transfer across to the bed |
| | Remove sling from patient |
| Stop position: | Patient on bed |

| Task 2: Resuscitation | |
|---|---|
| Start position: | Sitting position on the Contoura 1080 bed. |
| Task: | Participants enter room and lower bed using CPR button |
| | Bring in crash trolley and perform resuscitation. |
| Stop position: | Conclusion of resuscitation |

| Task 3: Lateral transfer from the bed to transfer chair using pat slide and sliding sheets | |
|---|---|
| Start position: | Sitting position on the Contoura 1080 bed. |
| Task: | Prepare patient for lateral transfer using slide sheets and a pat slide |
| | Collect and set up transfer chair in bed space |
| | Attach patient to transfer trolley |
| | Transferred patient on to the transfer chair |
| Stop position: | Patient on transfer chair |

(Source: HSE 2007 – *Reproduced with permission*)

***Figure 3.1 – Tasks for Bariatric FSE***




(Source: Annett & Stanton, 200, p.17 –reproduced with permission)

***Figure 3.2 – Part of an HTA of supervising an underground railway system***

From an ergonomics perspective, the aim of job or task design is to provide interesting, worthwhile work that in turn improves productivity and efficiency though reduced injuries and ill health, absenteeism, employee turnover and social stress.

When considering allocation of functions, task design and how the work is organised may be as important as hardware solutions such as better-designed furniture or job aids. There are a number of methods that can be used to improve the design of work including broadening and varying tasks, increasing responsibilities (job enlargement/enrichment), allowing control over work and encouraging social contacts.

Problems with computer work may be overcome by a more efficient arrangement of work and more appropriate software design as well as improved information displays and better designed furniture. Manual handling problems may be solved by either rearranging the job and eliminating the handling rather than installing a manual handling aid.

### 3.1.3 Work Organisation Factors to Consider in Allocation of Function

#### a) Fragmentation of Work

Over the last few hundred years there has been a tendency to reduce the complexity and to increase the repetitiveness of some types of work. This is referred to as the fragmentation of work or Taylorism. It describes production methods devised by Frederick W Taylor who was an early methods study expert. Complex jobs are broken down into simpler components each of which requires relatively little training and which an individual worker repeats. This approach was considered more efficient by some and was adopted in the earlier part of the 20$^{th}$ century by large manufacturers for production lines eg Henry Ford. This has spilled over into jobs in white-collar industries such as banking, insurance, and finance and increasingly into industries such as mining.

However, while there were perceived benefits to this approach a downside became more evident as the protection of workers' health and safety was given greater emphasis. Physical health problems particularly emerged as efforts to increase efficiency further were unsuccessful. People have physical and mental limits at work.

These limits vary enormously between individuals and workers' health and safety can be compromised where these limits are not understood and taken into account when work is designed.

**b) Task Variation**

In contrast to the perceived benefits for production many OHS recommendations advise strongly against the fragmentation of work and are in favour of task variation or multi-skilling. This is desirable for the prevention of many occupationally related disorders because it reduces constant exposures a range of both physical and psychological hazards.

Task variation can be achieved in three ways: through job enlargement, job rotation or the use of self-directed work teams:

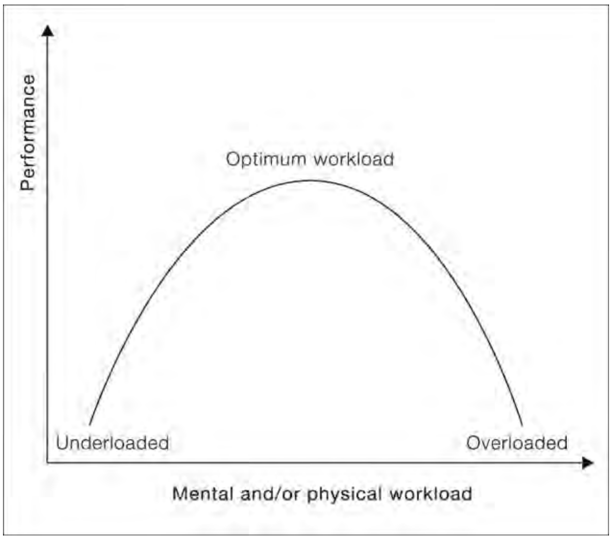
1. Job enlargement (enrichment): Increasing and varying the job content either by adding tasks or adding complexity to tasks. Broadening and enriching jobs in this way allows people to move through a succession of different jobs, each of which make different demands on the person's abilities. This encourages employees to reach their potential over time. It is a much more acceptable alternative for providing variety, but requires careful planning and longer training periods
2. Job or task rotation: Moving workers from one component task to another to bring variety to work although the job remains unchanged. It is a ready way of spreading the load of stressful jobs among a large group of employees, but it does have drawbacks. It is effective only where jobs are different enough to provide physical and mental variety. Many employees do not like rotating for a number of reasons, even when it is in their best interests to do so. It can be disruptive and time-consuming and workers may need to do tasks they do not like and are not good at.

Also, job rotation can mask the real causes of the problems and may only extend the period before problems eventually arise. Employees have to learn more skills and thus require more training and supervision

3. Self-directed work teams: More worker participation than the methods described previously. Workers are organised into groups and the planning and organisation of the work and responsibility for the end product may be delegated to them. Theoretically it gives people more control over the whole process rather than just over parts and encourages a much broader view of the job. This can be rewarding both for the company and the employees but it requires considerable time, training and investment in employees.

**c) Workload**

The individual's performance of a task can vary with the workload required. At extremely low levels of workload boredom may set in resulting in missed signals and a poor performance. Medium levels of workload are optimal and performance remains high, however further increases in workload may result in overload and a marked decline in performance.




(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 3.3 – Relationship Between Workload and Work Performance***

Workload can refer to both physical workload and mental workload (sometimes called cognitive load). Mental workload is the amount of cognitive processing required by an individual during the performance of a task.

Mental workload is affected by numerous individual and environmental factors that will affect an individual's ability to complete required tasks.

These factors include:

- *Individual*: Level of fatigue, stress and boredom/ arousal, training, skill level, prior experience, motivation level, perceived difficulty of task and accuracy needed for the task, type of task and if there are any time constraints will all affect an individual's ability to perform a task.
- *Environmental*: Level of illumination and noise, temperature, design of the workstation and human-machine interface.

**d) Under-Load and Overload**

When designing tasks to avoid both under-load and overload worker consultation is required as no two people are the same. If individual workers are to achieve greater productivity intensive training and a high level of worker support may be required.

**e) Job Satisfaction**

Job satisfaction refers to an individual's general attitude or feelings toward their work and work experiences. There can be major differences in job satisfaction between individuals and even between individuals performing the same job. An individual's level of job satisfaction is often interrelated with other aspects of the job, including work conditions.

There are three main areas that contribute towards an individual's experience of work satisfaction:

1. *Organisational aspects*-- Include incentives such as income; possibility of promotions; ability to be involved in decision-making; appropriate supervision; and the match between job expectations and reality.

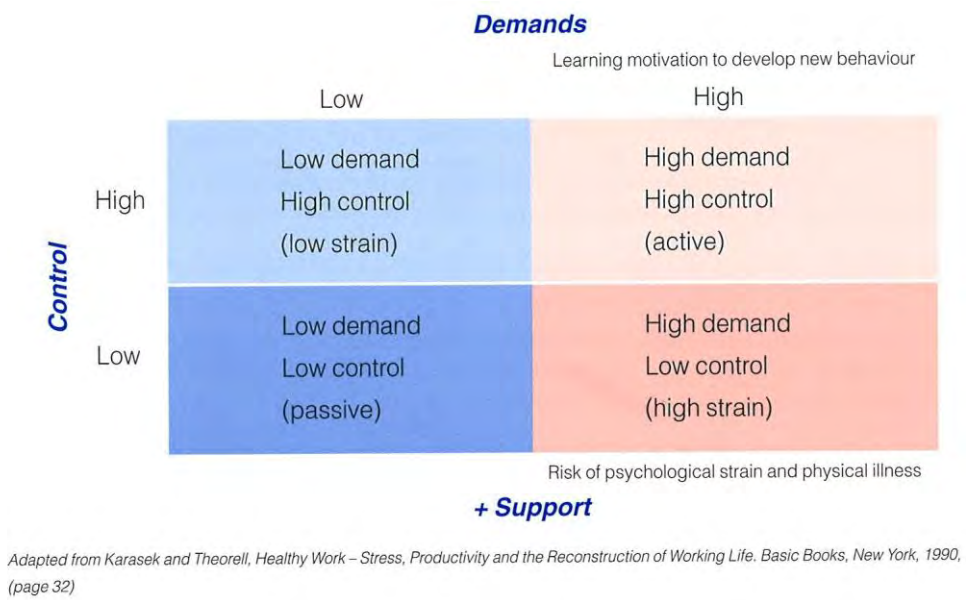
2. *General work aspects* -- Include workload; appropriate skill and task variety when performing work; significance of task performed to overall work outcome; autonomy or decision latitude in the job; appropriate feedback on work performance; and a suitable physical work environment.

3. *Personal characteristics* -- Including level of ability to perform work tasks; appropriate levels of experience; stress and coping abilities; general levels of self-esteem; personality; job expectations; and general life satisfaction.

Most people would like to believe that the work they do is of value and that when they work they are productive, efficient and produce high quality work (quality, quantity and time). Very few people achieve this consistently because they work in human designed (and therefore imperfect) systems. However, each person should be able to expect a safe and healthy job, with reasonable conditions of employment and reasonable remuneration or other reward.

**f) Work Demands and Job Control**

Job demands need to be balanced with a degree of control by the worker over how the work will be done. Those employees who have high demands placed on them but who have little job control (decision latitude) are the most likely to be at risk of developing psychological or physical disorders. This is illustrated in the following diagram. (Employees who have low demand and low control are by definition in a passive position.)




(Source: McPhee 2005, Adapted from Karasek and Theorell, Healthy Work - Stress, Productivity and the Reconstruction of Working Life Basic Books, New York, 1990, (page 32) – *Reproduced with permission)*

***Figure 3.4 – The 'Karasek' Model of Job Demands/Job Control***

Conversely those who have high demands and a high degree of control over how they meet those demands contribute to high levels of motivation, learning and new behaviours.

**g) Support**

A modifying influence in the demands versus control theory can be support. It is argued that support, or the lack of it, can either reduce or magnify the effects of problems at work.

Supporting people at work by developing their skills, minimising their weaknesses and helping them to cope with life stresses is part of good management. Managers need to understand the strengths and limitations of different types of technology and workplace design and how the limitations of some systems may lead to problems for users. This means full consultation with the people who will be doing the work from the start of the design phase through to the ongoing performance of the system.

People need consistent and adequate support throughout the design and implementation phases of new systems. Workers need to participate fully and provide feedback to designers and managers. Help desk services need to be appropriate and effective for the technology. People, especially older workers, need to learn by doing and to gain confidence with new systems. Managers need to keep a user focus and continually re-appraise and fine tune. Support must be kept going when the system is up and running especially for the crisis times - either at work or in individuals' personal lives.

### 3.1.4 Problems Arising from Poor Work Design

#### a) Sedentary Work

Prolonged sedentary work is becoming more the norm in workplaces everywhere and occurs mainly in offices, transport and manufacturing. While sitting all day is preferable to standing a combination of sitting and standing is the most desirable as it provides the necessary postural and physiological variation normal for human beings.

Design of work must allow for these postural variations and should improve levels of alertness and wellbeing. Many work places have introduced task rotation and exercise programs to overcome the possible harmful effects of sedentary work that include back pain, occupational overuse syndrome (OOS), problems for the digestion and circulation in the legs. However, these strategies are less effective than work with inbuilt variation.

#### b) Computer Work

More and more jobs involve work with computers and input devices such as keyboards and the mouse. Most people find the computer is an invaluable tool when used intermittently throughout the day. Problems arise for some people however when computer work becomes the total job as it may be physically repetitive and undemanding mentally.

In some cases computer work requires long hours of absorbing and intensive mental work so that the user is oblivious to time and physical and mental fatigue. Both these types of jobs can lead to physical problems such as OOS, eye fatigue and headaches.

It cannot be predicted accurately who will develop symptoms in high demand/low control jobs but theoretically all who do this sort of work are at risk. Given this, the two most important strategies for preventing problems lie in task design:

1. Keyboard output and skill levels are attainable by all keyboard operators within each job.
2. Deadlines are realistic for everyone and allow adequate breaks.

Some peaks and troughs can be expected but prolonged periods of either high intensity work or underload (more than a day or so) can precipitate problems in some more vulnerable people. If job demands continually outstrip the capacity of all or some groups to meet them, then some urgent reassessing will need to be done.

Computer training needs to match the needs of individuals, and the demands of and skills required by the job and the technology. It must be timed to match the introduction of the equipment and allow people time to learn. Appropriate support for people while they are learning is essential.

Ultimately work groups should be able to reassess their situation regularly to see if changes need to be made. The ability to control work demands at a manageable level for the individual and the group and problem identification and solving by a work group is very important.

### c) Repetitive Work

Repetitive work may involve repeated muscle activity involving the use of the same muscles in a range of apparently different movements or using different muscles in repeated movements that look similar. Sometimes this can lead to injuries. An injury may mean that the same activity is done completely differently after the injury and this is referred to as favouring the injured part, which could lead to further injuries.

Repetitive work processes are often described as monotonous and boring, with individuals performing this type of work often experiencing dissatisfaction. Such occupations may involve responding to intermittent signals eg console operation or require simple, repetitive movements eg factory process work.

Research has found that individuals who perform short repetitive tasks tend to make more errors than employees performing varied tasks, largely because the nature of repetitive work has the effect of decreasing an individual's level of cognitive arousal. Different individuals will experience different responses to repetitive work. A few will enjoy the routine nature of repetitive work and find this type of work relaxing, straightforward and free from responsibility. Others will seek greater mental stimulation.

Very simple and repetitive jobs can be automated and performed by machines, although certain repetitive jobs may still require the flexibility of human workers to perform them.

When repetitive work cannot be automated, it is important that job or task rotation or job enlargement be used to diversify the workers' activities, limit physical overuse symptoms and avoid boredom by incorporating more variety into the work.

### 3.1.5 User Trials

The primary concern of ergonomics is to design for the end user. The term 'user centred design' is often used in the Human-Computer Interface (HCI) and industrial design context, but can be applied across all domains of ergonomics application. User trials are often used to test equipment, products or devices with the potential user group. The purpose of the trial is to review and improve the design of the product by asking the potential end user their views and observe their interaction with the device.

Stanton et al. (2005, p.475-6), suggest 13 steps to undertake a user trial as outlined below. (Steps 14 and 15 have been added to complete risk management process).

1. Define purpose of the user trial – specify the outcomes of the trial – what are you really trying to assess
2. Define the task being undertaken in the trial – ensure that the task(s) being undertaken represent the range of functions the tool/device is designed for
3. Breakdown the task using a Hierarchical Task Analysis (HTA described in Section 2.1.1); this can form the procedure for the trial (next step)
4. Develop procedural list for the task(s) – ensures correct procedure and sequencing
5. Select User Trial participants - ensure representative of user population
6. Inform participants of trial purpose, and device/tool under examination.
7. Demonstrate task(s) – encourage interaction and questioning by participants
8. Execute trial
9. Measure with appropriate tools – questionnaire, workload assessment, etc
10. Interview participants
11. Debrief procedure

12. Analysis of data
13. Collate recommendations to improve design
14. Make design improvements
15. Re-test until achieve acceptable performance (criteria for performance being established in initial phases of trial)

User trials have a number of advantages and disadvantages. The most obvious advantage is that of gaining feedback from the ‘real users’ of the product/tool/device or system; the main disadvantage is that it is time consuming. However, making changes to a system or product once it is commissioned is far more costly than investing in good user trials before installation and understanding the issues and correcting them prior to commission or manufacture.

### 3.1.6 Problem Solving – Scientific Method

Ergonomists are usually called in to an organisation as a result of a problem – injuries arising from particular tasks, or difficulties with the human-equipment interface. Often then, the Ergonomist is in fact tasked with ‘retrofitting’ – either equipment, or process. In this role, the Ergonomist takes on two approaches, they are both scientists and practitioners.

This combination of roles is sometimes difficult to balance. Stanton (2005) states that as a scientist, the Ergonomist is

- Building on others work
- Testing theories of human-machine interface output
- Developing hypotheses
- Questioning methods and structure of work
- Identifying issues
- Collecting and analysing data
- Ensuring reliability of results

- Sharing results of their work

As a practitioner, the Ergonomist is

- Addressing ‘real-life’ problems
- Optimising the outcome of their intervention, even when it may be a compromise
- Ensuring cost-effective strategies
- Developing a range of trial solutions
- Analysing and evaluating change
- Developing benchmarks for best practice
- Sharing results of their work

Ergonomics methods, from a scientific viewpoint, must be valid and reliable. When determining which method to use, the Ergonomist asks themselves a series of questions (Stanton and Annett, 2000):

- How much depth is required in the analysis
- What data collection methods should be used
- How appropriate is the chosen method
- How best to present the analysis
- How much time/effort does each method require
- How much and what expertise is required
- What tools are there to support the method
- How reliable and valid is the chosen method(s)

The Ergonomist spends a period of time considering the nature of the problem, and what strategy to use to best measure, evaluate and report on that problem; and then how to best implement and evaluate the intervention.

Often systems under investigation are complex and may require a new method or modification of existing methods. In these situations, a pilot study is useful to determine the scope of the issues prior to a fully fledged investigation taking place.

This process can be seen in terms of: determine criteria for assessment; compare methods against the criteria; use the methods; implement ergonomics intervention; and evaluate the intervention as demonstrated in the flow chart below:

Determine criteria to be assessed

↓

Review methods against criteria

↓

Use chosen methods to assess issue

↓

Determine ergonomics intervention

↓

Implement ergonomics intervention

↓

Evaluate intervention

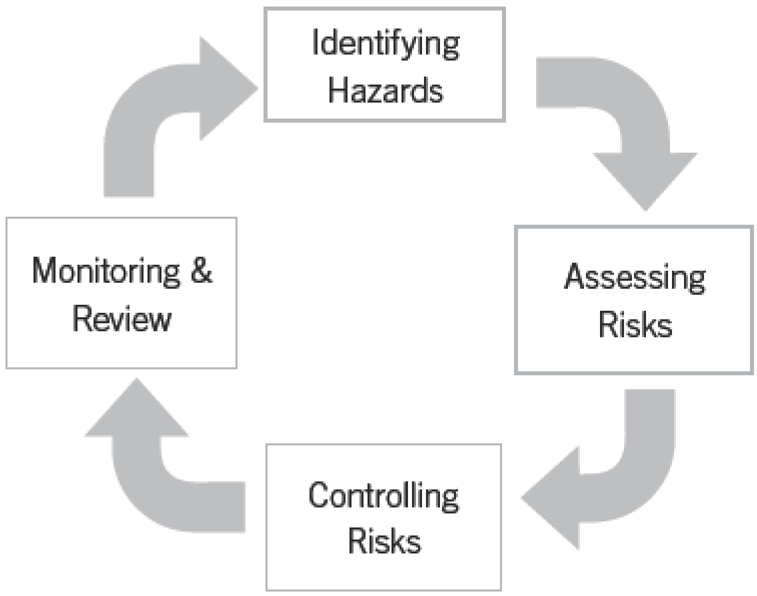
Stanton et al. (2005) reviewed the available ergonomic methods and found over 200 Human factors/Ergonomics methods in the literature, which they classified into the following categories:

1. Data collection techniques
2. Task analysis techniques
3. Cognitive task analysis techniques
4. Charting techniques
5. Human error identification (HEI) techniques

6. Mental workload assessment techniques
7. Situation awareness measurement techniques
8. Interface analysis techniques
9. Design techniques
10. Performance time prediction/assessment techniques
11. Team performance analysis techniques.

## 3.2 ERGONOMICS RISK MANAGEMENT

Risk Management is the process of hazard/risk identification, risk assessment, risk control and re-evaluation. In this topic, we are considering ergonomics risks in the workplace. The terms Risk Management and Risk Assessment are often used interchangeably; however, as a complete process involves identification, assessment, control and re-evaluation, we will use the term risk management in this manual.




(Source: ASCC, 2007 – *reproduced with permission*)

***Figure 3.5 – The Risk Management Process***

The application of the risk management approach for all types of risks is becoming increasingly important to reduce the probability that corporate objectives will be jeopardised by unforeseen events.

The focus is one of positive and directed due diligence rather than negative compliance and for many organisations this is a significant change in direction. Actual standards and legislation for risk management are set by individual nations and or states and territories. All generally require that risks to employee health and safety are managed in order to control those risks.

Risk management involves risk identification, assessment and control and the monitoring and evaluation of controls (solutions). Analysis of risk is at the heart of the risk management process. This is determined from the range of potential consequences and the likelihood (exposure and probability) of their occurrence. It can be as detailed and technically precise as is required by the process or equipment being assessed. However, for the most part, simple methods can achieve reasonable outcomes and the reduction of risks to an acceptable level for day-to day hazards.

Changes to OHS laws in many jurisdictions over the last few years require workers and supervisors to manage their own health and safety risks. Ignoring risks or imposing unsatisfactory solutions to problems is not morally or legally defensible. Problems should be identified and solved through a process of consultation and risk management. Both the process and the outcome are important. This implies that workers and managers must be informed about ergonomics and be able to apply ergonomics principles on a daily basis.

Risk management techniques, commonly used in business and safety management systems, can be adapted easily to ergonomics. They have the added advantage that systems safety personnel understand the process and can integrate it into a company's OHS program.

A risk management strategy in ergonomics involves identifying ergonomics hazards in the workplace, assessing them to decide how important each one is and then controlling them by the best means possible ie: finding an 'optimum' solution. It also involves monitoring to ensure that the process continues and is successful.

### 3.2.1 Definitions of Hazards and Risk

Hazard: the potential for harm

Risk: the probability that the hazard will cause injury or harm

A simple example of a hazard would be a slippery roadway; this hazard becomes a risk to the driver of a car if they drive too quickly for the conditions.

To commence the process of ergonomics risk management, we need to identify the ergonomics hazards within a workplace, or work system.

### 3.2.2 Ergonomics Risk Identification

The first step in controlling a risk is to identify that it exists either in your industry as a whole or at your workplace and which jobs might be affected. Which jobs or tasks are associated with difficulties, complaints, incidents or injuries? Where are those jobs?

In determining which tasks or activities may be hazardous and need to be assessed the following sources of information could be used:

- *Statistics and injury records:* for example, first aid records, records of accidents and near misses, workers compensation records and reports by supervisors/team leaders and employees. However, injury records from years past may provide a list of past problems and may not be a true indication of the hazards that currently exist.

- *Consultation with employees*: for example, formal supervisor/safety representative reporting, meetings, informal discussions, questionnaires.

- Direct *observation of the workers, tasks and the workplace*: for example, area inspections, walk through surveys, audits.

Often, teams of personnel are asked to conduct this process. They may be from the areas being assessed or from different areas. The workplace should be surveyed systematically to ensure that no hazard is missed. Ergonomic risk identification can be carried out on jobs/tasks, locations/areas, roles/duties or processes.

### 3.2.3 Ergonomics Risk Assessment

Risk assessment is necessary after possible sources of injury, loss or other problems have been identified. If all risks cannot be dealt with immediately it is important to deal with the most hazardous first. To do this it is necessary to determine the possible severity of the hazard and the likelihood of a problem occurring, ie: prioritise the risk management process.

Risk assessment should highlight:

- *Frequency of the risk:* is the risk common? How many people might be exposed to it? How many people might be effected if exposed?

- *Severity of the risk:* nature of the injuries and losses associated with the risk, cost of injuries/incidents or damage associated with the potential risk.

- W*ork and individual factors which might contribute to the risk:* the nature of the task, the load, the work environment, work organisation, training, individual capability.

The risk assessment will indicate the areas requiring risk control measures and it should be carried out in consultation with those who do the job.
Risk assessment is particularly important whenever:

- A work process and/or practice causes problems especially an injury; or

- A work process and/or practice is introduced or modified.

Due to the complexity of modern work systems and the interrelated nature of many hazards and risks many risk assessment methods now use a consultative team of people. This includes workers and supervisors as well as specialists in systems, processes, machinery, OHS and ergonomics. Depending on the nature of the problem the team uses different techniques to identify, assess and analyse risks for their potential to cause harm. The team is also valuable in considering possible solutions to problems.

Safety professionals have developed many techniques that are excellent for systematic determination of risk, particularly high-level safety risks. These include:

- Hazard and operability studies (Hazop)
- Failure mode and effect analysis (FMEA)
- Fault tree analysis (FTA)
- Machinery hazard identification
- Potential human error identification (PHEI)
- Workplace risk identification and control (WRAC)

These techniques are used for specific types of risk assessment such as commissioning of facilities and the implementation of procedures (Hazop); identifying the potential for human error and designing prevention strategies (PHEI); and identifying potential production or maintenance operation problems (WRAC).

### 3.2.4 Controlling Ergonomics Risks

In practice, finding solutions to some problems using control measures is often hard to achieve. Usually a problem is not solved with one solution because a range of control measures is required. Sometimes these are systems changes that can seem insignificant and unimpressive and certainly not as glamorous as the one-off solutions that are so often portrayed in solutions handbooks. However, achieving a solution should be the focus.

Sources of information on solutions can be found from:

- The workers who do the job including supervisors and managers
- Manufacturers and suppliers of equipment
- Specialists in particular areas of engineering, ergonomics, health and safety
- Other workplaces that perform the same or similar functions

### 3.2.5 Priorities

It is also important that appropriate controls are matched to the level of risk. This is referred to in safety as the hierarchy of controls and is required by law through OHS legislation in many countries. The first three in the hierarchy are known as hard barriers; the last two are soft barriers. They are:

- *Elimination* – eg: elimination of the hazard(s)
- *Substitution*
- *Engineering controls* – eg: reduction through design
- *Administrative controls* – eg: provision of policies and procedures, appropriate training, work breaks, job rotation and/or warning signs)
- *Personal protective equipment (PPE)*

Hard barriers are usually much more effective in reducing real risk and are required where the risks are high and there is the likelihood of a serious injury or fatality.

Soft barriers are generally less effective, as they rely on people's adherence to procedures or rules and are subject to error or violation. Compliance with rules and procedures is a major problem in any workplace and each individual must be highly motivated if they are to work effectively.

Training (awareness raising, procedures, skills) is a soft barrier but necessary at every stage to complement a well designed workplace and efficient systems. It is particularly important for the successful implementation of change. Sometimes training may be used as a substitute for hard controls, where there is the need for an immediate, temporary solution or where no other method of control is available. However it needs to be done very well in such circumstances. This training must always include information on why ergonomics is important and the general principles of risk reduction.

Education and training can modify peoples' perception of risk and sometimes their behaviour but there is much less evidence of success in training people to use a safe method. Therefore, while training is essential for all workers, used on its own, it is likely to be unsuccessful in reducing risks of injury.

### 3.2.6 Evaluating Controls

When monitoring hazards it is important to regularly repeat the hazard identification and risk assessment process to ensure that the solutions are working and, where necessary, make appropriate changes. Improvement must be continually monitored and ongoing.

The solution(s) needs to be evaluated in terms of:

- Effectiveness/impact on the problem
- Availability including long-term implications
- Cost benefit and or cost effectiveness of particular solutions

Evaluation of the solution in operation is often forgotten as people move to solving the next problem. Sometimes the people responsible for the solution are so committed to it they are unwilling to recognise that there are residual difficulties or that it does not work at all. Therefore evaluation is essential.

It is also necessary to evaluate solutions adopted from other workplaces. A solution that is successful elsewhere may be introduced to solve a problem without assessment of local requirements. This may create other problems. Assumptions about the benefits of new equipment, tools, furniture or systems of work need to be challenged and tested before they are universally accepted. It is important that the people who are most likely to be affected make the decision but they must be fully informed of the options, problems and advantages.

It is important to evaluate the solution at the appropriate time(s). Its immediate success does not guarantee that it will remain successful especially when circumstances or workers change. Evaluations of some sort should be conducted at a minimum of six to 12 monthly intervals.

Ongoing monitoring of ergonomics problems and their solutions should be built into the company's OHS audit system.

Information on the effectiveness of solutions may be gathered through informal feedback or discussions with users or with informal or structured interviews. Many people take 'before and after' photographs or videos, undertake follow-up risk assessments, fill out checklists or questionnaires, or repeat measurements made before the changes.

A risk assessment should always include a review to evaluate the impact of the process and the implementation of the solutions. Unfortunately this rarely occurs. There is a great reluctance to revisit problems unless there is an obvious failure or lack of progress.

Sometimes people are so committed to their solutions they are reluctant to admit that they do not work. Others move on to the next problem and assume that the proposed solutions have been implemented and are working. This may not be the case. Some solutions may work well, while others may not have been implemented appropriately and others may have made no impact at all on the problem.

There might be little indication of continuing or new problems as a result of the intervention until such a review is undertaken. An honest and timely examination of how well the intervention or solution has worked is important but it is not easy to achieve.

## 3.3 MEASUREMENTS AND INFORMATION GATHERING

### 3.3.1 Ergonomics Standards

Standards can be viewed as a set of rules defined by consensus. Humans have developed sets of rules and measures agreed to as a standard since ancient times – for example length measures in Egyptian times, and volume measures, monetary measures in Roman times. By developing standards, we can ensure uniformity and application across a number of areas or countries. This in turn makes trading easier, and forms a common understanding, 'language' and acceptance.

Today, there are standards developed across every aspect of our lives. The International Organisation for Standardisation (ISO) is the primary body responsible for standardisation globally. When considering standards relating to human factors/ergonomics, the ISO and the European Committee for Standardisation (CEN) are the main organisations involved.

A standard is defined by the ISO as

> "*Documented agreement containing technical specification or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes, and services are fit for the purpose served by those making reference to the standard" (2004)*

The ISO is a federation of national standardisation bodies from 146 countries; it is a non-government organisation, and considers a wide range of interested parties when making standards: users, producers, consumers, governments, and the scientific community.

The ISO (2004 ISO Strategic Plan 2005-2010) states its mission is to promote the development of standardisation and related activities in the world to facilitate international exchange of goods and services and to enhance cooperation in the areas of intellectual, scientific, technological and economic activity.

To develop ergonomics standards, there is a technical committee, ISO TC 159 "ergonomics". This committee comprises of 4 sub-committees (sc), whose responsibilities are;

SC 1: Ergonomic Guiding Principles
SC 2: Anthropometry and biomechanics
SC 3: Ergonomics of human-system interaction
SC 4: Ergonomics of the physical environment.

However, this is not an exhaustive list of the standard committees related to ergonomics! There are also ergonomics standards that have been developed by other ISO and CEN committees.

Standards can by accessed and used by a number of bodies, such as:

- Users
  - Direct users: designers, testers, advisors, regulators
  - Indirect users: consumers, workers, general public
- Companies/organisations
- Governments
- Consumers

Standards provide basic structured descriptions, performance standards, solution standards; measurement standards.

Additionally, there are guidelines for occupational health and safety management that have been developed by the International Labor Organisation (ILO) which are also relevant to ergonomics.

The ILO, part of the United Nations, represents employees, employers and government groups. Its purpose is to promote social justice and internationally recognised human and labour rights (ILO, 2004). Guidelines are suggested ways of doing things, and are not mandatory.

Each nation will also have its own sets of standards, and should be consulted whenever considering ergonomics issues.

An excellent description of ergonomic standards can be found in Karwowski, W Handbook of Standards and Guidelines in Ergonomics and Human Factors, 2006.

### 3.3.2 Methods of Information Gathering/Measurement

There are a number of different ways in which we can measure or estimate workloads on the human. However they all have limitations and should be used with care. An individual's knowledge and experience are extremely important in judging when loads may cause him or her harm. When considering which technique to use to gather relevant ergonomics information, selection should be guided by the accuracy of the methods, criteria to be evaluated (movements, responses, errors, etc), acceptability and appropriateness of the methods, the abilities of the designers to be involved in the process, and cost-benefit analysis of the methods. (Stanton and Young, 1999, p. 9.)

There is a range of measures that can be used to quantify physical and psychophysical load on the body. In the following section we will discuss observational and subjective techniques and well as uses of models and simulation methods.

#### a) Observational Techniques

Observational techniques are used to gather both physical and verbal data on task performance. Consequently, these techniques can be used at the prototype and operational stages of the design cycle.

Observational techniques are of three main types:

- Direct (observe task being performed)
- Indirect (video task and review later)
- Participant observation (learn the task yourself and record observations while performing task)

These techniques can document system tasks, sequencing of tasks, duration and frequency of steps in the process, movements required and verbal interactions inherent in the task performance.

The procedure for conducting an observational technique would consist of the following steps (Stanton et al., 2005, p. 39-40).

1. Define the objective of the analysis
    a) Determine product or system to review
    b) Identify the environment observation will take place
    c) Identify user group(s)
    d) Determine range of scenarios to be observed
    e) Decide on data required

2. Define the scenario(s)
    a) Define scenario(s) in detail, for example contingency situations such as emergencies; wet weather if the device will be used outdoors, etc

3. Develop observational plan
    a) Determine exact factors to observe
    b) Decide how to observe these factors
    c) Determine time required for observation

- d) Decide on roles and activities of members of observation team (if more than one)
- e) Plan observation by meetings, walk-throughs, etc
- f) Gain support of organisation and those under observation

4. Pilot the observation
   - a) Collect data to improve full observation study
   - b) Identify specific areas to improve
   - c) Review steps 1-3 above to ensure improved full observation study

5. Conduct observation
   - a) Record observation (video or audio)
   - b) Transcribe recordings
   - c) Ensure all relevant data is gathered

6. Data analysis
   - a) Collate transcripts for full understanding of observation
   - b) Transform transcripts to data format required (eg: task sequencing, etc); coding may be required
   - c) Investigate software that may assist

7. Further analysis
   - a) Use data to inform ‘higher level’ analyses, such as a Hierarchical Task Analysis; error analysis, etc

8. Participant feedback
   - a) Ensure you provide feedback, written or verbal (meeting) to all participants

***Table 3.3 - Advantages/Disadvantages of Observation Techniques***

| Advantages | Disadvantages |
|---|---|
| "Real life" snapshot | Can interfere with task performance |
| Multiple data can be collected simultaneously | Prone to bias: participants may alter their behaviour if they are being observed |
| Wide application, variety of domains | Time consuming, especially data analysis |
| Provides objective data | Cognitive aspects of task performance difficult to obtain |
| Detailed data of physical and social aspects of task performance is collected | Can be expensive |
| Can be used in existing and proposed systems | Cause of error not always easily determined |
| Useful starting point for more complex ergonomics analysis | Requires team of people with expertise in observation studies |
| Specific contingency scenarios can be investigated | Limited experimental control by analyst |

(Source: UOW - Adapted from Stanton & Young 1999 and Stanton et al 2005)

### 3.3.3 Rating Scales, Questionnaires and Check Lists

Another method of gathering ergonomics information is by gaining subjective information from the worker/human. This can be achieved by the use of rating scales, questionnaires, and checklists. These scales are useful to reflect individual subjective views on ergonomics issues. Individual perception is in turn influenced by a myriad of factors, such as age, gender, experience, feelings about the workplace (influenced by work organisation factors), personality etc.

#### a) Rating Scales

Rating scales have been developed for many psychophysical measures (that is the relationship between the physical effort and psychological perception of effort). In ergonomics, rating scales are used to determine the individual's perception of their effort and discomfort at work.

The most common scales used in ergonomics are ones incorporating either category or interval scales. Category scales rank items into categories based on attributes such as level of difficulty; a commonly used example is the revised Borg CR-10 scale of perceived exertion and discomfort (Borg, 1982; 1990), which has been widely used in ergonomics research.

| | | |
|---|---|---|
| 0 | Nothing at all | |
| .5 | Extremely weak (just noticeable) | |
| 1 | Very weak | |
| 2 | Weak | (light) |
| 3 | Moderate | |
| 4 | | |
| 5 | Strong | (heavy) |
| 6 | | |
| 7 | Very strong | |
| 8 | | |
| 9 | | |
| 10 | Extremely strong (almost maximal) | |
| • | Maximal | |

(Source: UOW - Borg, 1982; 1990)

***Figure 3.6 – Borg's CR-10 Scale Rating of Perceived Exertion (RPE)***

Interval scales rank items into categories based on greater or less than each other in quality or quantity, for example speed, temperature. An example of this scale in ergonomics is a Likert scale of pain experience.

Subjects can be asked to rate one aspect of their work, or many; they can be asked to compare different circumstances such as pre and post an ergonomics intervention at the workplace, or between a standard and their experience.

When using rating scales, it is essential that the tool is checked against the following criteria (adapted from Marras and Karwowkski, 2006, p.37-2):

The tool is

- Valid: does the tool actually measure what it sets out to measure?
- Reliable: are the results repeatable either in another situation, or by another rater (inter-rater reliability)
- Sensitive: provides adequate distinction between levels of load
- Specific: able to distinguish between the components of the task that cause the workload
- Not intrusive: has minimal impact on the actual task performance
- Transferable: able to be used across a wide range of situations

Rating scales, as for observation techniques, can be used at the prototype and operational stages of the design cycle.

**b) Questionnaires**

Questionnaires are another well used ergonomics technique. Questionnaires can be used to survey a potential user population, or to survey an individual about a specific product, work procedure, etc. Questionnaires often use a 5 or 7 point Likert scale, which can determine how relatively good or bad the person finds the job, task, use of tool, work arrangement, etc. As for all research questionnaires, the design of the questions are of utmost importance to gain the most valid and reliable information.

Questionnaires can be used to inform the ease of use of equipment, satisfaction /dissatisfaction and user views on a product/system.

Once again, questionnaires can be used in the prototype and operational aspects of the design cycle, and provide a chance to 'dig deeper' into the user's perceptions and inform design improvements.

The use of a questionnaire requires careful planning. The process described by Stanton et al. 2005, p. 30-33, provides useful guidance, and is summarised below:

1. Define study objectives: detailed listing of study goals; determine type of questions (open, closed, rating, etc.).

2. Define the population: who do you wish to survey? Select specific groups within the work population; determine necessary sample size.

3. Develop questionnaire; introduction, information for respondent, and summary. NB: avoid lengthy questionnaires; 2 pages maximum.

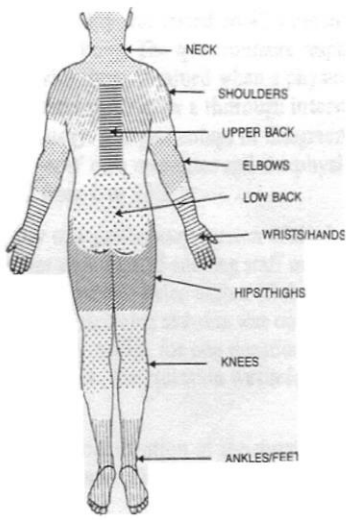
4. Pilot the questionnaire: identify any issues and rectify for full survey. Pilot with colleagues and ask for critical review – make changes and then pilot on small group of population to be surveyed and ask for feedback via interview. Survey again with larger sample of population. Review and make changes.

5. Administer questionnaire: determine best strategy, eg whole population gathered while questionnaire administered, or deliver online, etc.

6. Data analysis: code and statistically analyse.

7. Review and feedback: provide feedback on survey results to surveyed population.

A commonly used example of questionnaires used in ergonomics research is the Nordic Questionnaire for musculoskeletal discomfort (Kuorinka et al., 1987). This questionnaire asks a series of structured questions about pain experience in different body parts as a result of musculoskeletal effort. An example of a modified Nordic questionnaire from research in the cleaning industry is provided below.




| Some questions about how your body is feeling.... | | |
|---|---|---|
| 1. Have you at any time during the last 12 months had trouble (pain, discomfort) in your: | 2. Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble? | 3. Have you had trouble at any time during the last 7 days? |
| Neck<br>☐ No ☐ Yes | ☐ No ☐ Yes | ☐ No ☐ Yes |
| Shoulders<br>☐ No ☐ Yes, in the right shoulder<br>☐ Yes, in the left shoulder<br>☐ Yes, in both shoulders | ☐ No ☐ Yes | ☐ No ☐ Yes |
| Elbows<br>☐ No ☐ Yes, in the right elbow<br>☐ Yes, in left elbow<br>☐ Yes, in both elbows | ☐ No ☐ Yes | ☐ No ☐ Yes |
| Wrists/hands<br>☐ No ☐ Yes, in the right wrist/hand<br>☐ Yes, in the left wrist/hand<br>☐ Yes, in both wrists/hands | ☐ No ☐ Yes | ☐ No ☐ Yes |
| Upper back<br>☐ No ☐ Yes | ☐ No ☐ Yes | ☐ No ☐ Yes |
| Lower back (small of the back)<br>☐ No ☐ Yes | ☐ No ☐ Yes | ☐ No ☐ Yes |
| One or both hips/thighs<br>☐ No ☐ Yes | ☐ No ☐ Yes | ☐ No ☐ Yes |
| One or both knees<br>☐ No ☐ Yes | ☐ No ☐ Yes | ☐ No ☐ Yes |
| One or both ankles/feet<br>☐ No ☐ Yes | ☐ No ☐ Yes | ☐ No ☐ Yes |

(Source: Weigall & Bell, 2005 – *reproduced with permission*)

***Figure 3.7 – Example of use of Customised Nordic Questionnaire, extract from cleaning worker survey***

### c) Checklists

Checklists are often used in the OHS arena. For Ergonomists, checklists can be used to identify specific ergonomics risks inherent in a task, job or work environment; or to check a product or system against a bank of set criteria. Checklists could be used at any stage of the design process, from concept, design, prototype and through to actual operation.

There are many ergonomics checklists in use, and some good examples can be found in manual handling guidance material around the world, such as the Health and Safety Executive (HSE) in the UK and the National Institute for Occupational Safety and Health (NIOSH) in the US websites, and the Australian Safety and Compensation Council (ASCC) to name a few.

While checklists can be adapted and modified for specific situations, it is important that an understanding of the checklist and how it has previously been used is undertaken.

Advantages of checklists include their ease and speed of use; results are available immediately and do not require many resources such as personnel, training and technology. Disadvantages include little consideration to cognitive aspects of the task or interface under investigation; no allowance is made for the context in which the task, job, etc is undertaken; and it is a simplistic approach to evaluation which may miss important ergonomics aspects of the task, job, work environment or system under analysis.

**d) Uses of Models and Simulation**

Many areas of ergonomics research and investigation involve the use of models. These models can be mathematical (eg: signal detection theory), physical, structural or verbal (Sanders and McCormick, 1992, p. 61). The way models (eg: information processing) are organised can be abstract; scaled down versions of reality (eg: model of a workstation); or a visual representation of an operational sequence, or simulation of a task/process/workstation.

They describe systems and subsystems and the interaction that occurs among and between these systems, and are methods of testing designs and identifying issues. Models enable designers to anticipate issues without full scale trials of equipment, products, systems, etc.

In other words, models allow Ergonomists and designers to anticipate or predict problems; guide research enquiry; and form a framework to organise data. Many models provide normative data – for example the NIOSH equation which provides an optimum load that can be lifted under ideal conditions by the 'normal' population and allows comparison of the real lift task in the workplace, with the 'ideal'.

Simulations can be computer based or physical entities. Computer simulation models a process or system and allows changes to specific components to predict changes or consequences in the process. For example, the output of a system could be increased and a computer simulation be used to determine bottle-necks, delays, etc and inform staffing requirements.

Physical simulations or 'mock ups' are designed to look, feel or act like a specific system, workstation, controls, etc. As a consequence, they can be simple or elaborate. Good examples include pictures of control desk layout and a mock up of cockpit of an aircraft, or bridge of a ship.

# 4. MUSCULOSKELETAL DISORDERS

This topic discusses disorders from manual handling and repetitive work in relation to upper limb disorders. The causes of these disorders, as well as risk management strategies for the workplace are discussed.

## 4.1 MANUAL HANDLING

### 4.1.1 Introduction and Definition

**Definition:**

Manual handling has been defined as:

> *'Any activity requiring the use of force exerted by a person to lift, lower, push, pull, carry, or otherwise move, hold or restrain an object.' (ISO 11228-1:2003). Note that the object may be an item or an animal or person.*

Manual handling also describes repetitive actions with or without force, sustained work postures, exposure to whole-body or hand-arm vibration, bending, twisting and reaching.

Manual handling occurs intermittently in most jobs. In some codes of practice and guidance material (such as in Australia and the UK) repetitive tasks such as packing, keyboard work and using hand held tools are included in the definition. This avoids a rather artificial separation of heavy and lighter work, which may be confusing and complicate the process of prevention.

Any manual handling activity constitutes a hazard and a potential for injury unless demonstrated otherwise. The activity may be light or heavy, repetitive or intermittent. Where manual handling is a substantial or significant part of a job it is essential that all risks are identified and minimised. These jobs occur in a range of industries and organisations such as construction, manufacturing, health care, food processing, farming, printing, hospitality and mining.

Some work involves continuous manual handling for most of the day. Warehousing, the removals industry and delivery are examples of such jobs. Great care is needed in these situations to reduce the impact of handling during a work day by correctly pacing work, reducing unnecessary handling and through the use of lifting aids, job and workplace redesign and training.

Generally human handling of materials and people is expensive and inefficient, as well as posing significant risks to health to those who do it. This is especially true where the workload takes people to the limits of their work capacity.

Teaching people specific lifting techniques to overcome lifting problems has mixed success in reducing the risks of injury. Sometimes techniques can be helpful in specific situations but some techniques place extra demands on the muscles and joints eg: squat lifting (bent knees and straight back), which is slower and physiologically more demanding. It may also increase the risk of further injury for people with damaged hips, knees or ankles.

### 4.1.2 The Nature and Causes of Manual Handling Disorders (Musculoskeletal Disorders)

The majority of problems arising from manual handling are associated with sprains and strains mainly of the back and neck. However, other parts of the body are also affected most notably the shoulders, knees and ankles. Injuries in these areas occur from different aspects of manual handling tasks such as overhead work (neck and shoulders), walking on rough ground or areas with difficult access (knees and ankles). Most manual handling injuries are cumulative, developing over many months or years of overload. These manual handling injuries are termed musculoskeletal disorders (MSDs). When they are related to occupation, they are termed work-related musculoskeletal disorders (WMSDs or WRMSDs). These disorders are also known as cumulative trauma disorders (CTD).

Despite the rapid technological advancements and increasing mechanisation in the workplace, musculoskeletal disorders continue to be one of the main causes of occupational disorders in the developed world. For example, the European Agency for Safety and Health at Work (2000) conducted a survey of its members and found musculoskeletal disorders accounted for 30-46% of all work-related injuries. Buckle & Devereux (2002) reported that work-related musculoskeletal disorders accounted for anywhere between 15% and 70% of reported work-related disorders in the European Union, with variations in the estimates depending on the country (different reporting and compensation systems). Across the developed world, work related musculoskeletal disorders account for approximately 30-40% of workers compensation claims (note, this is number of claims, not costs!)

Musculoskeletal injury occurs when the capacity of the tissues is exceeded. The tissues are commonly muscles, ligaments, tendon and cartilage. We will explore this concept as we progress through this module.

A difficulty with determining the work-relatedness of musculoskeletal disorders is the interplay between an individual purportedly suffering the injury and the work task(s), including psychosocial factors (eg: workplace organisational factors such as job design and job control), psychophysical factors (eg: acceptable weight limits, see Snook, 1985), pre-existing or co-existing musculoskeletal disorders, functional capacity and intensity of task demands. In other words, the causation of musculoskeletal disorders is multifactorial and involves the interaction among a combination of occupational and non-occupational factors.

The United States National Institute for Occupational Safety and Health (NIOSH) conducted a critical review of the epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity and lower back (Bernard, 1997) and were able to link specific work-related risk factors with musculoskeletal disorders. This review included the investigation of causation of both physical and non-physical risk factors.

The review categorised the evidence for each physical risk factor in terms of 'strong evidence', 'evidence', 'insufficient evidence' and 'evidence of no effect' of the particular risk factor. The risk factors under investigation were repetition, posture, force and vibration, or a combination of these factors.

A summary of the findings for definite evidence in risk factors for various body parts is below:

***Table 4.1 - Risk Factors for WRULD***

| Risk Factor/ Body Part | Repetition | Force | Posture | Vibration | Combination |
|---|---|---|---|---|---|
| Neck & Neck/shoulder | ✓ | ✓ | ✓✓ | × | |
| Shoulder | ✓ | × | ✓ | × | |
| Elbow | × | ✓ | × | | ✓✓ |
| Hand/Wrist | | | | | |
| *Carpal Tunnel Syndrome* | ✓ | ✓ | × | ✓ | ✓✓ |
| *Tendinitis* | ✓ | ✓ | ✓ | | ✓✓ |
| *Hand-arm vibration syndrome* | | | | ✓✓ | |

✓✓ Strong Evidence
✓ Evidence
× Insufficient Evidence

| Risk Factor | Lifting/Forceful Movement | Awkward Posture | Heavy Physical Work | Whole Body Vibration | Static Work Posture |
|---|---|---|---|---|---|
| Back | ✓✓ | ✓ | ✓ | ✓✓ | × |

✓✓ Strong Evidence
✓ Evidence
× Insufficient Evidence

(Source: UOW)

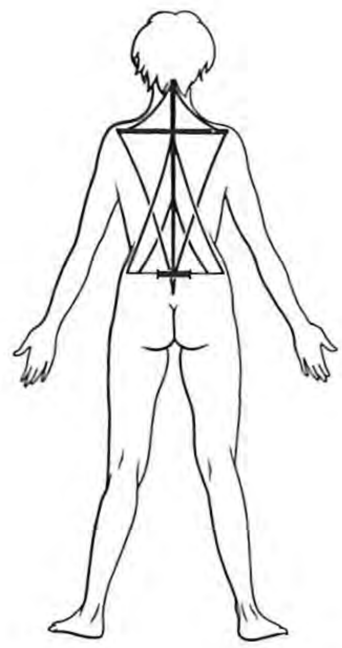
### 4.1.3 Low Back Disorders

Back disorders are the most common causes of workers' compensation claims, sick leave and early retirement in the developed world. They are usually painful and no truly effective medical or surgical treatment exists for a large number of cases. They are believed to arise from damage to the spine and surrounding structures brought about by an accumulation of strains placed on the back over time.

These disorders emerge most commonly in middle aged and older people although it is not unusual for symptoms to be reported by teenagers and young adults subjected to high levels of physical stress. In some cases acute injuries, resulting from severe trauma, such as car accidents, precipitate symptoms in young people with little evidence of prior damage. Nevertheless, in most people symptoms and signs develop over many years and the precipitating event is unlikely to be the cause of the disorder – musculoskeletal injuries are cumulative in nature.

#### a) The Spine

The spine is the axis of human movement and must meet two competing mechanical requirements: rigidity and plasticity. The muscles and ligaments act like the stays on a ship's mast to achieve this. The spine sits on the pelvis and extends to the head and neck. The shoulders are set transversely and act like a mainyard to stabilise the upper spine and this is linked in turn by muscles and ligaments to the pelvis.



(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 4.1 – Supporting Structures of the Spine***

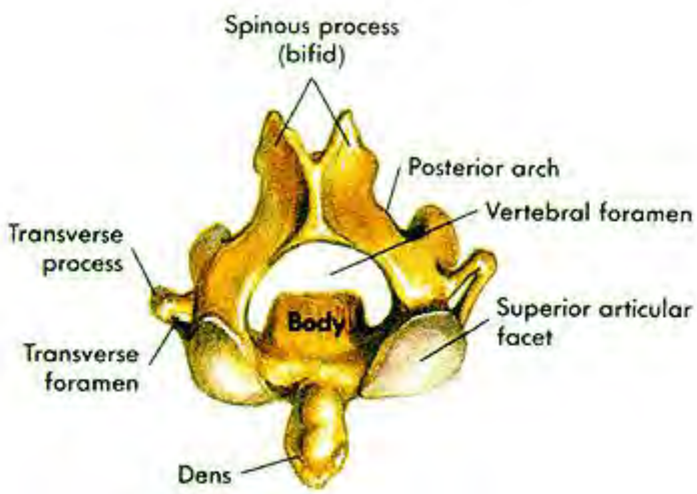
These multiple components superimposed on one another and interlinked with muscles and ligaments allow for movement and stability. It is therefore a remarkably adaptable and flexible structure.

Flexibility and adaptability come at a price and that is strength. The spine is not well designed for the heavy loads and the repeated abuses it suffers in modern life. It needs to remain reasonably flexible and strong to function correctly.

Being overweight, lacking physical fitness and exposure to overuse lead to injuries and these are common in leisure and work. Most injuries, especially in the early stages, are simply muscle strains and small tears of the ligaments or other supporting soft tissues. However, over time more serious injuries can develop and may result in damage to the vertebrae and, more commonly, the intervertebral discs. Therefore back injuries are nearly always cumulative in nature and arise after months or years of excessive loads on the structures of the back.

**b) Vertebrae**

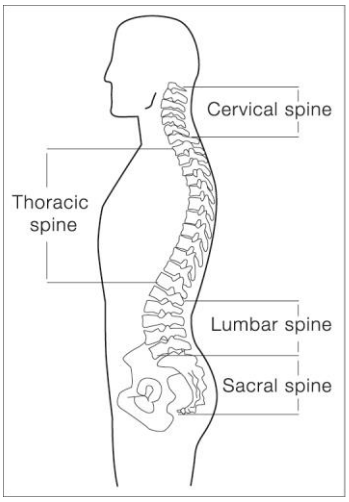
The spine is made up of a series of 24 bones called vertebrae. These bones form a canal to encase the spinal cord and protect it. Discs and a series of muscles, fine ligaments and capsules hold the 24 moveable vertebrae together. The discs act as shock absorbers and allow the spine a great range of movement and postures, which are controlled and activated by the muscles. Ligaments and capsules protect the smaller joints in the spine. They are arranged in an 's' curve for maximum stability and strength, the three curves are the cervical, thoracic and lumbar curves. There are four fixed vertebrae in the lower end of the tailbone known as the coccyx. At the rear of the vertebrae are facet joints, which link each vertebrae and keep the spine rigid in an upright posture. This characteristic protects both the spinal cord and the discs.






(Source: Mosby's Medical Encyclopedia)

***Figure 4.2 – Plan View of Cervical Vertebra Showing Bony Features***




(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 4.3 – The Spine, Side View***

**c) Discs**

The discs sit between the vertebrae and primarily absorb shock transmitted through the spine. They also physically keep the vertebrae apart and allow movement. The discs are avascular, that is they have no direct blood supply, nor do they have direct nerve supply. The discs have a central nucleus which acts as the shock absorber gel, and this structure is surrounded by a series of strong fibres to protect the nucleus. The discs undergo natural degeneration with age, and this degeneration is exacerbated by poor manual handling leading to micro-damage of the disc, such as repeated lumbar flexion, twisting, and this effect is increased by handling a load under these conditions.

**d) Injury Mechanisms of the Spine**

As noted above, manual handling injuries do not usually occur after one 'insult' – they are cumulative in nature. A number of forces (compression, shear and torsional) act on the spine during manual handling tasks, and these forces affect different structures. The mechanism for this is an accumulation of micro-damage that exceeds the tissues capacity to repair. (Burgess-Limerick, 2003).

Essentially, damage occurs continually with sub-failure magnitude loads – for example repeated low load lifting such as loading/unloading boxes of pamphlets from a conveyor, or prolonged sitting over a working life.

To prevent this accumulation of tissue micro-damage, appropriate ergonomics design of systems of work, jobs, tasks, etc is essential.

(Source: UOW, 2008)

***Figure 4.4 – Hospital Linen Workers Sorting Laundry on Conveyor Line***

McGill (2002, p.150) provides a useful review of the risk factors for low back disorders based on epidemiological evidence, tissue-based studies and personal variables as follows:

**Epidemiological Evidence:**

- Static work postures, specifically prolonged trunk flexion and twisted and/or laterally bent trunk posture
- Seated work postures
- Frequent torso motion, higher spine rotational velocity, and spine rotational deviations

- Frequent lifting, pushing and pulling
- Vibration exposure, particularly seated whole-body vibration
- Peak and cumulative low back shear force, compressive force and extensor moment
- Incidence of slips and falls

**Tissue-based Studies:**

- Repeated full lumbar flexion
- Time of day (time after getting up from bed – the discs decrease in height over the day due to effect of gravity and load)
- Excessive magnitude and repetition of compressive loads, shear loads and torsional displacement and moments
- Insufficient loading so that tissue strength is compromised
- Rapid ballistic loading (eg: landing following a fall)

**Personal Variables:**

- Increased spine mobility
- Lower torso muscle endurance
- Perturbed motor control patterns (leading to inefficient muscle co-ordination/use)
- Age
- Gender
- Abdominal/torso girth

### 4.1.4 Risk Assessment

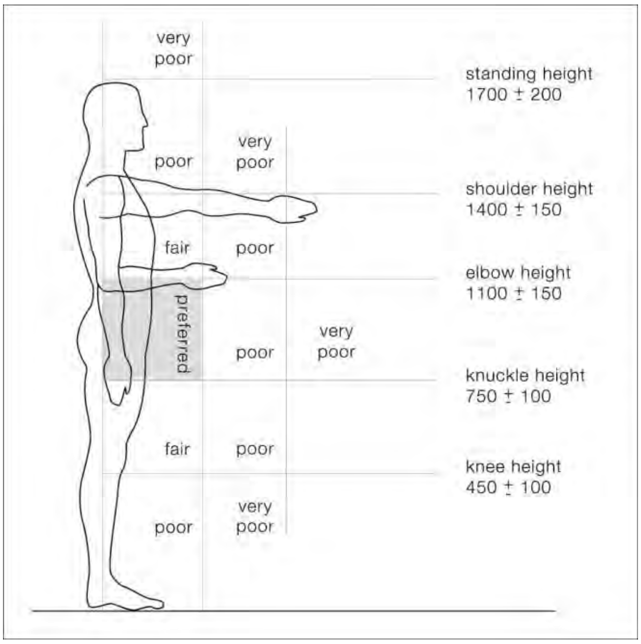
From the evidence discussed in the previous section, several indicators for risk of manual handling tasks in the workplace emerge: weight and load (force), frequency of lift (repetition), distances moved (force, posture), workplace layout (posture, vibration), and personal variables.

**a) Weight and Load**

Load should not be confused with weight. Load is force. The weight of an item may be considerable but with appropriate lifting aids the force required to move it might be minimal. The load experienced by an individual can be influenced not just by the nature of the object to be lifted, but also by task design, organisational and personal factors.

In physical work weight is just one aspect of load on the body. In Australia the guidance material does not include weight limits for loads because of the other factors which impact on risk from lifting, such as:

- Distance of load from the body (moment)
- Range through which weight is lifted
- Origin and destination of lifts
- Postures assumed in order to lift (bent, and bent and twisted postures are the ones to which most risk is attached)
- Speed of movement
- Characteristics of the load




(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 4.5 – Height Ranges for Lifting (mm)***

European standards however include limits for mass, but combined with the other risk factors of frequency of the lift, position of the object being lifted from/to, the cumulative mass of the lifting and carrying task over a day, etc.

The British guidance material incorporates the ISO standard and provides risk assessment in the form of red, amber and green. This form is available for download at http://www.hse.gov.uk/msd/mac/index.htm

For repetitive lifting there are the added factors of:

- Frequency of lifts
- Duration of lift, and
- Cumulative loading (leading to fatigue)

Handling away from the body, bent twisted postures and speed of movement are now considered to be the factors that create the greatest risks for injury.

**b) Frequency of Lifts**

Frequency of lifts between jobs may vary a great deal. The question is: how frequent is 'frequent'? In some regulations in Australia lifting more than twice a minute or a movement sustained for more than 30 seconds at a time is classified as frequent. This is a good guide for practical purposes but each situation needs to be considered in relation to other factors that contribute to load and worker fatigue.

ISO 11228-1: 2003 provides recommended limits for mass and frequency of lifts for lifting tasks of short duration (≤ 1 hour) or medium duration (≥ 1hr ≤ 2 hrs); and for cumulative mass handled per day in terms of object position and distance carried.

While these are useful there are many worker individual factors which impact on capacity and these will be discussed in the next section on matching job demands to worker capabilities. The standard describes strategies for reducing the risk of manual handling tasks by decreasing the frequency, mass, range of heights lifted from/to and the distance carried. It must be noted that the guidance limits set out in the standard are based on strict criteria, and these must be compared to the actual work situation, before applying these 'limits' in the workplace too hastily. These strategies follow ergonomic principles as described in Section 4.1.6 on principles of handling and prevention.

**c) Matching Job Demands with Worker Capabilities**

Human beings are not well adapted to heavy physical work, their physical skills lying more in the areas of speed, flexibility, adaptability and range of movement. Therefore there are considerable limitations in designing heavy work for the average person.

Determining and matching job demands with the capacities of individual workers is particularly important in physically stressful work such as manual handling.

There is a range of task and individual factors that need to be considered in job design where manual handling is involved. These include:

- *Physical demands (physiological, biomechanical, anthropometric)* - the workplace and job design features eg: work height, reaches, workplace layout, design of loads, how far a load is carried and doubling handling.

- *Psychological demands (cognitive and organisational) -* the way the work is done, mental work demands including meeting work targets, control over work, support in the workplace, training and the organisation of work.

- *Individual or personal characteristics* - age, physical capabilities (age, sex, stature, ethnicity), fitness for the job including return to work after holidays, health including previous injuries and past exposure to heavy lifting; training for the job skills and experience.

Research carried out over the last 25 years indicates that heavier weights, repetition and force beyond an individual's capacity, and work and workplace design which force workers into awkward or constrained postures lead to problems. Individual workers may initially cope with demands that exceed their capabilities in one or more of the following ways:

- Short cuts in work procedures leading to unsafe practices
- Consistently working at a higher pace than is healthy with an increased risk of chronic or accumulated fatigue and injury especially as they age
- Change of job by those who are unable to meet work demands imposed.

Problems may arise gradually over time in people who adapt in the short-term. They then become evident years after the origins of the disorder have been forgotten. Drawing any kind of cause-effect relationship between the disorders and the initial causes is difficult if not impossible.

**d) Risk Assessment Techniques**

As for all OHS risks, a risk management approach is to be used to identify, assess, evaluate, control and recheck the control of manual handling risks. Risk assessment processes can be simple or detailed (ISO 11228-3:2007 Ergonomics Manual Handling Part 1,2,3), depending on the complexity of the issue under investigation.

Simple risk assessment techniques include a comparison of the activity under review with ideal condition levels such as outlined in ISO 11228-1: 2003, where reference data is provided for manual lifting, beginning with recommended limits for mass and frequency of lift, etc. Alternate techniques are provided in checklist and chart formats such as that of the HSE in the form of Manual Handling Assessment Charts (MAC) and the National Standard for Manual Tasks, 2007 with the accompanying document, *National Code of Practice for the Prevention of Musculoskeletal Disorders from Performing Manual Tasks at Work* (2007) (Australian Safety and Compensation Commission).

Again, as for all OHS risks, consultation with the worker is imperative for a comprehensive risk assessment process.

More complex manual handling issues can be addressed with formal ergonomics techniques. These techniques fall into the following types of approaches: biomechanical, physiological, and psychophysical models. Each of these methods has limitations, and require specific training in their use. Outlined below is a description of the theory behind the approaches, and examples of techniques that can be used. To summarise the three different approaches, see the table below:

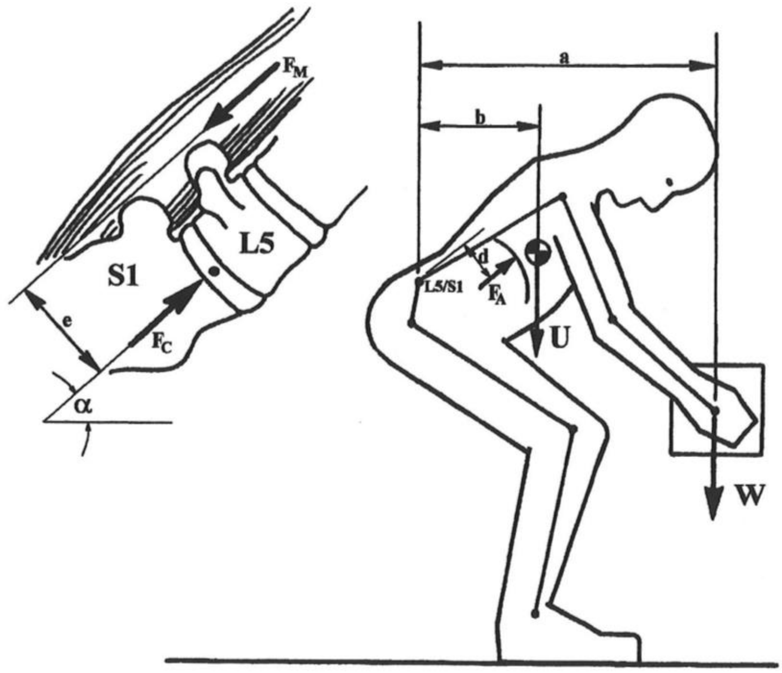
***Table 4.2 – Biomechanical, Physiological and Psychophysical Models of Manual Handling Risk***

| Discipline | Design Criteria | Cut-off Value |
|---|---|---|
| Biomechanical | Max. compression force | 3.4kN<br>L4/5 or L5/S1 joints |
| Physiological | Max. energy expenditure | 2.2-4.7kcal/min |
| Psychophysical | Max. acceptable weight | Acceptable to 75% of female workers & about 90% male workers |

In addition to these approaches, there are two others: the NIOSH (National Institute for Occupational Safety & Health in the US) equation, which combines the three approaches above, and secondly, observational postural assessment tools which are also a combination of aspects of biomechanical, physiological and psychophysical approaches, with the addition of tools such as the Quick Exposure check (QEC), David et al (2005) and the Manual Tasks Risk Analysis (ManTRA)) Burgess-Limerick et al (2004), which also consider work organisational factors.

**e) Biomechanical Methods**

The goal of the biomechanical approach is to design tasks that do not exceed the capacity of the musculoskeletal system. To do this models are developed based on set criteria for compression limits for L4/L5 or L5/S1 joints, and/or maximum joint torques. To determine if a task is acceptable with respect to these criteria, a biomechanical model can be used to provide estimates of forces. Biomechanical models of the low back can be used to estimate in vivo shear & compressive forces acting on the spine at either L4/L5 or L5/S1. The models are typically 2D or 3D static, dynamic or quasi dynamic models of the lumbar spine, and once data is entered, will provide outputs estimating the physical loading on spinal structure.




(Source: Stevenson, 1999 – *reproduced with permission*)

***Figure 4.6 – Simplified Link Model of Lifting for Static, Two-dimensional Analysis of Low Back Forces, showing L5/S1, with an enlarged view of this joint on the left (adapted from Chaffin & Andersson, 1984)***

Examples of these models include the two dimensional static strength prediction model (2D) (Chaffin, 1967) or 3D Michigan model (Chaffin and Andersson, 1984) or the Lumbar Motion Monitor (LMM$^{TM}$) (Marras et al., 1993). Estimations in the 2D model are made on a split-second movement and calculated using a software package. It is based on a model developed by the USA National Institute of Occupational Safety and Health (NIOSH) and known as the NIOSH equation.  The values in the 2D model are given in terms of forces on different parts of the body including the lower lumbar spine given the weight being handled, distance from the body, body posture.

The model is used to evaluate the strength requirements at the major joints and to estimate the low back spinal compression forces for lifting tasks. However, there are many limitations using this method especially where there are unbalanced postures and movements and/or dynamic lifting tasks.

In these cases it may underestimate strength and compression forces. The 3D model has overcome some of the problems of the original 2D Model but it is complex to use and there are still limitations in practical work situations.

The LMM$^{TM}$ is a portable stretch gauge shaped rather like the skeleton with a harness that attaches it to the body. It is connected to a portable computer with software that analyses a number of components of movement of the spine including acceleration, velocity and range of movement in three planes. The package allows for comparison of results against LMM$^{TM}$ benchmarks. It has proved useful in research but is less usable in real world situations in highly varied tasks or in cramped spaces.

There are limitations to this approach in both application (as noted above) and in the data that is used to determine the normative data in the models. The spinal tolerance limits are from cadaver studies (too difficult to get ethics approval in live subjects!), the loads tested are cumulative compressive loads at L5/S1 and so estimate what is really occurring in the live human during lifting activities. The advantage and usefulness of biomechanical modelling is that it provides relative comparison of alternatives in task designs rather than providing a definitive measure of manual handling 'load' of musculoskeletal risk.

**f) Physiological Methods**

Effort can be estimated measuring the cardio-respiratory system's capacity for work eg: heart rate, oxygen uptake, and circulation. Heart rate can be measured continuously using telemetry. The heart rate (HR) is indicative of oxygen ($O_2$) demand – HR increases to carry more $O_2$ to working muscle. From these measurements energy expenditure can be calculated. This is usually done using the individual's own resting heart rate for base line comparison as no two people are exactly the same.

The general acceptable method of determining maximum HR is to deduct the subject's age from 240. For example the maximum HR for a 40 year old would be 200 beats per minute (bpm).

Another method of measuring physiological effort is the Borg rating of perceived exertion scale (often referred to as the RPE). Workers are asked at intervals how hard they think they are working. They can nominate one of 15 precisely defined categories from ranging from 'no exertion at all' (6) through 'very light' (9) and 'hard (heavy)' (15) to 'maximal exertion' (20). By adding a zero to the numbers the resulting values roughly equate with heart rate. Higher numbers are then related to the resting heart rate to get an estimation of the individual's capacity and exertion. Modified versions for localised areas such as the legs, back, arms and neck are also used.

| | |
|---|---|
| 6 | No exertion at all |
| 7 | Extremely light |
| 8 | |
| 9 | Very light |
| 10 | |
| 11 | Light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Extremely hard |
| 20 | Maximal exertion |

(Source: UOW - Borg 1982, 1990)

***Figure 4.7 – Borg Rating of Perceived Exertion (RPE) Scale. A 15-level scale***

**g) Psychophysical Methods**

Estimation of the individual's capacity to undertake certain types of physical work can be achieved through questioning people during the task. They are asked to put a numerical or word value on how hard they think they are working and/or whether or not they could maintain that pace for a specified period (usually an eight-hour-shift).

In the USA tables have been developed based on individuals' judgments of acceptable loads for a given work period. These are known as the Snook tables after the researcher who developed them. The method takes into account the whole job and integrates biomechanical and physiological factors.

Snook (1978), the pioneer of this method, describes this approach as one in which "the worker monitored his own feelings of exertion, and adjusted the weight of the object until it represented the maximum acceptable weight of lift." In other words, the approach relies on the worker report of feelings of exertion. The tool developed by Snook and Ciriello (1991) (Snook tables) is not sensitive to metabolic demands (the body's energy requirements), or bending and twisting of the spine.

This psychophysical approach, then, also has limitations. Some studies have found that many subjects overestimate and some underestimate their capacities. The tables are useful for assessing weights on the basis of acceptability rather than on safety.

**h) Combination Method: NIOSH Equation**

An alternative approach developed in the USA uses three common lifting indices. The first is the lifting index, which was developed with the NIOSH equation. This uses the ratio of the load to be lifted to the recommended weight limit as calculated by the equation. The second is the job severity index.

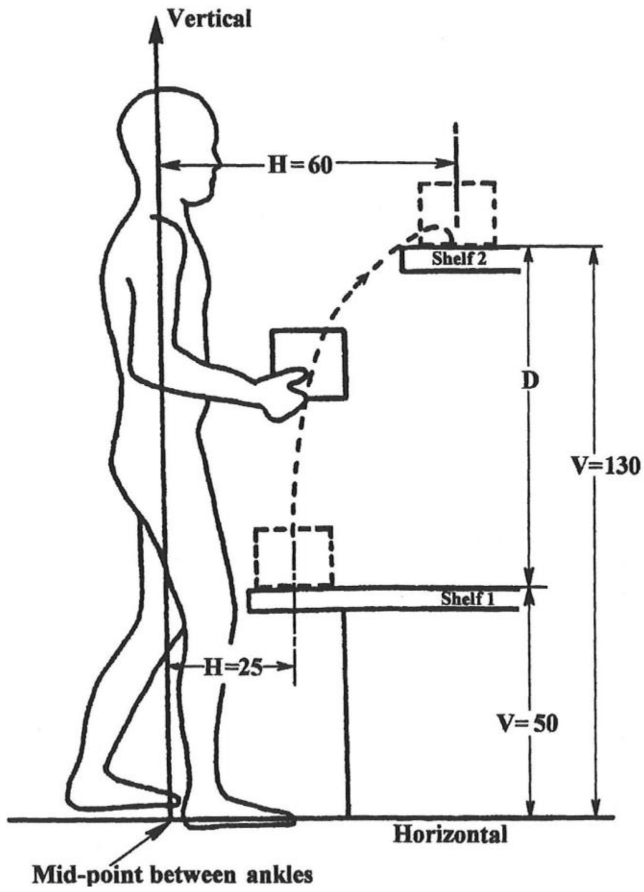
This is calculated from the job demands that are identified through tasks analysis against worker capacity that is either measured or estimated. The third index is the lifting strength rating. It is calculated from the weight handled in the job and the strength of a strong person in the postures observed for handling the weight.

All three indices aim to assess the job demand against the capacity of people working under the job conditions. The latter can be used to assess lifting demands where load and workplace factors vary. Nevertheless they do not quantify precisely the risk involved. They are more useful in comparing the relative severity of two jobs.

The NIOSH guidelines use biomechanical, physiological and psychological criteria to set lifting limits that are integrated. These are set in terms of the recommended weight limit, which is a formula that takes into account the height at which the lift commences, the vertical travel of the lift, the reach distance, and the frequency of lift. The formula is usually referred to as the NIOSH equation and recognises that risk factors interact and multiply the risk. However, it cannot be used for other manual handling activities such as carrying, pushing pulling or lifting people. It also does not take in account sudden or unpredicted conditions such as a shift in loads or foot slip.

Additionally, there have been criticisms of the NIOSH equation. The threshold values are based on data from only 27 cadavers (dead bodies), and other researchers have found that risk is underestimated (Lavender, 2003; Jager & Luttmann, 1999).

The revised NIOSH Lifting Equation Application manual is available at www.cdc.gov/niosh/doc94-110/




(Source: Stevenson, 1999 – *reproduced with permission*)

***Figure 4.8 – Example of use of NIOSH Equation for a hypothetical lift in sagittal plane, showing H and V values (in cm) at origin and destination***

**i) Epidemiological Methods**

Epidemiology is the study of diseases and disorders in populations. In this approach measures of the health effects of work on people are studied. The effects of exposure to certain hazards such as manual handling can be indirectly calculated by examining the numbers of new or recurring injuries or illnesses recorded in people who carry out manual handling. If the occurrence of particular disorders is higher than expected statistically then these can be linked with general or specific parts of the work.

However, some disorders such as those of the musculoskeletal system occur normally as the result of life activities and they are also cumulative in nature.

It may take many years before the detrimental effects of the work become apparent and even then the contribution of work to a disorder can be unclear. These disorders are very difficult to study in epidemiology because of this.

A simple epidemiological method that is frequently used to collect information on sprains and strains (musculoskeletal disorders) is the Nordic questionnaire (Kuorinka et al 1987) (referred to in Section 3.3.3). This is a standardised questionnaire that is used in conjunction with other measures of occupational or task-related workloads. It consists of a series of questions concerned with the individual's history of musculoskeletal problems in both the last week and the last 12 months. Some questions relate specifically to the low back. The rest cover the neck, shoulders, elbows, wrists/hands, upper back, hips, knees and ankles/feet.

Body maps are included with the questionnaire. These are drawings of the body on which individuals mark where they are experiencing discomfort or pain. The questionnaire is easy to administer but requires some specialist knowledge to analyse and interpret.

There are number of other methods that have been developed but all need care in their administration and some specialist knowledge.

**j) Postural Methods**

These methods estimate the numbers of undesirable postural combinations (those found to be associated with the development of back pain and other sprains and strains) and the proportion of the work task where these postures are required; for example Ovako Working posture Analysis System (OWAS), Karhu 1977, the Rapid Upper Limb Assessment (RULA), McAtamney & Corlett 1993, and the Rapid Entire Body Assessment (REBA) McAtamney & Hignett 1995.

In OWAS video recordings are made of work tasks for later analysis of postural load. The working postures adopted during the work are classified by a method that defines the positions of the back, upper and lower limbs as well as force used. Recordings of observations are made on work postures and activities are made on anything from a five to 30 second intervals.

They are entered into a computer and a program estimates the proportion of time in certain postures. The least desirable ones are the bent, or bent and twisted postures (work below the knees with or without twisting to the side), standing or balancing on one leg or in an awkward posture, and work above the shoulders. Weights can be added to the calculations but are considered in gross terms only. Combinations of these factors are classified by an experienced Ergonomist according to the percentage of time spent in non-neutral postures and force exerted.

RULA and REBA are survey methods developed for use in ergonomics investigations of workplaces where musculoskeletal disorders are reported. They provide a quick assessment of postures along with muscle function and the external loads experienced by the body.
A coding system is used to generate an action list that indicates the level of intervention required to reduce risks due to physical loading.

Ranney (1997, p.48) has outlined key aspects of working postures which indicate risk to musculoskeletal health. These include:

- Limb segment inclined with respect to the line of gravity – this indicates a joint moment of force is required for that movement or task, and requires muscular or ligamentous forces to support the limb
- A joint angle close to end range of movement (extreme posture) – this indicates load on ligaments, and probable compression of blood vessels and strain on nerves

- Joint positions away from optimal working range – this alters the efficiency of muscles and tendons and leads to fatigue and stress/strain
- Change, or no change, in posture – indicates the repetitiveness or static characteristic of the task

### 4.1.5 Job Design and Training

The ergonomic approach to manual handling is to begin with the question, "Is the manual handling of objects by a human necessary?" Eliminate manual handling wherever possible. Having humans manually handle objects is often slow, costly and likely to cause injury to the workforce. Overall the approach must be consistent with risk management, that is, eliminate or reduce the risk of injury. Any changes implemented to reduce the risk of manual handling must be checked to ensure the new process/equipment does not in fact create other hazards. Inherent in any change in work process is adequate training and skilling of the workforce to manage the new process/equipment.

Should the task not be eliminated, investigate mechanisation to remove the human involvement in manual handling. If this is not possible, investigate assistive devices such as hoists, vacuum lifts, etc.

This process can be summarised as:

1. Eliminate manual handling activity; if unable to do this
2. Assess the risk posed by the activity and redesign to eliminate the risk; if unable to do this
3. Reduce the risk with redesign of the load, the work area or introduce mechanical aids and equipment.

Changes to reduce the risk of manual handling injury can be made to the task, the job, the workplace, the work organisation or the actual object being lifted.

Particular issues occur with the handling of people or animals, and this type of manual handling incurs a great deal of risk. Animals do not behave in consistent, predictable ways; the same is true of children, or adults in pain, or people with specific medical conditions such as dementia, stroke, etc.

Workers in these settings must be provided with access to relevant information, training, equipment, appropriately designed work areas and staffing levels to best manage the manual handling of people.

The work environment is also important for the performance of manual handling tasks. Lighting, temperature, noise, wet surfaces, strong winds and vibration are examples of environmental factors that will affect the ability of someone to carry out manual tasks.

**a) Job Design Key Points**

- Any manual handling is costly and inefficient so the workplace should be redesigned to minimise it wherever feasible
- Correctly estimate individual's capabilities in terms of handling weights, cumulative loads, and work rates and design for these. Design handling jobs to accommodate the weakest, the smallest and the slowest workers
- Consider the cumulative effects of weights handled and the different planes of motion
- Consider the combined effect of task variables (such as height of lift, size of the load) and worker variables (such as age, sex, body weight, anthropometric dimensions)
- Avoid work postures that are awkward, prolonged or outside preferred range
- Avoid manual handling activities while seated

- Avoid work movements that are repetitive, require excessive strength and endurance, require excessive speed, are jerky, restricted, inefficient or obstructed
- The time for one basic element of a task to be completed is affected by the preceding and succeeding elements; consider the whole process
- Provide well-designed manual handling aids where appropriate
- Optimise environmental variables such as temperature, humidity and air velocity for handling tasks

**b) Training**

The concept that workers can be trained to approach manual handling tasks safely and effectively, is not supported by studies of manual handling training outcomes (Chaffin, 1986; Daltroy et al, 1997). This is thought to be because there is little ‘transferrability’ from the training setting to ‘real life’ and that the techniques proposed as safer (such as the squat lift) actually are more difficult to perform and place greater strain on the heart and knees (an issue for ageing workers in particular). Industry often use training as their ‘manual handling strategy’ as it is easy to implement.

The only way to manage manual handling risk in the workplace is to identify it, assess it and control it with the aim being to firstly eliminate and secondly mitigate. Training is important in any changes in work systems or practices as a result of the risk management control. Training in risk assessment and ergonomic principles has been found to be effective to promote change in technique (eg: Gagnon, 2005).

From a preventative viewpoint, workers should be trained to identify manual handling issues and report them as well as consider control strategies.

### 4.1.6 Principles of Handling and Preventative and Protective Measures

As stated in the previous sections, the way to manage manual handling in the workplace is to undertake a risk management approach. Simple risk assessments are available from regulator organisations, such as the HSE in the UK and the ASCC in Australia (as well as individual states and territories).

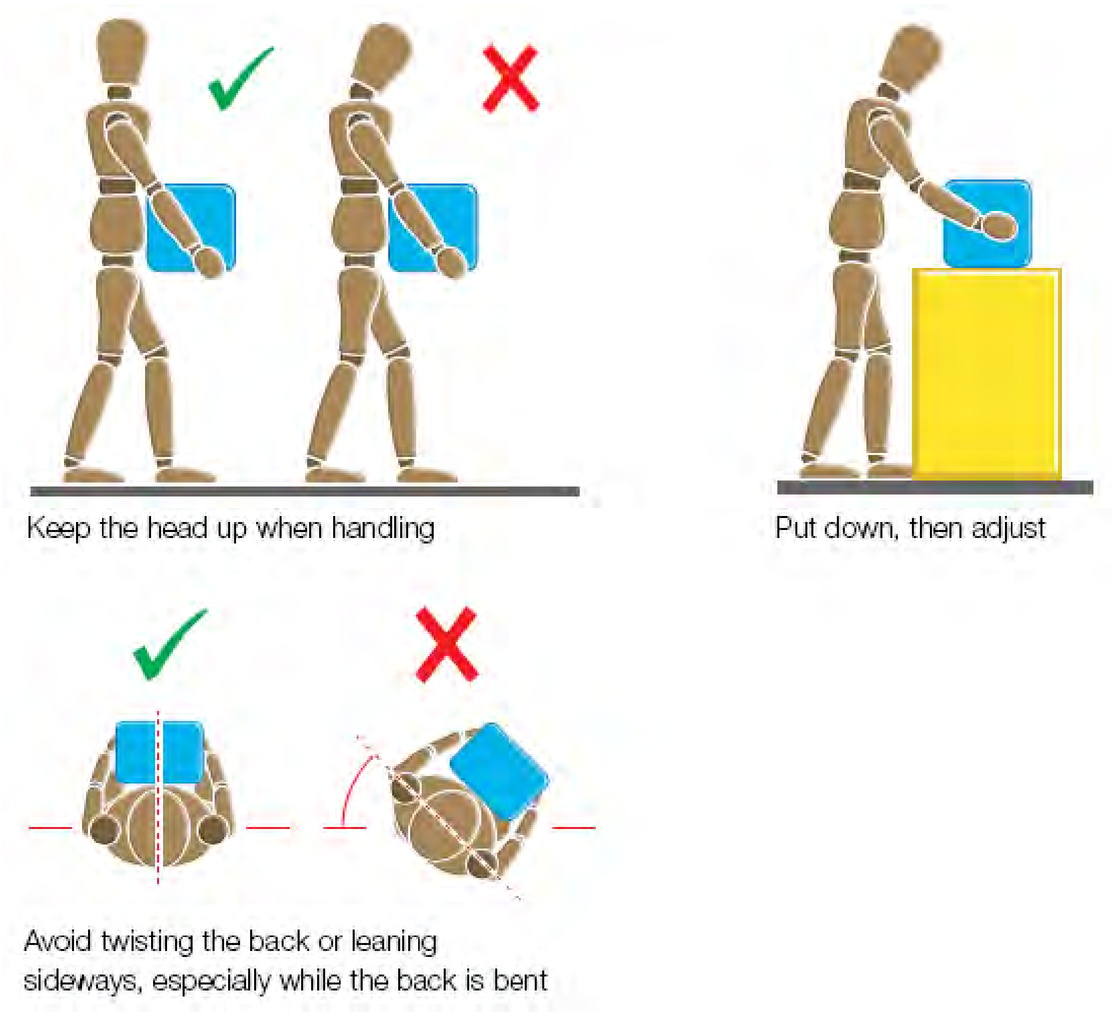
The HSE has published a useful document, 'Getting to grips with manual handling'; while the ASCC has published useful guidance material on manual tasks with the new Code of practice for the prevention of musculoskeletal disorders from performing manual tasks at work, 2007.

The assessment components examine the manual handling tasks, the loads being handled, the working environment, individual capacities, any mechanical handling aids or equipment that is involved as well as work organisation factors.

To assist industry, general guidance is provided for lifting and handling:

1. Plan the lift before lifting/handling
2. Keep the load close to the waist (close to the centre of gravity to minimise rotational forces on lumbar spine)
3. Keep a stable position
4. Ensure a good grip on the load
5. Utilise 'good posture' all through the lift (upright to minimise any risk of torsional or shear forces on spine)
6. Avoid twisting or sideways bending (minimise torsional forces on spine)
7. Keep the head up (by looking ahead, the risk of spinal flexion is minimised)
8. Move smoothly with the load (ballistic movements lead to injury)
9. Lift to your capacity

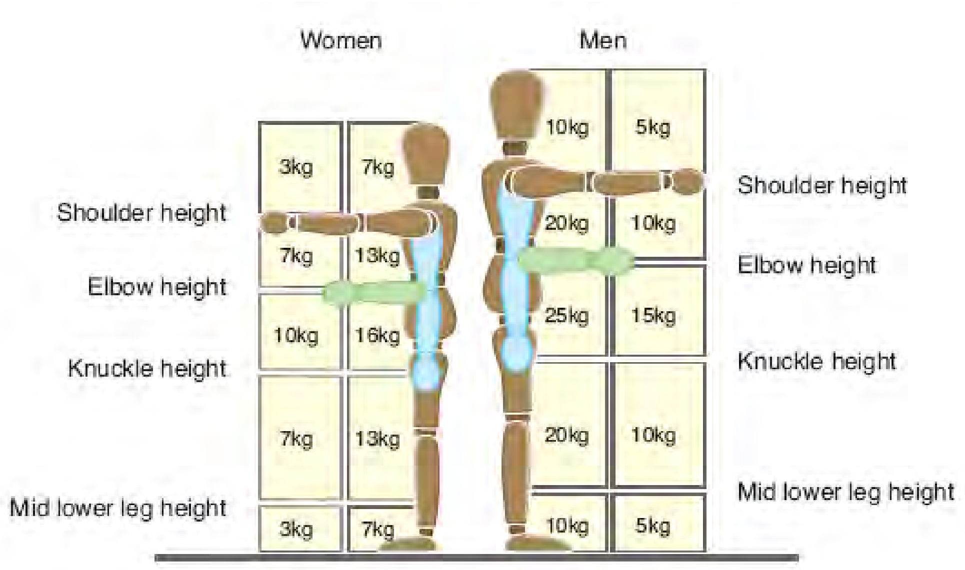
10. Adjust the load position after you put it down, not before (sliding load is much easier than handling entire mass)




(Source: HSE Getting to Grips with Manual Handling – *reproduced with permission*)

***Figure 4.9 – General Guidance for Lifting & Handling***

HSE also provide general guidance on what is ‘safe’ to lift and lower at various working heights (in ideal work conditions and when load is easily grasped with 2 hands from front on to the load with no twist and does not account for carrying the load). In light of all the evidence discussed in the previous sections of this topic, use this information as GUIDANCE only and consider all the other factors we have discussed in this section. Comparison of an actual work task with these guidance figures will assist you to decide if further risk assessment is required.




(Source: HSE Getting to Grips with Manual Handling – *Reproduced with permission*)

***Figure 4.10 – Lifting & Lowering Mass Guidance***

While this is useful information as a 'first glance' indicator, it should never be used as the sole indicator as it is too limited to one aspect of the work tasks. Few manual handling activities in the workplace only involve standing and lifting and lowering tasks.

For a more complete review of the whole task, it is recommended that the risk assessment in the Australian guidance material is used, or the Manual Handling Assessment Chart (MAC) developed by the HSE in the UK.

## 4.2 WORK-RELATED UPPER LIMB DISORDERS (WRULD)

### 4.2.1 The Nature and Causes of WRULD/Repetitive Strain Injuries/Cumulative Trauma Disorders

The phrase "work-related upper limb musculoskeletal disorders" includes a variety of upper limb degenerative and inflammatory diseases and disorders, which result in pain and functional impairment. Affected areas typically include the neck, shoulders, elbows, forearms, wrists and hands (Buckle & Devereux, 2002). Names for these types of disorders include: cumulative trauma disorder (CTD), repetitive strain disorder (RSI), occupational cervico-brachial disease (OCD), occupational overuse syndrome (OOS) and more commonly work related upper limb disorder (WRULD).

These types of occupational injuries have been well known over history, examples of occupations include tailors, shoe makers, milk maids; and more recently VDU workers involved with repetitive data entry and vibration induced hand and wrist disorders, such as jack hammer operators.

Colombini et al. (2002) state that the incidence of occupational illnesses of the upper limbs has been constantly increasing and that in 1990, 'cumulative trauma disorder' accounted for over 60% of all occupational illnesses in the USA.

For the disorder to be work-related, work tasks and conditions must exacerbate or cause the disorder. This sounds straightforward, but of course it is not. Earlier in this section we examined the evidence for musculoskeletal disorder risk factors from the meta-analysis by Bernard et al (1997) for NIOSH. Outlined in Table 4.3 is the particular evidence for upper limb disorders.

***Table 4.3 – Evidence for Risk Factors for WRULD***

| Risk Factor/ Body Part | Repetition | Force | Posture | Vibration | Combination |
|---|---|---|---|---|---|
| Neck & Neck/shoulder | ✓ | ✓ | ✓✓ | × | |
| Shoulder | ✓ | × | ✓ | × | |
| Elbow | × | ✓ | × | | ✓✓ |
| Hand/Wrist | | | | | |
| *Carpal Tunnel Syndrome* | ✓ | ✓ | × | ✓ | ✓✓ |
| *Tendinitis* | ✓ | ✓ | ✓ | | ✓✓ |
| *Hand-arm vibration syndrome* | | | | ✓✓ | |

✓✓ Strong Evidence
✓ Evidence
× Insufficient Evidence

(Source: UOW – adapted from Bernard et al, 1997)

From the evidence it is clear that posture is a definite risk factor for the neck and shoulder, while a combination of factors are a risk for the elbow and wrist/hand.

Use of our upper limbs in functional activity, whether at work or at home usually involves static loading of the postural muscles and active use of the dynamic muscles for task completion. For example, when typing on a keyboard, the shoulder, neck and scapular musculature is stabilising the arms for dynamic work of the hands and forearms. However, using the evidence such as the findings of Bernard, allow us to determine whether or not manual tasks involving the upper limbs pose a risk to musculoskeletal health for workers.

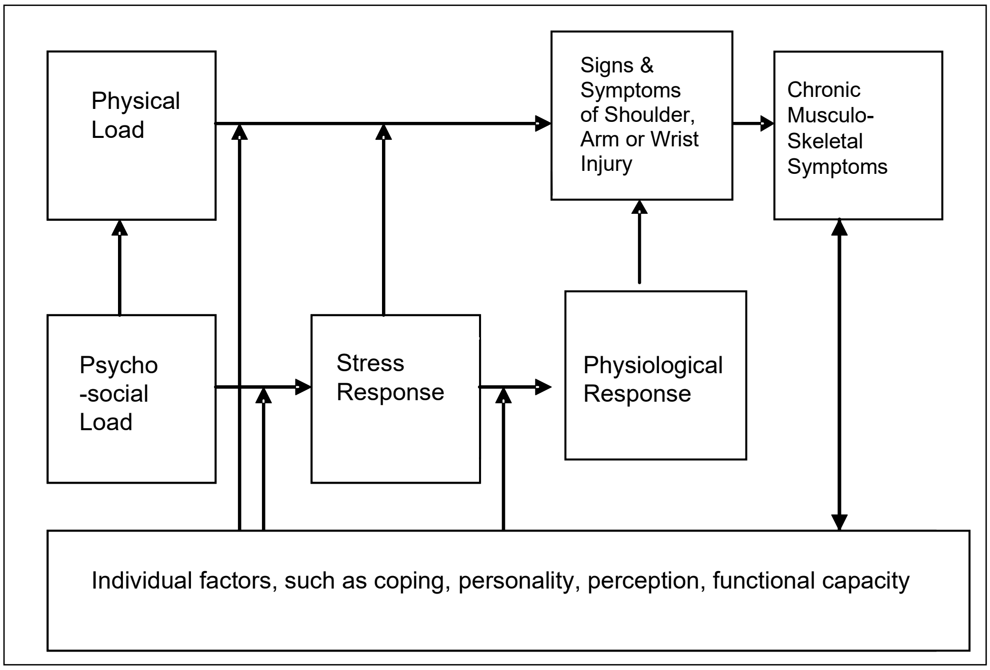
To add to the complexity of WRULD, other research into the causes of WRULD indicates that age, gender (female), psychosocial factors and work organisational factors are also significant. A summary of the known risk factors for WRULD is outlined in Table 4.4.

***Table 4.4 - Summary of Known Risk Factors for WRULD***

| Physical Risk Factors | Psychosocial Risk Factors | Individual Risk Factors |
|---|---|---|
| Repetition | Job demands | Age |
| Force | Job control | Gender |
| Posture | Social relations at work | Socioeconomic status |
| Vibration | | Pre-existing musculoskeletal disorders |

As outlined in Section 4.1, the causes of manual handling injury relates to demands exceeding tissue tolerances. In WRULD, the link between cause and effect is more difficult to tease out. The nexus between the physical risk factors, psychosocial factors, and individual risk factors is complex.

Figure 4.11 below, adapted from Bongers et al, (2002) is a useful model for understanding the interaction, where it can be seen that individual factors interact with psychosocial load, physical load and physiological response to produce chronic musculoskeletal symptoms.

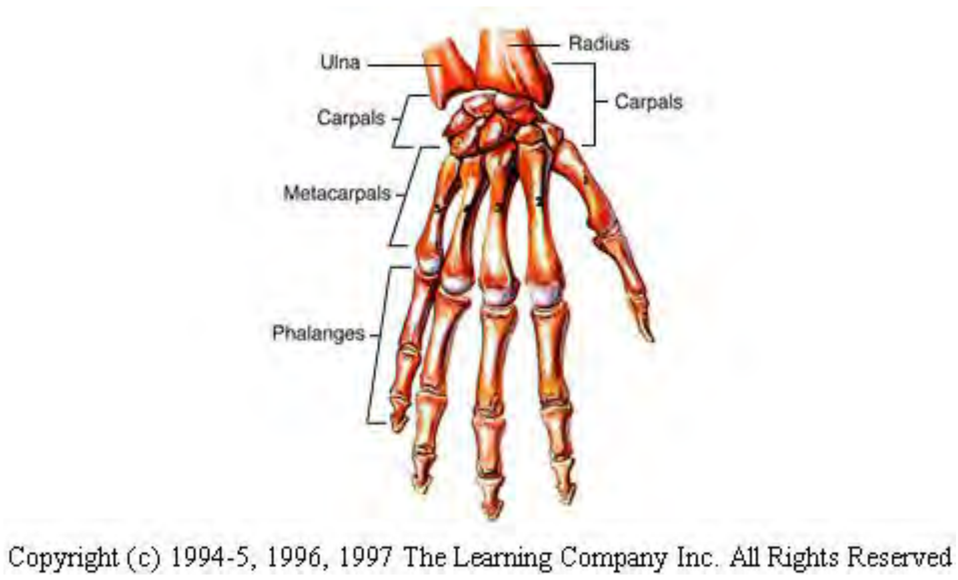



(Source: UOW - adapted from Bongers et al 2002)

***Figure 4.11 - Interaction between Psychosocial Load, Physical Load and Individual Factors and Symptoms and Signs of Shoulder, Arm or Wrist Injury***

**a) The Upper Limb**

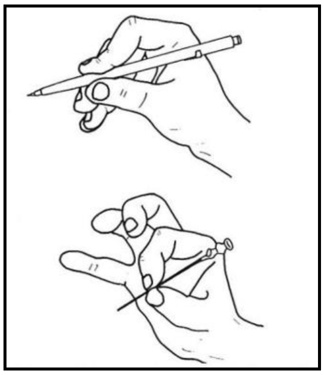
Let us now examine the structure of the upper limb; it comprises of the hand, wrist, forearm, upper arm and shoulder. The hand is comprised of 19 bones with a further eight in the wrist. It is highly flexible but also delicate and has evolved to manipulate and feel small items with a great degree of sensitivity and skill. It does not have intrinsic strength or mechanical power as the muscles of the hand are very small and are adapted to fine movements and precision.




(Source: Mosby's Medical Encyclopedia)

***Figure 4.12 – Bony Structure of the Hand***

Some mechanical power, however, can be achieved through the larger forearm muscles acting on the fingers and through body leverage. Therefore the hand can perform two different types of grasp - the pinch or precision grip and the palmar or power grasps.

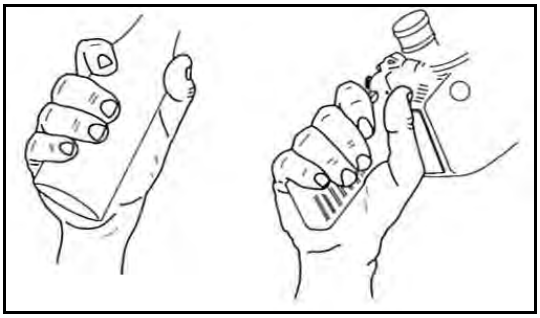


(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 4.13 – Precision or Pinch Grip***

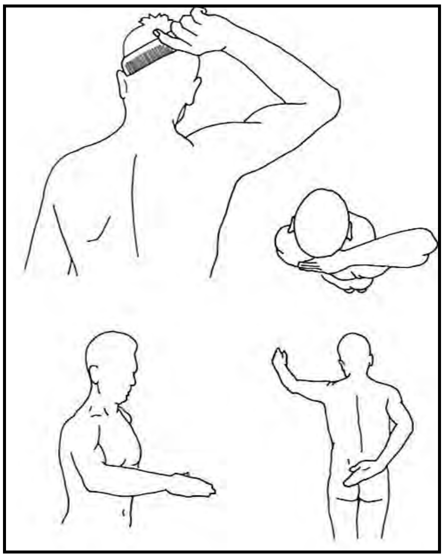
Both require the forearm and particularly the hand to be stabilised. This is achieved by forearm, upper arm, shoulder and trunk muscles which for the most part are working statically.

The manipulative ability of the hand is improved by the full range mobility of the shoulder joint, the hinge action of the elbow and by the rotation of the forearm at the elbow and wrist.



(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 4.14 – Power or Palmar Grasp***



(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 4.15 – Shoulder Function/Range of Movement***

**b) Injury Mechanisms**

The hand is a delicate and highly complex machine at the end of a highly flexible lever on a mobile body but its ability to perform depends to some extent on the rest of the body. Where the shoulder or the trunk cannot be positioned for optimum movement of the hand all three areas may suffer strain. This possibility must be considered in relation to the physical layout of work or the demands of the task.

Similarly where joints are in their outer or inner positions (away from neutral position) repeatedly or long periods, all structures – capsules (connective tissue around a joint), ligaments (strengthening tissue in a capsule), tendons (joining muscles to bones) and muscles – may be stressed. For most people such positions are held for short periods and are desirable intermittently. They are not difficult or damaging unless maintained for long periods or repeated many times. Sitting, reading or sewing with the neck bent is an extreme posture and may lead to considerable discomfort if continued over any length of time.

Work that requires the human body to adopt fixed postures and to repeat movements has become common over the last two to three hundred years. In such jobs the body must work in a way that it was never evolved to do. Repeated movements, be they light or forceful, and fixed work postures, such as at a computer terminal, a work bench or conveyor line put mechanical stress on the body. This cumulative loading on muscles, their capsules and ligaments sooner or later results in fatigue and perhaps strain, and eventually WRULD.

When considering work activities and potential risk for WRULD, it is useful to consider the postural clues that can be observed. Ranney (1997, p. 54,55) provides a list of risks to look for in work tasks for the shoulder, and then the hand and forearm. He notes that the potential damage these risk factors may cause is dependent upon exposure. Possible risk signals outlined by Colombini et al (2002) have also been included in Tables 4.5 and 4.6 outlined below:

### *Table 4.5 - Risk Factors for the Shoulder*

| Risk Factors for the Shoulder | |
|---|---|
| High moments at the shoulder | • Hands far from body, especially if with load<br>• Arms out from body or above mid-torso (weight of arms alone ~ 4 kg.) |
| Static load on the shoulder<br>(NB continuous low loads can be just as fatiguing and lead to injury as infrequent high loads | • Arms held out from body continuously without support<br>• Shoulder girdle elevated<br>• Tools held continuously |
| Awkward shoulder posture | • Working above shoulder height (eg: painting)<br>• Working with arm behind the trunk (eg: reversing machinery) |
| No time for tissue recovery | • Continuous repetition of same activity<br>• More than 1/3 strength required for 1/3 of task time. This may lead to incomplete recovery |

(Source: UOW - adapted from Ranney 1997 & Colombini et al. 2002)

### *Table 4.6 - Risk Factors for the Hand and Forearm*

| Risk Factors for the Hand and Forearm | |
|---|---|
| High forces and very repetitive work | • Cycle time of up to 15 seconds for at least 4 hours within a shift<br>• Little ‘rest’ time between cycles (arms in constant movement) |
| High forces required by task | • Use of fine grips rather than gross grips<br>• Fine grip required to lift object > 900g<br>• Individual fingers used for task (eg: pressing action)<br>• Fingers in hyperextension<br>• Gloves used for task (increases grip requirements due to fit issues)<br>• Lifting activity with palm down (pronation)<br>• Handling of objects > 2.5 kg |

| Risk Factors for the Hand and Forearm | |
|---|---|
| Non-optimal postures (extreme, end of range) | • Sustained flexion/extension > 30º<br>• Rapid, continual wrist movements<br>• Sustained ulnar or radial deviation<br>• Jerky, flicking or tossing movements of the wrist<br>• Sustained full pronation |
| Static loads | • Use of gloves for task<br>• Activity requires wrist to remain in extension<br>• Continuously holding an object |
| Power tools used<br>• High vibration<br>• High torques/poor torques | • 'Kickback' observed from power tool<br>• Vibration – leads to mechanical injury of tissue and may lead to nerve damage |
| Sharp edges and hard surface | • Contact with sharp/hard surfaces by fingers or palm<br>• Hitting/hammering trim or parts with palm of hand |
| High precision placement requirements<br>• Increases time<br>• Increases static loading<br>• Increases force requirements | • Holding parts to fit together<br>• Sustained awkward posture to assemble parts |

(Source: UOW - adapted from Ranney 1997 & Colombini et al. 2002)

The following illustrations and photographs demonstrate potentially 'unsafe' postures of limbs and joints.

(Source: ASCC, 2007 – *reproduced with permission*)

***Figure 4.16 – Prolonged sitting at desk with flexed neck & trunk posture***

(Source: ASCC, 2007 – *reproduced with permission*)

***Figure 4.17 – Repetitive movements of the fingers is required to open pliers because the tool has no return spring. Repetitive use of pliers requires awkward movements and postures of the hands***

(Source: BP International Limited – *reproduced with permission*)

***Figure 4.18 – Working above head height with shoulder at extreme range of movement***

### 4.2.2 Risk Assessment

From the evidence discussed in the previous section, several indicators for risk of WRULMD in the workplace emerge: weight and load (force), frequency of activity (repetition), distances moved (force, posture), workplace layout (posture, vibration), duration of tasks, psychosocial factors, work organisational factors and personal variables.

As in any risk management process, the first step is to identify, then assess, control and recheck to ensure there is no residual risk, or the new controls do not in fact create another, unforseen, risk.

**a) Risk Assessment Techniques**

***i) Simple Techniques***

The simple risk assessment described in the standard has four components:

1. Gather preliminary information of the job task
2. Conduct hazard identification and risk estimation procedure and checklist
3. Overall evaluation of the risk
4. Remedial action required

The standard rates risk with a three colour zone approach: green (acceptable risk), yellow (conditionally acceptable) and red (not acceptable). Should the initial risk assessment produce yellow or red zones, the higher order and more complex risk assessment is to be undertaken, and this is to be done with a prescribed tool, the Occupational Repetitive Action Index (OCRA Index), Colombini, et al 2002.

An alternate and extremely useful tool for assessing the risk of WRULD in the workplace is that of the HSE in the UK. The HSE Risk Assessment Worksheet focuses on the key risk factors of repetition; working posture for each of the upper limb body segments; force; working environment; psychosocial factors and individual differences. It provides prompts for specific issues, control options and an action plan.

### *ii) Complex Techniques*

More complex tools include RULA (all discussed in Section 4.1.4), REBA, QEC, and OWAS and the tool used for detailed risk assessment in the international standard, ISO 11228-3 Ergonomics – Manual Handling – Part 3: Handling of low loads at high frequency, OCRA (occupational repetitive action). OCRA has been selected for use in the standard, as it is based on epidemiological data, considers the known risk factors and can assess 'multitask jobs'. (ISO 11228-3:2007 (E), p. 8). Ergonomists will select the tool most appropriate for the task(s) under examination.

### 4.2.3 Principles of Control, Preventive and Protective Measures

The principles of control, prevention and protective measures reflect the risk factors that have been discussed in Section 4.2. This may entail some complex changes to work organisation as well as modification of actual work stations and areas. Colombini et al. (2002, p. 137) categorises the types of changes required for prevention as structural, organisational, and training and retraining. The suggestions by Colombini have been combined with those of Bridger (2003) and Helander (2006) to provide the following guidelines and suggestions:

### a) Structural Modifications

- Use of ergonomic work tools (appropriately designed tools, handles, grips, etc)
  - Bend tool handles to 5-10º (to avoid wrist deviation)
  - Avoid extreme ulnar and radial deviation (utilise a neutral wrist posture)
  - Use low forces when rotating or flexing wrist
  - For finger pinch movements, keep forces below 10N, as this represents 20% of weakest operator maximal pinch strength

- Optimal/ergonomically appropriate workstation layout, equipment, etc.

    - Angle parts to be assembled for optimal postures
    - Ensure appropriate bench heights
    - Ensure suitable chair for task
    - Ensure adequate work areas

- Reduce identified excessive use of force, awkward postures, and any compression of tissues (eg: wrist permanently resting while hand is working)

    - Encourage use of large muscle groups rather than fine, intrinsic muscles of hands
    - Design products for gripping with hand rather than requiring a pinch grip

**b) Organisational Modifications**

- Ergonomically designed job (appropriate pace, rest breaks/pauses, task variation)

    - Rotate workers between high-repetition and low-repetition tasks/jobs
    - Use machinery for repetitive jobs and use workers for variable tasks
    - Allow workers to set own pace to minimise time or pacing pressure
    - Use ergonomic criteria when planning work systems and purchasing equipment

- Reduce duration of frequent and repetitive movements

    - Design out tasks requiring rapid movements

  - Limit repetitive movements to 2000 per hour or less
  - Eliminate very repetitive tasks/jobs (< 30 second cycle time)

- Ensure adequate recovery time
  - Eliminate unnecessary overtime
  - Avoid repetitive work in extreme temperatures
  - Build in pauses in work cycles

**c) Training and Retraining (in addition to above strategies)**

- Strategies for task variation, rest breaks, work pauses
  - Train management/those responsible for work system

- Provide appropriate information on specific risks and injuries
  - Inform of risks and damage associated with repetitive tasks

- Provide techniques for task performance in line with ergonomics principles
  - Train the workers to perform tasks in
    - → Required order
    - → Use both limbs whenever possible
    - → Avoid unnecessary movements/actions
    - → Grip objects correctly
    - → Communicate with Supervisor regarding changes in work, or signs of discomfort

# 5. WORKPLACE, JOB & PRODUCT DESIGN

## 5.1 WORK ENVIRONMENT

### 5.1.1 Principles of Workplace and Work System Design

In ergonomic work system design, the person is the focus, with the aim of optimising human performance and well-being. This 'work system' refers to:

> *"A system comprising one or more workers and work equipment acting together to perform the system function, in the workspace, in the work environment, under the conditions imposed by the work tasks" (ISO 6385)*

The general design principles include allowing people postural stability and postural mobility. The most common occupational disorders are musculoskeletal, and these are often as a result of lack of attention in the design to body dimensions and body posture, muscular strength and demands on muscles, and body movements.

The impact of work stress is also considered in design, with the aim of making demands on the worker that facilitate improved system effectiveness without resulting in excess stress and resultant physiological and or psychological impairment. (Refer to Section 2.3, Psychology at work, for more detail.)

Visual discomfort, visual fatigue, and reduced vision are consequences of environments that lack well designed or well controlled lighting. For example luminance that is very high can create glare; high contrasts can contribute to fatigue from the eyes continually readapting; and low luminance reduces the user's ability to detect detail. (Refer to Section 6.1 for discussion regarding vision and lighting).

To achieve optimal working conditions, the workplace layout and work systems require careful design.

This design process must take into consideration multiple users with different characteristics, including people with special requirements. It must also include the interaction between the user or users and all the components of the work system such as the tasks, equipment, workspaces and the work environment and the movement of people and materials.

Workplace and work systems design therefore covers more than the individual workspaces and looks at access between workspaces and other functional areas of the organisation eg stores, maintenance, plant room. A workplace may be within a building, a construction site or a mine site; the cab of a vehicle or quite literally 'out in the field' in the case of geologists, farmers, surveyors or environmental officers.

The layout of any workplace should consider traffic flow with the view to reducing slips, trips and falls; manual handling risks; traffic accidents involving vehicles eg forklifts; emergency and fire escapes.

The main phases of the design process (based on ISO 6385 principles) are:

- Formulation of goals
- Analysis and allocation of functions
- Design concept
- Detailed design
- Realisation, implementation and validation
- Evaluation

The process of design is iterative, and works best within a multidisciplinary team representing the key stakeholders, users and design professionals.

**a) Layout of Workspaces**

Workstations and workspaces are the immediate, physical surroundings of the worker.

They can serve a range of different purposes from being the area in which a person works all day to an area that is used by a variety of people for different purposes intermittently. They can be discrete areas such as a computer workstation or part of a larger work area such as a workshop or production area. No matter what they are, workplaces must conform to basic ergonomics principles to accommodate users.

***i) Workspace Size***

The workspace itself must be of a suitable size. Often this is dictated by external factors that have nothing to do with the people working in the area, the equipment they are using or the activities they are performing.

Within buildings, limitations in space and location may be related to the cost of rent, building availability or a lack of planning. Sometimes functions outgrow spaces: more and more people or equipment are fitted into the same space and arrangements become increasingly ad hoc. Redundant or infrequently used equipment may not be removed or relocated and may be left to clutter the work area. Lighting, temperature control and ventilation may be inappropriate for changed functions and arrangements. In these cases review is needed urgently. However, no matter how adequate they may seem all workspaces need regular reviews to ensure that they are adequate and provide a safe and healthy work area.

In mining and similar industries such as construction and agriculture a person's workspace may change constantly or may be mobile such as the cabin of a piece of plant or machinery. These may be difficult to control fully due to the requirements of the building, farming or mining process. In these cases the same rules apply – the workspace must be adequate for the workers and the functions that they need to perform.

The longer the worker is in the workspace during a work shift the more critical the design becomes.

One area of concern when considering workspace size is access by maintenance personnel to machinery in a breakdown situation. Environmental conditions in the field may be difficult and these are compounded by difficult and even dangerous access to components and parts of the machine. Heat, cold, excessive moisture, mud, dust, fumes, restricted spaces and difficult access may add to the problems normally experienced in a workshop where mechanical aids and some protection from the elements are available. Under these conditions each task needs to be assessed for ergonomics risks in conjunction with accident and production risks.

***ii) Workspace Arrangements***

The arrangement of the individual workspace is important especially when the work is stationary and performed in either the sitting or standing position. It depends largely on the type of work being done and the equipment being used. The physical arrangements must permit correct and appropriately supported work posture and unimpeded movements by each worker. The workspace arrangements may have to be modified for each individual if the work is critical.

A number of competing demands may make it impossible to have a perfectly arranged workplace or to meet all recommendations simultaneously so the aim is to achieve an optimum overall. In any workspace there needs to be sufficient space for the use and storage of a range of equipment including tools and appliances, lifting aids, components and spare parts, computer-related equipment and supplies, manuals and reference material, personal protective equipment (PPE) and fixed items.

The location and storage of tools, fixtures, equipment and material used at any workstation should be within the reach of the worker and not cause awkward postures during use. In some cases where items are used intermittently it may be preferable to store them away from the workstation. This has two benefits: it allows the employee more space and encourages them to move about from time to time.

**b) Workshops and Other Industrial Work Areas**

In designing workshops and other industrial work areas, the following factors should be considered:

- *Access* - hatches, steps/stairs and walkways need to be adequate for the biggest person wearing PPE and carrying equipment such as tools and testing devices.

- *Size of the work area* - the largest workers should be able to adopt comfortable work postures in the work area and it should also accommodate all the equipment that is required to do the work safely.

- *The design and selection of tools and job aids* - particularly where access and workspaces are limited may need special attention

- *Temperature and other environmental conditions* - humidity, heat, cold, fumes, oils and dusts need to be measured and any unwanted effects on the worker must be controlled.

- *Visual requirements of the task* - need to be assessed and any special requirements must be met especially where workers need to wear protective or prescription eyewear.

- *Noise levels* – within prescribed guidelines or suitable hearing protection provided. Environmental conditions such as heat and humidity may need to be reassessed if hearing protectors are worn.

- *Wearing of PPE* – needs consideration in task and workplace design eg hearing and eye protectors, hard hats, cap lamps and batteries, self-rescuers, and gloves.

**c) Designing for Maintenance Tasks**

There are a number of considerations for maintenance personnel when working on machinery either in a workshop or in the field. Most of these relate to poor access, restricted work spaces especially when large tools needs to be used or PPE must be worn, inadequate tool selection and/or design, heat and cold, poor visibility, noise and environmental pollutants.

In the last few years manufacturers have made significant design changes to plant to reduce both the time required to undertake routine maintenance and the health and safety risks for maintenance personnel.

Ergonomics design and risk assessments are now required for the design, manufacture and registration of plant in some Australian states through the respective OHS legislation. There is a lot of information on body size and strength and this should be used to ensure that workspaces for maintenance personnel are adequate.

The following design issues need to be considered in any workplace and especially in workshops, industrial and construction areas and for maintenance tasks:

### *i) Design Issues*

*Workspace*

- Work areas can accommodate the number of people required to do the job without posing a hazard
- Height and space restrictions are minimised
- There is adequate access and visibility for maintenance and routine checks
- There is an optimum location for operators on or near machinery and equipment while working
- All sized users are considered in the design of the work areas
- The flow of product or components is logical
- Seating areas are sufficient for easy access and correct adjustment

*Walkways and stairs*

- Free, even and uncluttered walkways on and around the machinery and equipment wide enough to be able to walk forward are provided
- Changes in levels of walking surfaces are minimised
- Slip and trips hazards are eliminated (this includes maintaining temporary floors and uneven ground which may be a work area or walkway)
- All holes or depressions where a foot could get stuck or which may pose a trip or a fall hazard are covered or otherwise eliminated
- Well-designed steps, footholds and ladders for access to the machinery and equipment are provided
- Slip-resistant surfaces on all walkways and steps are provided

- Steps have the following characteristics: minimum of 200 mm deep; lowest step maximum of 400 mm off the ground; steps at least two boot widths wide
- Handrails are within reach of the smallest person and comply with the relevant Standards

*Plant and machinery*

- Sharp edges and protruding obstructions are minimised or eliminated
- Pinch points and moving parts that could crush hands, feet, or the body are eliminated
- Fixed and moveable equipment are located with consideration for proximity to the work area, access, use and storage

*Supplies and equipment that are handled*

- All loads (including tools) are stored so that they can be handled close to the body and at about waist height. Avoid deep storage bins; low, deep or high shelves for heavy or awkward items; and ensure that walkways are kept clear
- Designated storage areas for supplies and equipment with adequate, safe access are provided
- Reach distances are minimised or reduced especially for moving and handling loads
- The need for bending especially bending with twisting is minimised
- Minimal work is carried out above the shoulders or below the knees
- There is minimal manual handling of supplies and equipment, most particularly double or multiple handling

*Environmental factors*

- Work areas are lit adequately
- Loud noise is controlled at source
- Work areas are designed to minimise the use of PPE

### 5.1.2 Workstation & Equipment Design

Workstation design refers to:

*"The combination and spatial arrangement of work equipment, surrounded by the work environment under the conditions imposed by the work tasks" (ISO 6385)*

Work equipment refers to:

*"Tools, including hardware and software, machine, vehicles, devices, furniture, installations and other components used in the work system" (ISO 6385)*

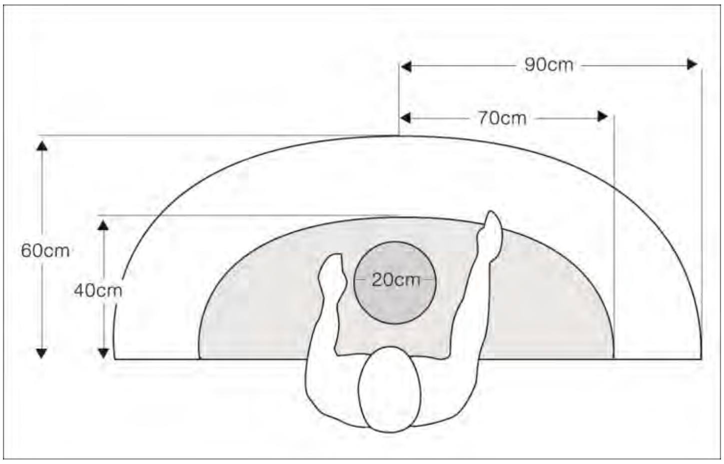
When designing workstations such as consoles and workbenches, the following factors need to be taken into account in order to accommodate the user:

- Horizontal work area
- Working position
- Work height (the height at which the hands are working)
- Viewing distances and angles
- Reach distances
- Access and clearance

Each of these factors is outlined below.

**a) Horizontal Work Area**

These spaces need to include the use of materials and work equipment in the primary and secondary work areas (most frequently and easily accessed) and in the seldom-repeated activities in the tertiary work areas (furthest away).




Source: McPhee, 2005 - *reproduced with permission*)

***Figure 5.1 – Horizontal Work Area showing primary & secondary work spaces***

**b) Working Position**

A sitting position is generally preferred for fine manipulation, and accurate control work; continuous light manual work; close inspection (visual) work; and where foot controls are regularly used. In sitting there should be enough space between the underside of the work surface and the seat for the legs and to allow movement.

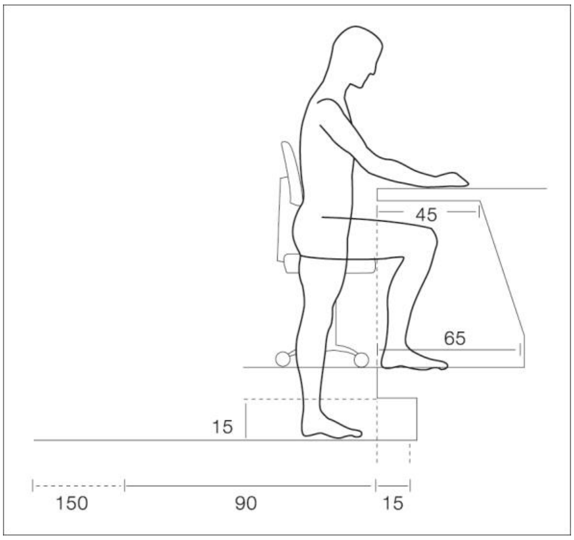
The operator should be seated for constant or repetitive use of foot controls. Where multiple functions are carried out the foot should be used for controls requiring gross movements and the hand for the finer controls eg: driving a vehicle.

A standing position is preferred where heavier manual handling work is performed; where there is no leg room under equipment; or where there are many controls and displays over a wide area that have to be monitored.

Standing work requires even, resilient floor surfaces such rubber matting or carpet. This also reduces the risks of slipping.

Opportunities to sit or stand during the day, preferably as part of the job also should be included. Large and smaller users should be accommodated in these arrangements.

This may be achieved with height adjustable seating, height adjustable work benches or an adjustable standing platform.



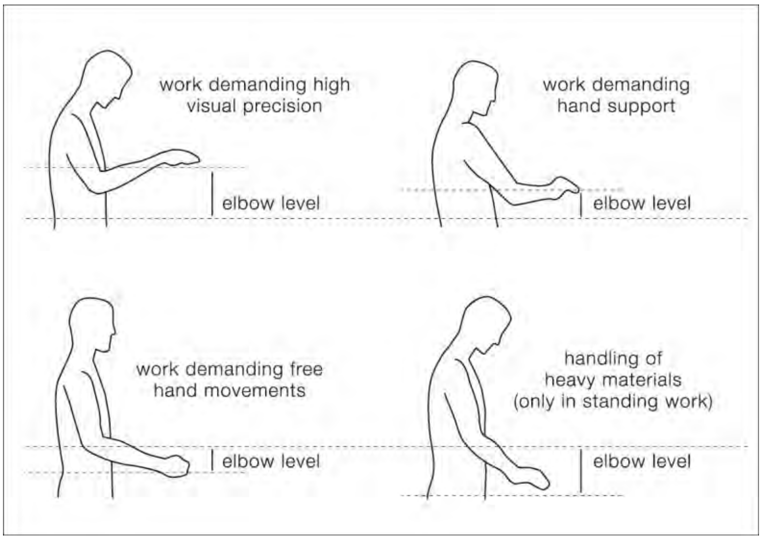

(Source: McPhee, 2005 – *reproduced with permission*)

***Figure 5.2 – Leg Space (cm)***

**c) Work Height**

Preferred work heights depend upon the nature of the task and the need for visual and manual precision as well as the handling of heavy components. In most manual tasks the work height should be at a level just below the elbow with the upper arm held in a vertical position close to the body.

For fine work involving close visual distances the work height should be raised to achieve this with minimal neck flexion and arm supports provided where appropriate.

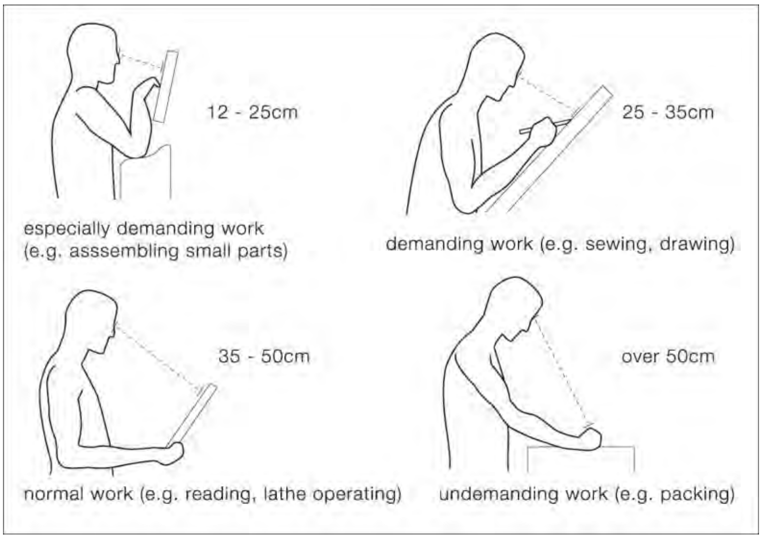



(Source: McPhee, 2005 - *reproduced with the permission*)

***Figure 5.3 – Functional Working Heights***

**d) Viewing Distances and Angles**

Viewing distances for work should be proportional to the size of the work object. A small object requires a shorter viewing distance and a higher work surface. The most frequently viewed object should be centred in front of the worker. Recommended viewing angles vary depending on the work posture from 45$^{o}$ (forward leaning posture such as at a desk) to 15$^{o}$ (backward leaning such as in a control room) and how long a fixed gaze is required. Bent neck postures should not be maintained for more than a few minutes at a time without change. Distances should enable young and older workers to see properly without strain on the eyes or the muscles and joints.




(Source: McPhee, 2005 - *reproduced with the permission*)

***Figure 5.4 – Functional Viewing Distances***

**e) Reach**

Arm and leg reach should be based on the dimensions of the shortest user and taking into consideration the postural, task requirements and working position.

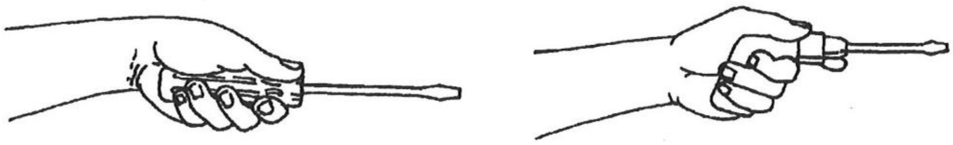
**f) Access and Clearance**

Space allowances for horizontal and vertical clearances and access to the workstation; access to machines and equipment used by operators and for maintenance personnel must be incorporated into the design of the work stations. These allowances must be based on the dimensions of the largest user.

### 5.1.3 Tools

Tools are devices designed to extend human physical capabilities of reach, force application and precision movement thereby enhancing performance. Unfortunately they can also be a source of injury when inappropriately used or incorrectly designed.

Forces are generated from the human musculoskeletal system through the tool to the work piece and vice versa. Stresses arising from excessive forces and poor postures are frequently the result of poor tool design or inappropriate use. In some cases if a tool slips, breaks or looses purchase acute injuries can occur.



(Source: Stevenson, 1999 - *reproduced with the permission*)

***Figure 5.5 – An example of improved hand tool design – bending the handle not the wrist***

Tools are grasped in the hands and may be simple or may have controls. Generally mobile equipment is larger and is activated by controls eg: handles, buttons, knobs that have to be gripped, moved or turned by the application of manual or pedal force. These linkages become part of what is called the user interface. In some cases the status of the equipment can be transmitted to the operator through a display of some kind.

**a) Handles**

Gripping characteristics such as handle shape, palmar or pinch grips, output required eg: power or precision work should be considered. Tools should have handles that have the proper shape, thickness and length to prevent pressure on the soft tissues of the hands and to allow a good firm grasp. They should be free of sharp edges and pinch points.

Insulate contact surfaces to prevent electric shock, burns or the transmission of unwanted vibration. Use low voltage electrical power and double insulation where possible.

**b) Forces**

The forces required to grip tools during use should be minimal and prevent slippage particularly where gloves are required eg hot, dirty or clean work. The grip surface should be compressible, non-conductive to vibration, heat, cold and electricity. Flanges can be used to stop the hand slipping down the tool or to keep a heavy tool slipping out of the hands when being carried.

If the tool is required to deliver power then it should have a power grip handle design ie: the hand should be capable of gripping the tool with four fingers on one side of the handle and the thumb reaching around the other side locking on the index finger.

Where precision work is being required, the tool should have a handle that allows it to be gripped by the thumb and the first finger, or the thumb and the first and second fingers.

**c) Design**

All edges and corners of the tool and associated equipment should be rounded off and sharp, protruding elements avoided.

Tools should be designed so that they can be held and used with wrist and hand in the neutral position. Where the task requires large forces or has to be performed over extended periods, the tool should permit the arms and shoulders to be used.

Align the tool's centre of gravity with the grasping hand so the operator does not have to overcome rotational movement or tool torque.

Ensure that the transmission of noise and vibration is minimised. Guard all moving parts.

**d) Type of Operation**

Power operated tools should be used instead of muscle power where possible. Using a single finger to operate a power tool is not recommended especially where it is repetitive and/or is required for extended periods. While the majority of the population prefers to use the right hand tools should be designed so that they can be used with either hand.

**e) Weight**

Tool weight should be minimal. Where tools are heavy counterbalancing devices can reduce the weight. The tool should be easy to set down and pick up.

(Source: ASCC, 2007 - *reproduced with the permission*)

***Figure 5.6 – Use of concrete saw requires application of high force and sustained awkward postures of back and neck***

**f) Controls**

Detailed advice regarding the design of controls is covered in Section 5.2.4.

**g) Mechanical Aids**

Job aids need to be well designed for the purpose and readily accessible if they are to be used when they should. For instance lifting aids need to be compact, easy to move and use, stable and safe.

Storage is often a problem and this needs to be considered when purchasing. In some cases moveable lifting aids such as cranes and hoists can be installed overhead thereby overcoming storage problems.

Height adjustable benches and jigs need to be sufficiently adjustable to accommodate all users and work tasks. Anthropometric tables (ranges of people sizes) are often used to guide designers in this. Adjustments should be easy and quick to make from the working position.

Wheels on mobile equipment should be of sufficient diameter to enable them to be rolled over rough or uneven surfaces without undue force and without the risk of sudden uncontrolled movements.

Maintenance programs must ensure that job aids meet legislative requirements and function as the manufacturer advises.

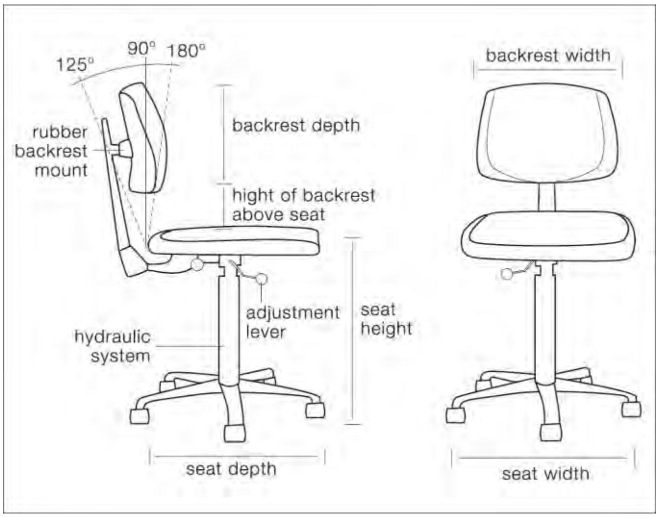
### 5.1.4 Chairs and Seating

#### a) Seated Work and Sitting Postures

Standard work postures recommended in most guides and textbooks are a starting point for seat and work height adjustment. No posture, no matter how good, can be maintained for more than 15-20 minutes before small changes are required. No seat, no matter how comfortable, will allow the user to sit comfortably for more than about an hour at a time without having to move and make significant changes in posture.

Therefore seated work should be mixed with standing and walking. The best way to guarantee that this happens is to design work with a mix of tasks that require employees to get up from a seat and stand and/or walk.

Work at desks and standard-height workbenches require a standard adjustable work chair.




(Source: McPhee, 2005 – *reproduced with the permission*)

***Figure 5.7 – Basic Office Chair for Computer, Office and Control Room Work***

Work at sit/stand workstations may require a higher chair. However, these can be unstable and are not recommended where alternative arrangements are possible. In some cases some work can be done in sitting in one part of the work area and in standing at another part. This may require more space as well as planning.

**b) Work Chairs**

Designing optimum chairs is an ongoing process with much work still to be done. Nevertheless the basic requirements for a work chair do not change. It should provide adequate support for the user while working, should not place any unnecessary stress on any part of his or her body and should positively encourage optimum posture while allowing for comfort and efficiency and minimum muscle fatigue.

There are three major factors that have to be considered when sitting on a work chair.

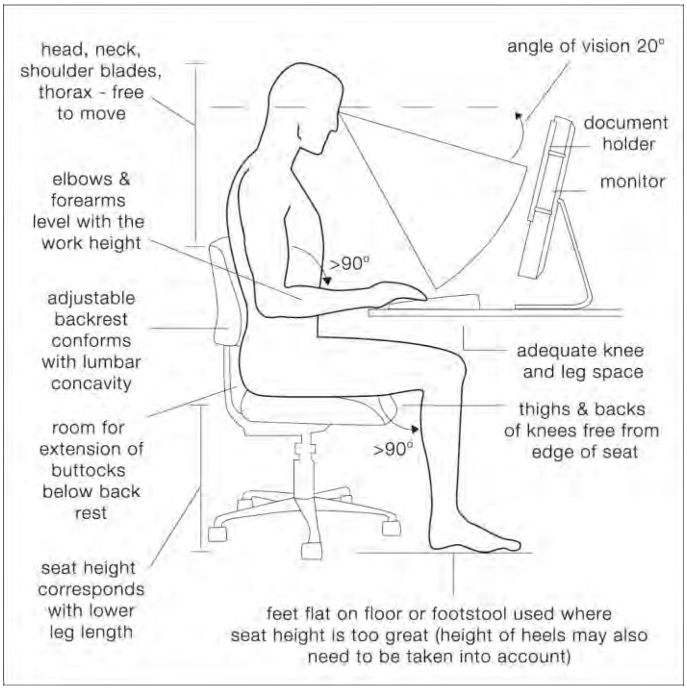
1. The posture of the spine and in particular the position of and the pressure within the discs

2. The type and amount of muscle work required to maintain work postures (static and active) and individual fatigue tolerance levels
3. Compression of tissues (blood vessels and nerves) particularly at the back of the thighs and behind the knees

Non-adjustable chairs are used in common areas such as tea or waiting rooms, where people are not required to sit for long periods in the same spot every day, or where chairs may need to be stored from time to time. These should suit most of the population (middle 90%) to a reasonable degree. The seat height should be in the range of 410–430 mm with a seat depth of no greater than about 360 mm. The seat should have a backrest which is from 80–130 mm above the seat and where practicable (indoors) should have sufficient padding to prevent 'bottoming out' (insufficient suspension/cushioning).

Ergonomics considerations for work chair comfort include:

- As a starting position elbows should be level with the work height, forearms horizontal and upper arms hanging freely
- The head should be able to be held erect with the backrest of the seat conforming with the curve of the lumbar spine
- There should be room for the buttocks below the backrest
- There should be adequate space forward for the legs stretched out and for knees and thighs under the bench top or desk
- Chair height should be sufficiently adjustable in relation to work height and lower leg length to accommodate tall and short people
- Feet should be placed flat on the floor to reduce pressure on the soft tissues at the back of the thighs. Very small users may need an adjustable footstool even when the seat height is adjustable
- The backs of the knees should be free from the front edge of the seat so there is no pressure on the soft tissues




(Source: McPhee, 2005 – *reproduced with the permission*)

***Figure 5.8 – Optimum Sitting Position***

These considerations provide a starting point for chair and desk/work bench adjustment. Individual requirements and certain jobs will mean that postures may vary from this but the principles will remain the same.

### 5.1.5 Vehicle Cabs

There is a large body of ergonomics information available for designing cab spaces, and controls and displays in cabs. Much of it relates to control processes generally but is also applicable to cab controls.

#### a) Ingress/Egress

Adequate hand holds to assist drivers' access to cab should comply with applicable standards. Hand holds must not be placed where driver's hand might be vulnerable to danger.

#### b) Operator's Space

The design of the operator's space must be sufficient for comfort, visibility and operation of equipment such as communication devices.

Operators should be able to reach controls and see displays comfortably and easily from the seated position. Any manoeuvres necessary for the operation of the machine should be able to be performed safely and without unnecessary fatigue or discomfort. Controls should be within an 180$^{o}$ radius of the operator and within easy reach especially in free-steered vehicles (not on rails or tracks).

Good access to the seat and within the cab is dependent upon adequate space between the seat and other equipment and fixtures in the cab. Some seat adjustment fore and aft is usually necessary. Seat swivel will be necessary for machines but there are limited applications for this (cranes, draglines, backhoes etc) and adequate space must be available in the cab.

Tripping or catching hazards and obstructions, both within the cab and while gaining access to it, should be eliminated or modified so as not to cause injury or accidental activation. Sharp corners should be rounded and protrusions padded or recessed or more space provided for access to the seat and equipment.

Line-of-sight requirements for vision outside the cab should be specified. Usually this assumes a control panel in front of the operator and at least 15$^{o}$ uninterrupted line of sight below the horizontal in front of and to the sides of the cab. Rear vision mirrors and other aids to vision should be designed so as not to distort angles, distances or perspective and should give clear and uninterrupted view of the area to be seen. Visibility should be sufficient to see people, obstacles and the state of the work area (the road, objects or materials being moved) that may be critical to the operation or to safety. Mapping the operator's sight lines can be undertaken for different vehicles and machines.

Noise and dust should be minimised through design and maintenance eg: appropriate seals on doors and windows and air filtration systems that are well maintained. There should be adequate, accessible storage space for manuals and other items kept in the cab.

Monitoring should be undertaken to ensure the adequacy of the design and maintenance of the operator's space.

**c) Cab Seats**

Seat design and adjustments should be suitable for the type of work, the conditions, the vehicle and the operators. It should be robust and not have components that are easily broken, torn or damaged.

The specifications for a cab seat should take into account the range of sizes of operators, their job, the type of machine being operated, and opportunities to leave the seat. The seat should be able to accommodate about 97% of all operators (accommodating the extremes of the population, the very small and very large may be expensive and unnecessary). It should be designed for the job and the type of machine being operated.

(Source: UOW, 2008)

***Figure 5.9 – Example of Forklift Seat***

(Source: KAB Seating – *reproduced with permission)*

***Figure 5.10 – Example of Forklift Seat***

The longer an operator is required to sit in the seat without a break the more closely the seat should meet the required specifications. Operators need to get up out of the seat and walk about at least 5-10 minutes in each hour depending on shift length and percentage of the shift spent in the seat.

Height adjustment of the seat is usually necessary to enable short and tall operators to see critical areas outside the cab. Height adjustment of seats in smaller vehicles such as cars and 4WDs are usually not possible due to low roof heights. Some fore/aft adjustment as well as height adjustment in the seat will be necessary to accommodate smaller and taller users.

The detrimental effect of the excessive seat height can be reduced to a small degree by a seat tilt adjustment. However, operators may not be able to use the backrest as effectively with the seat tilted forward.

The backrest height needs to allow free shoulder and arm movement (usually below shoulder height) where there is no acceleration or deceleration fore and aft and no significant lateral movement (such as seats in cranes, drag lines and ship loaders).

A higher backrest is required for on-road and off-road vehicles to support the driver during acceleration and deceleration. The backrest should be firm and supportive, adjustable in height, slightly concave laterally with a lumbar support area that is convex vertically. If there is significant lateral movement within the cab the sides on the seat and the backrest should be slightly raised.

The seat cushion should effectively distribute pressure but not 'bottom out' with heavy users. Where there are significant jolts and jars or other types of whole-body vibration suitable seat suspension will be required.

Seat swivel may be required in machines such as cranes, draglines, bulldozers and ship loaders. If it is provided operators should be able to activate the seat swivel quickly and easily and should be encouraged to do so rather than twisting in their seats. As well, some mechanism for preventing swivel when it is not required should be incorporated.

All adjustments should be achieved easily and quickly from the seat position. Recommendations for adjustment should be provided, preferably attached to seat.

(Source: KAB Seating – *reproduced with permission)*

***Figure 5.11 – Example of Marine Seating for up to 150 kg person***

Armrests are usually not recommended in travelling vehicles as they impede the operation of controls. Where they are considered to be necessary their length and height need to be specified in keeping with current patterns of use and should not interfere with arm movements. They should be able to be stowed when not in use.

Seat belts should be provided where required.

Recommendations for adjustment and regular and timely maintenance should be provided, preferably permanently attached to the seat in some way or displayed in the cab eg: transfers on wall. It should be easy to change or repair seat and backrest covers.

*Table 5.1 – Cab Seat Design Considerations*

| Driver/Operator Seat Dimensions | |
|---|---|
| Seat | Seat depth -- 380–480 mm<br>Seat width – 450 mm (min)<br>Angle -- 5-10º backwards<br>The seat may be slightly dished (raised sides - max 25 mm transverse, 40 mm lengthways)<br>Height adjustment in the seat (at least 130 mm, 200 mm preferred)<br>Height adjustment range above floor level- - 370–500 mm<br>At least 150 mm of travel fore/aft adjustment of seat (AS 2956.5)<br>Front edge and sides of the seat--- well rounded to avoid pressure on the underside of the operators' thighs (approx. 60 mm radius) |
| Backrest including Lumbar Support | Height above seat -- approx 200–250 mm (position of mid lumbar support above seat)<br>Angle adjustment of backrest -- 95-120º to horizontal |

**d) Vehicle Displays**

Display screens should have characters and graphics that can be read with ease at a specified distance. They need to be stable and adjustable in height, angle and distance from the operator’s eyes. Graphics should be clear. Consider design and layout, size, colour, contrast, font and stability of the image.

Reduce specular reflections by matt and non-reflective surfaces and dark colours where appropriate. Consider surface treatments of the screen, careful placement and orientation of the unit and the use of glare-reducing blinds and window treatments.

These must be easy to use and clean and there should be no decrease in visibility to the outside at night for the operator.

Primary displays should be in the direct line of sight of the operator. Displays that are used infrequently may be placed out of the direct line of sight of the operator. Information displayed needs to be large and clear enough to be seen under sub-optimal conditions.

The best viewing angle is at approximately $15^o$-$35^o$ below the horizontal line of sight. If operators use bi- or tri-focal spectacles consider height adjustment for screens that allows screens to be lower or spectacles prescribed for each operator for screen work.

Displays should be grouped and/or located according to their function, the critical nature of the information and the frequency of usage.

Illuminated displays should have a dimming feature for night use.

**e) Vehicle Controls**

The shape, texture and angle of the handle, length of lever, separation, location, resistance and travel of controls need to be specified to optimise the operators' comfort and performance.

Optimum positioning of lever controls in relation to the operator is important. For continuous or repeated use the upper arm should be in a comfortable position and close to the operator's trunk.

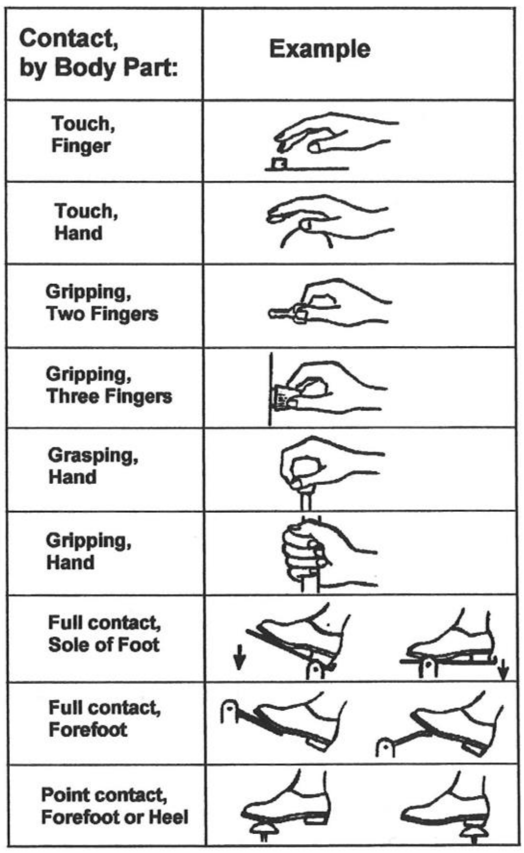
The angle of handles should be considered carefully. The position of function is with the thumb up and the palm of the hand facing inwards. A handle that was slightly angled away from the body may be more comfortable than a straight alignment. See also Posture and Movement, Section 2.2.

A round grip provides more flexibility for changes of hand position, if that is required.

Finger convolutions are not recommended for the handle because they cannot suit all users. If friction or better grip is required consider higher friction surfaces. However, if the palm has to rotate around the handle this is inadvisable.

Lever, knob and button motion stereotypes should be observed (as described in Section 5.2 following). Where local recommendations or standards apply that are contrary to the general recommendations these need to be examined carefully for risks of incorrect operation and a clear guideline outlining reasons for choosing one or the other should be developed. Training times for inexperienced and new users need to be taken into account.

Levers are good where speed of operation is required but are poor for accuracy.  The size, shape, colour and location of knobs and switches and other controls must be matched to usage and their importance.




(Source: Stevenson, 1999 – *reproduced with the permission*)

***Figure 5.12 – Parts of the body which might be used to operate controls***

### *i) Layout of Controls*

Controls should be:

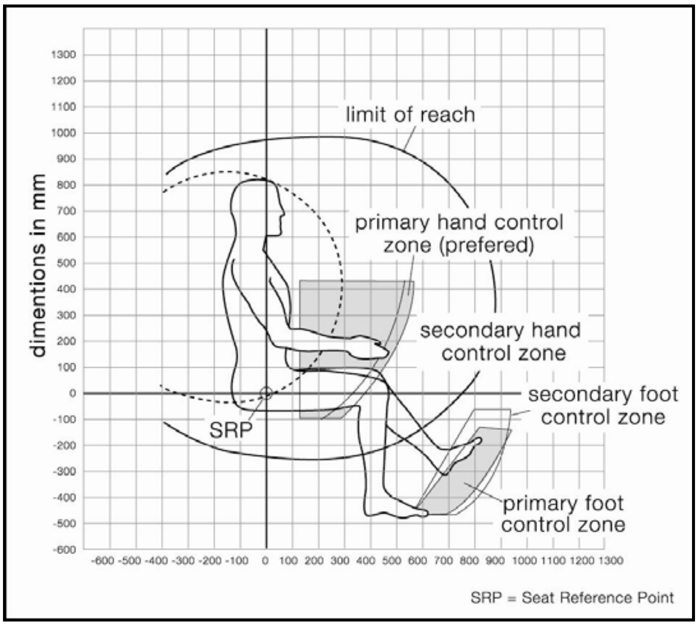
- Laid out and designed to allow easy and safe operation and to prevent confusion over allocation of controls to functions or direction of operation
- All primary controls including their displacement should be located with their neutral position and, if possible, all other positions in the zone of comfort
- All secondary controls should be located within the zones of reach

Controls, control linkages, hoses, tubes and connections should be located so they are not likely to be damaged by foreseeable external forces ie: used as a step, requiring maximum hand or foot forces to be exerted. They should be easily accessible for inspection.

The operator should be able to turn the steering wheel at least 180° within the zone of comfort.

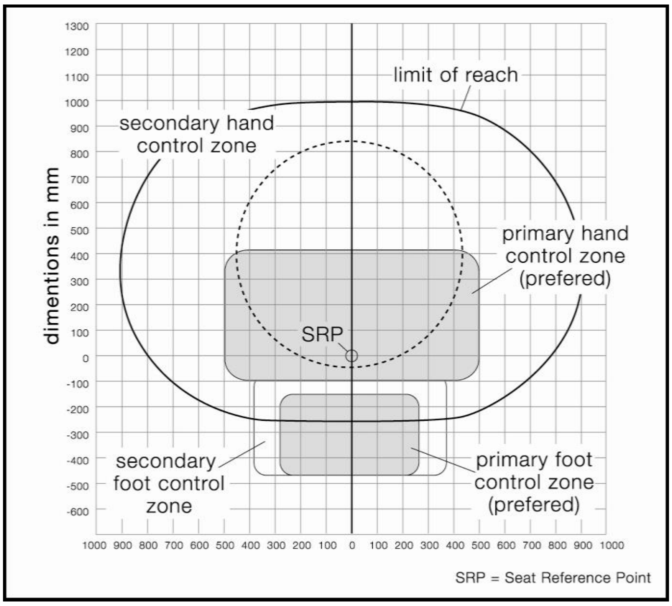
The distance between control levers, adjacent foot pedals, knobs, handles, operator's body and other machine parts need to be sufficient to allow unhindered operation without unintentional actuation of adjacent controls.

Design controls so that they can be actuated within the appropriate zones to eliminate potential interference between the body limbs when simultaneously operating the hand and foot controls.



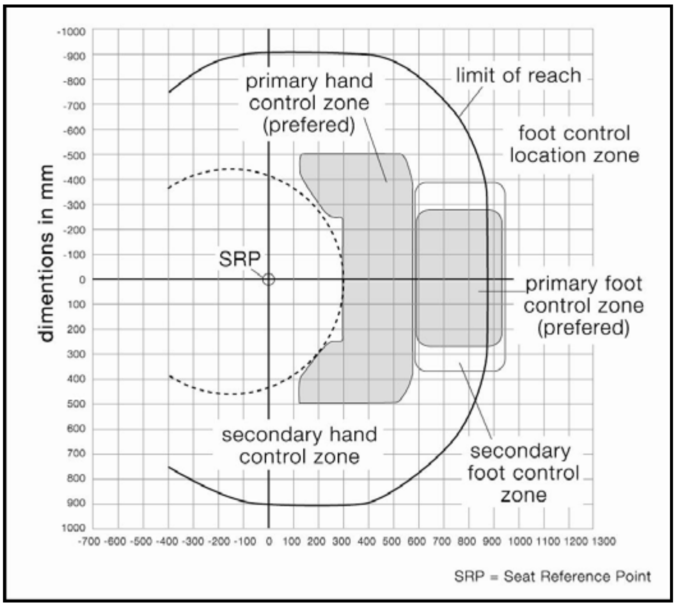

(Source: McPhee, 2005 – *reproduced with the permission*)

***Figure 5.13 – Location of primary & secondary control zone side elevation (Society of Automotive Engineers {SAE})***




(Source: McPhee, 2005 – *reproduced with the permission*)

***Figure 5.14 – Location of primary & secondary control zone front elevation (Society of Automotive Engineers {SAE})***




(Source: McPhee, 2005 – *reproduced with the permission*)

***Figure 5.15 – Location of primary & secondary control zone plan view***

### *ii) Hand Controls*

In general for larger forces where the operating force is one hand the arm is extended forward at 30° to the trunk. For high speed and accuracy the hand should be close to and in front of the body. Where switches are incorporated into the handle they should be far enough apart to prevent inadvertent actuation.

### *iii) Foot Controls*

The exact shape, separation, location, angle, resistance and travel of foot controls are critical for control and ease of use. Some adjustability in seat height may be required to accommodate taller and shorter operators.

Foot controls are quick to use and force can be applied easily. However, they do not give accurate control. Separation should be greater than 50 mm.

The final design should integrate the particular requirements of the operators including the prevention of accidental operation especially in emergencies and ergonomic design principles.

Simultaneous hand and foot control operation fixes the operator's posture and can be tiring for periods of greater than an hour. Therefore regular breaks will be required throughout the day.

#### *iv) Air Conditioning Controls*

Controls for air conditioning should be located with primary or secondary controls (see Figures 5.13, 5.14 & 5.15). Function of each control should be identified in some way and should be easy and simple to use. Displays of information on the status of the air conditioning unit should be clear and unambiguous requiring minimum instruction to understand.

Noise from an air conditioning unit should be minimal and should be measured on maximum with the machine on full power with the doors closed. Airflow should be adjustable and able to be directed away from the operator. Outlets should be spread around the cab to ensure an even temperature in all areas.

Temperature of and airflow into the cabin should be able to be controlled by the operator.

### f) Other Cab Features

#### *i) Sound Levels in the Cab*

Noise generated by the vehicle or outside it should not expose the driver or passengers to excessive noise levels as prescribed in relevant standards for an eight-hour equivalent. Noise generated by the vehicle or outside it should not expose the driver to peak levels that exceed limits laid down in legislation.

### *ii) Visibility*

Ensuring that all surfaces are matt and non-reflective may reduce specular reflections (mirror type). Avoid painting bonnets and parts in front of the driver/operator white or other light colours. Blind spots should be reduced to a minimum and where they remain they should be brought to the attention of the operator and others in the area. Line of sight must not blocked in any critical function by controls, displays or other parts of the cab.

### *iii) Mirrors*

Mirrors or other devices are used to enhance visibility. They must be large enough and correctly positioned to enable the operator to see behind and to the sides of the vehicle.

Distortions created by curved mirrors should be brought to the attention of the operator and extra training may be required.

Extremities of the vehicle or machine should be visible at all times from the cab.

### *iv) Accessibility of Various Items*

Ease of viewing of fluid level gauges/sight glasses enables regular checks to be made without difficulty or error. Misinterpretation of information should be minimised by the design of the sight glass/gauge, which should be easy to clean.

Ease of access to filling points and batteries for checking, filling or removal helps to reduce the risks of expensive errors, accidents or injury while filling and saves time.

Toolboxes (where they are required) should be easily accessible from either the cab or the ground and should be lockable.

***v) Guidelines and Standards***

The Society of Automotive Engineers (SAE) in the USA produces standards that are applied widely in the design of vehicle and machinery cabs. They should be referred to for specific design standards. Australian Standards contain information on the **minimum** design standards for operating cabs generally some of which has been derived from the SAE.

### 5.1.6 Computers (Visual Display Terminals) & Workstation Design

#### a) Computer Tasks

Computers are great tools and are used in most jobs these days. However, problems arise when they become a total job with little variation of tasks, postures or movement throughout the day. As with every sedentary job it is important for people's wellbeing and health to ensure that they undertake a variety of activities during a working day. Where possible, the organisation of the work, including the job content and the furniture designs, should encourage user movement. For example it is recommended to mix computer work with other tasks such as filing, telephoning, meetings etc.

Software design is also important, as described in Section 5.2.5. Flexibility and ease-of-use are often traded off for more features or a higher-powered system that are not utilised by the majority of users. Training and support facilities such as help functions and fully competent colleagues are essential for most users of computer systems. Flexibility and useability of software decrease the need for highly specialised and expensive training, which should be conducted on a need-to-know basis.

Younger people, especially those who may have studied computing or have used a computer at school will have far more confidence with and understanding of computer systems than older people.

People over the age of 60 are likely to be less experienced and less confident users of computers than younger people. Training will need to be organised differently and focussed for older and younger users.

Most users over 45-years-old will need reading spectacles or prescription task spectacles to read the screen as well as any source documents. The size and readability of both the font and display icons will be important for this age group.

**b) Computer (VDT) Workstations**

There is no one computer workstation design suited to all users, as the design is dependent on the user's tasks and the inter-relationship between their different tasks. The International Standard relating to VDT workstation layout (ISO 9241-5) recommends that prior to any design work, a thorough task analysis is undertaken. This must include an assessment of the task and subtasks including their frequency, importance, position of visual objects, duration and type of use of any associated equipment.

The Standard also reminds the designer to consider the location and use of the hands, and to include an assessment of posture, reach distance, device manipulation and the complexity of the movements.

In summary, the computer (VDT) workstation should be carefully designed to take account of:

- *Users* – their age, physical characteristics such as height, their education and training, and their experience
- *Type of computer equipment used* – its age, special features, and general design
- *Users' tasks*

c) **Chairs and Desks**

These should accommodate the range of height and sizes of users. Ideally the desk and chair should be height adjustable, with the chair having a properly shaped and padded adjustable back support.

Alternatively, if cost is a problem, different height chairs with an adjustable footstool or foot rail may be a solution. Most importantly, users should be given instruction on how to adjust the workstation for themselves and why it is important. Refer to Section 5.1.4 for further information regarding chairs and seating.

(Source: WorkSafe Victoria – *reproduced with permission*)

***Figure 5.16 – Appropriate seated computer workstation arrangement using footrest***

d) **Computer Equipment**

*i)* ***Screen Image***

Characters, figures and other aspects of the display should be easily read. A black-on-white image is easier to read than the reverse. The use of colours should not diminish the clarity of the image or the information. The information display should not be compromised by additional material on the screen which is not used regularly eg: toolbars, rulers.

Larger screens may improve image clarity but need longer focal lengths (↑ distance to focus on image) than the average sized screen and therefore up to 50% more desk depth. Older users will have difficulty with smaller fonts and less contrast.

***ii) Keyboard***

This should be:

- Detached from the screen
- Thin - not > 30 mm at home row of keys on QWERTY keyboard (starting ASDF)
- Matt finish
- Dished keys
- Clear, etched figures on keys
- Firm travel and end-feel of keys

***iii) Mouse***

The mouse should:

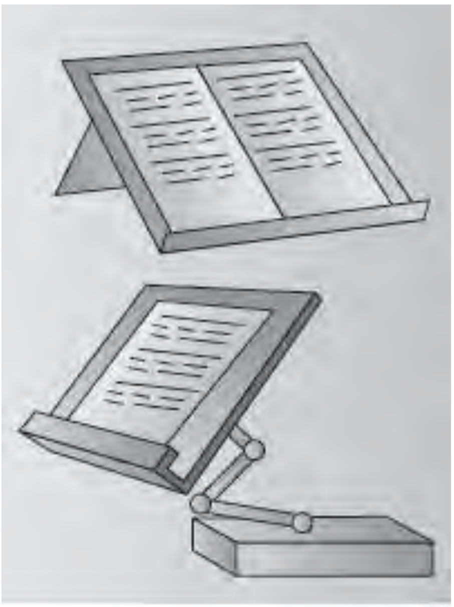
- Have adequate resistance to movement but sufficiently sensitive for fine control
- Be shaped appropriately
- Be large enough to be easily grasped by the hand
- Have firm travel and end-feel of keys
- Have adjustable resistance

***iv) Screen***

The screen should be adjustable in height, angle (vertical axis), tilt (horizontal axis) and distance from the operator (larger screens need up to 50% more space).

### *v) Document Holders*

These should be made available for source material. There are various designs for different types of work and documents. Some work better than others. If source documents are a standard shape and size a raised and tilted surface of any kind may be suitable. Books and special items may need particular designs that are available commercially.



(Source: WorkSafe Victoria – *reproduced with permission*)

***Figure 5.17 – Document Holders***

### e) The Visual Environment

The visual environment should be carefully designed. Lighting, either natural or artificial should create no glare, bright spots or annoying reflections in the visual field of the computer user. Reflections from the screen must be avoided. If possible computers should be positioned away from windows. If this is not possible the terminal should be at right angles to the window. Curtains and/or blinds are necessary to reduce glare from windows.

Generally speaking lighting levels should be lower than is normal for artificially lit rooms. Usually 300-500 lux (measure of light falling on a surface) is recommended as optimum if source documents or reference material are to be read easily.

Similarly, light fittings should be at right angles to the screen and to either side of the user. One-centimetre 'egg crate' light filters (specific design) reduce glare by shielding direct light from the side of lights. Refer to Section 6.1 for further advice regarding illumination and lighting.

**f) Assessing Computer (VDT) Workstations**

There are many checklists that assist the user to assess the above points. The best ones do not provide specific measurements and dimensions but rather encourage and assist the assessor to understand the user's task demands and to identify any workstation design or layout issues that are restricting the user's ability to perform their work comfortably, safely and efficiently.

It is important to remember that one cannot complete a workstation assessment without a specific user and without some knowledge of their tasks. For example one workstation design may suit a large, left-handed data entry operator working from small papers, but be a poor design for a person of different stature, different handedness and performing different tasks that require reference to multiple items of information presented in a variety of different formats.

One recommended assessment checklist is available online from the Cornell University Human Factors Group, at:
http://ergo.human.cornell.edu/CUVDTChecklist.html

This checklist is appended for your reference. Other recommended and easily accessible tools are:

HSE VDU Workstation checklist (2003), HSE, UK
http://www.hse.gov.uk.msd/campaigns/vduchecklist.pdf

A Guide to Health & Safety in the Office (2006), WorkSafe Victoria, Australia
http://www.workcover.vic.gov.au/wps/wcm/resources/file/ebcb9c435c881f7/officewise.pdf

## 5.2 INFORMATION, DISPLAYS & CONTROLS

### 5.2.1 Design Principles For Displays & Controls

Work often requires the use of human-machine interaction, where:

- The machine displays information to the operator
- The operator use control actuators to affect the machine (switches various functions of machine on and off)
- The machine in turn provides feedback to the operator

To ensure accurate and efficient use of the machine, and as required under International Standards, both the control actuators and the displays must be designed with consideration of issues such as:

- Suitability for the task – including function allocation, complexity, grouping, identification, operational relationship
- Self descriptiveness – including information availability
- Controllability - including redundancy, accessibility, movement space
- Conformity with user expectations – including compatibility with learning and practice and with consistency
- Error tolerances – including error correction, error handling time
- Suitability for individualisation and learning – including flexibility

(Principles above as listed in IS EN 894-1: 1997)

A description and examples of the application of these principles follows.

### 5.2.2 Information & Displays

Ergonomics is concerned with all aspects of communication but most importantly it has contributed substantially to our understanding of displayed and oral information (machines communicating to people). It has also developed some basic principles for communication systems.

In all jobs the communication of information is important. In some jobs it is critical. Depending on its nature and how essential it is to communicate precisely and quickly there are a range of methods that can be used. The objectives of a communication system are:

- *Detectability* -- the intended receiver can sense the signal
- *Recognisability* -- the intended receiver can tell what the signal is
- *Intelligibility* -- the intended receiver can tell what the signal means
- *Conspicuousness* -- signal is attention-getting

#### a) Visual Displays

Of the display types, the use of visual displays is most common for the transfer of information.

Simultaneous perception of a large amount of information by humans is best achieved through the eyes and the form in which it is presented must be suited to as many people as possible. Therefore visual information displays should be clear, concise and precise. There should be no doubt about what information is being communicated to the user. In order to achieve this, a range of design rules applies.

Displayed characters may be illuminated such as on a computer screen or on a flat surface such as on the page of book. For legibility consider size, shape, spacing and contrast. In continuous text lower case letters are preferable to upper case.

Capitals should be reserved for the first letter in a sentence, and for headings, titles, abbreviations and proper nouns. Use a familiar typeface, plain and without ornamentation. Use proportional spacing for letters and do not right justify as the spaces become disproportionate to the words, making it harder to read.

Apart from the design of the display its location is critical. For information to be read and interpreted correctly it must be in the user’s line of vision, it should not have reflective surfaces or be able to be degraded by high levels of light. The more critical the information the more it must be easily seen and interpreted.

If analogue displays are used (dials and pointers) to indicate levels or speed for instance be sure that increments are sufficient to be able to be detected and they are not subject to parallax error (whereby a change in observer’s position leads to a perceived change in measurement display).

Displays should be readable from the user’s position without them having to use awkward postures or movements. This is particularly important when information is critical. All information necessary to the normal functioning of the machine, equipment or system needs to be displayed in a readily interpretable form.

The design of information displays and instruments should enhance the operator’s capacity to determine the state of the machine accurately, easily and when it is needed. The aim is to minimise errors, operator fatigue and wear and tear on machinery.

**b) Auditory Displays**

Using auditory displays requires variation in the sound using different intensity, frequency, duration, timbre, or in the duration of intervals between specific sounds. The use of an auditory display may alert the user and precede a forthcoming visual display, and in emergency situations both an auditory and visual display may be used simultaneously.

The use of auditory displays is indicated in the following work situations:

- The operator's vision is already occupied
- The information requires immediate actions
- The message is simple and short
- The work is undertaken in the dark or with limited vision; or
- When the operator must move within the workplace

Auditory displays allow communication with an operator even when they may be occupied with other tasks.

When designing auditory displays consideration must be given to the operator's ability to detect, identify and interpret the sound.

**c) Tactile Displays**

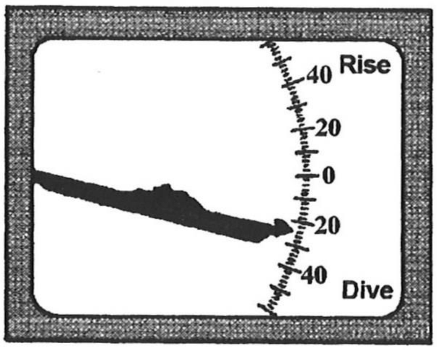
These displays use the state of a surface, and the contours or relief of objects to convey information. The operator then applies touch or pressure to interpret the information. Tactile displays tend to supplement rather than replace other displays, except in cases where workers have a sensory impairment such as blindness.

As with other display types, the display must be easy for the operator to detect, identify and interpret. For example if gloved hands are used on the display the display should have exaggerated features for easier detection, and displays of different shapes should be sufficiently different from each other for easier discrimination.

**d) Quantitative & Qualitative Information Displays**

As Stevenson (1999) outlines, information displays can present the same data in different ways, and this is dependent on the level of detail required and the speed at which it must be understood. Consider what type of instrument display is best suited to the data, without adding any unnecessary complexity.

For example digital or analogue displays or a combination of the two may be used where a quantitative measure such as a specific temperature or pressure must be interpreted.




(Source: Stevenson, 1999)

***Figure 5.18 – Example of Representational display of Submarine Dive***

Where detailed quantitative data is not required, a representational display is well suited to providing rapidly understood advice, such as a change in status of the machine or system. For example this display may simply show zones to represent normal operation, an impending problem, and danger. Alternatively, a system of warning lights with or without an auditory signal may be used.

### 5.2.3 Danger and Information Signals

The phrase 'danger signals' range from emergency signals where people should leave the danger zone immediately, or take urgent action for rescue or protection, to warning signals where people should take preventative or preparatory actions.

A warning is a message that is intended to provide information concerning a possible unpleasant or negative consequence of either an action or a non-action. Warnings can be provided in several ways:

- *Verbal speech* - warnings given by co-workers or supervisors
- *Auditory non-verbal signals* -- the timer on the stove sounding that food is cooked

- *Visual signals* -- traffic lights
- *Signs, labels or symbols* -- a traffic stop sign or a warning label on a hazardous substance or the non-smoking symbol

The type of warnings given will depend largely upon the situation and for whom the warning is intended. For example, an auditory non-verbal signal would be lost in a noisy work environment.

Organisations should consider what type of warning would be suitable to use in a particular circumstance and ensure that the warning is appropriately designed. For example, when using written signs to convey a warning message, the type of language used in the message should be taken into account- use short statements in plain language with symbols where appropriate. Colour/s of the sign, the typeface and the suitable placement of the sign in the workplace need also to be considered.

Where the operator might be in a fixed position the visibility or audibility of warning signals need careful attention.

With visual danger signals, the discrimination between signals requires the use of different characteristics such as colour of the signal light, location, relative position of lights, and temporal pattern.

Colour-blindness needs to be considered where red/green combinations might be used for danger and operational status.

With auditory danger and information signals, the sound can be made to have different characteristics to indicate different situations. For example quick pulsed bursts or alternating pitches indicate danger, short sounds indicate caution, while a prolonged sound following danger signal indicates normal conditions or all clear.

Further detail regarding auditory and visual danger and information signals is provided in the relevant Standards.

The following summary outlines characteristics of signals as recommended by the International Standard for the system of auditory and visual danger and information signals (ISO 11429: 1996).

***Table 5.2 – Characteristics of Signals (ISO 11429: 1996)***

| Message Category | Auditory Signal | | Visual Signal Colour |
|---|---|---|---|
| | Character Available for ON Phase | Temporal Pattern | |
| DANGER – urgent action for rescue or protection | Sweeping<br>Bursts<br>Alternating pitch (two or three frequency steps) | Continuous or alternating on/off<br>Alternating on/off<br>Continuous alternating on/off | RED |
| CAUTION – act when necessary | Only one sound with constant spectrum, minimum duration 0.3 s | Alternating on/off<br>Clearly distinct from emergency evacuation<br>At most two different lengths of on segments in pattern the first one long | YELLOW |
| COMMAND – need for mandatory action | Two or three different sounds each with constant spectrum | Continuous or alternating on/off | BLUE |
| ANNOUNCEMENT / INFORMATION – public instruction | Two tone chime | High-low non-recurrent, followed by instruction | No light signal, normally. If needed, yellow non-recurrent double flashes |
| ALL CLEAR – danger past | Sound with constant spectrum | Continuous, at least 30 s<br>Signal following a preceding warning signal | GREEN |
| Note: Synchronism between sound and light is not generally required, but can improve perception | | | |

(Source: UOW – adapted from ISO 11429, 1996)

**a) Safety Signs and Labels**

The primary objective of safety signs is to warn or caution. The device should be noticeable, recognisable and understandable. They may fall into specific classifications of warning or caution signals or signs; or hazard advisory or instructional. They need to meet the following criteria:

- *Conspicuousness* – the sign should stand out and be located where most people would look
- *Emphasis* – words or symbols should imply danger. Words such as ‘danger’, ‘hazard’, ‘caution’ and ‘warning’ are suitable. Symbols should be standardised and immediately indicate the nature of the hazard
- *Legibility* – when words and messages are used the size and style of letters and contrast with them and the background need to be sufficient to be read. A border separates the message from the background.
- *Simplicity* – use as few words as possible; keep information short and simple; tell the observer what to do or what not to do; avoid acronyms or abbreviations
- *Intelligibility* – say exactly what the hazard is and what might happen if the warning is ignored.
- *Visibility* – make sure that the sign is visible under all expected viewing conditions
- *Permanence* – devices and sign materials need to be resistant to aging, wear, soil, vandalism and deterioration due to sunlight or cleaning.
- *Standardisation* – use standard signs and symbols where they already exist. If local, long-term usage is likely to be better understood this might be acceptable.

However, consider interpretation by visitors and newcomers. Wherever possible ergonomics principles should apply.

### 5.2.4 Controls

Controls provide a method for workers to change the status and operations of a machine. The control actuator may be operated by light touch on a button, grasping and moving a lever, turning a dial, using a foot on a pedal, or other means.

Any controls should be within the reach of the worker when operating the equipment. The forces required to engage the controls should be within the worker's capabilities but not so light as to be inadvertently activated or difficult to control speed or force. The direction of movement of the controls should be consistent with the expected outcome eg moving the control lever forward moves the equipment forward. Ensure that weight-holding is separate from the force, guidance and control functions.

#### a) Layout

Specific considerations in the design of controls should include the following:

- Laid out and designed for easy and safe operation, and to prevent confusion over allocation of control functions or direction of operation. When operators are moving from machine to machine with similar functions controls should be standardised for position, function and operation as far as practicable
- Organised into primary and secondary groups
- Arranged so that similar functions are together (dissociate if confusion is likely) and position with sufficient space between controls to prevent unintentional operation
- Backlit with a dimmer switch for easier identification at night

- There are safeguards against accidental or inadvertent operation for critical controls eg locate out of easy reach; separate; or use guards, recessing, collars or an opening cover

(Source: LG Pty Ltd – reproduced with permission)

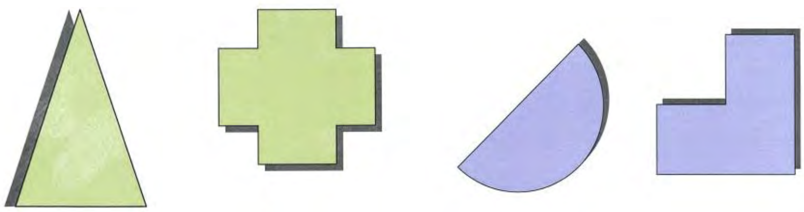
***Figure 5.19 – Example of Good Layout of Controls on Induction Cooktop***

**b) Shape and Size**

Each control should be readily distinguished by its location, type, shape, feel.

The size, shape, colour and location of knobs and switches and other controls must be matched to usage and their importance.

Size should accommodate large feet (pedals) or small/large hands and account for the need to wear protective clothing like gloves or safety shoes.



(Source: UOW)

***Figure 5.20 – Examples of Shapes for Control Knobs***

**c) Movement, Effort, Resistance and Feedback**

Movement of controls should produce a consistent and expected effect. Control force and function need to comply with conventions. Recommended control motions should be observed. For example pushing a control forward will elevate forklift tines and pulling back will lower tines; pushing to left will lead to movement to left.

Optimum force should be required to activate control and movements should be consistent with the natural movements of the arms or legs. Angle of push or pull should be designed for optimum control and movement. Control type should be selected to provide the most appropriate movement or activation control eg: levers for the application of force and speed, smaller controls for fine control and accuracy.

Controls should provide feedback so that operator knows at all times what his/her input is accomplishing. They should have distinct resistance gradients at critical control positions.

Static friction should be minimised (resistance to control movement initiation) as use of excessive force may cause overshoot and correction may be required.

Sensitivity of adjustment controls should be related to the degree of control required especially if they are heavy. Excessive force should not be required for small increases. For instance small movements should not produce large unwanted increases eg: volume control.

**d) Labelling and Identification**

The purpose and location of all controls must be clear. Controls should be marked with etched labels or permanent paint of contrasting colour ie white on black or black on white.

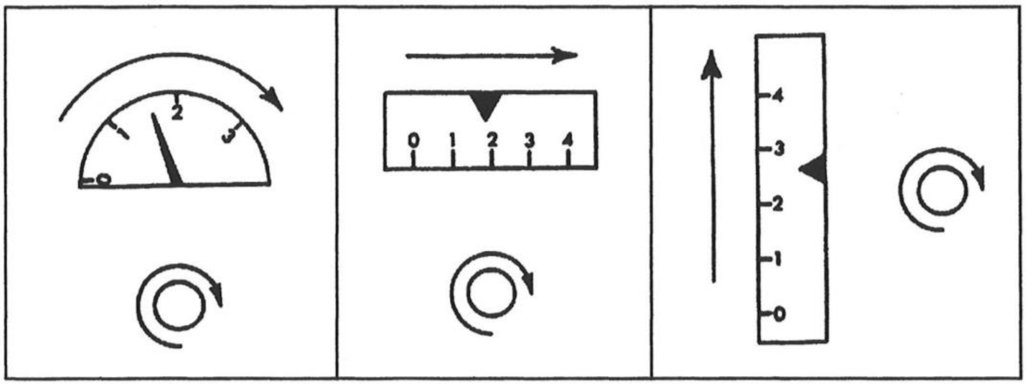
Lighted switches can provide quick identification and feedback on condition and function.

**e) Remote Control Devices**

Special attention needs to be paid to the design of remote control devices and there are many aspects where incorrect design could cause disastrous consequences.
The design of the control, the environment the operator is working in and physical load of remote control on operator are examples and factors to consider.

**f) Compatibility When Combining Displays and Controls**

Where the design of controls and displays does not take into account the user's knowledge, habits or capacity there will be a lack of compatibility. For example a common problem is confusing placement of controls to the displays, such as dials equally spaced along the front of a domestic cooktop, where the cooktop has 4 hotplates arranged in a square. The different spatial arrangement and grouping of the controls and the displays can result in user error.




(Source: Stevenson, 1999 – *reproduced with permission*)

***Figure 5.21 – Some Compatible Arrangements of Controls & Displays***

With experience in operating tools and machines people develop knowledge and expectations about the movement of mechanical objects - such as the way pointers move over scales and dials. Bridger (2003) explains that where the movement on a display is inconsistent with a population's assumptions, the message may not be understood.

For example a common belief or 'population stereotype' that applies to many controls is that clockwise movement refers to an increase or the passage of time, while anticlockwise refers to the reverse.

Even after learning and practice of a new or different movement, people can revert to their stereotypical behaviour and this is particularly the case in times of stress or haste. In Europe the issue of stereotypical behaviour can be a problem when people used to driving on the left hand side of the road and in right hand drive cars (such as drivers from the UK) are faced with the opposite situation, and at times of stress or in emergency situations the likelihood of error with the driving task increases.

***Table 5.3 - Recommended Direction of Movement for Controls***

| FUNCTION | DIRECTION |
|---|---|
| On | Down (switches),<br>right, forward, clockwise,<br>pull (pull/push type switch) |
| Off | Up (switches)<br>Left, backward, anticlockwise, push |
| Right | Clockwise, right |
| Left | Anti-clockwise, left |
| Forward | Forward, down |
| Reverse | Backward, upward |
| Raise | Up, back, rearward |
| Lower | Down, forward |
| Retract | Up, backward, pull, anticlockwise |
| Extend | Down, forward, push, clockwise |
| Increase | Forward, away, right, clockwise, out |
| Decrease | Backward, towards, left, anticlockwise, in |
| Open valve | Anticlockwise |
| Close valve | Clockwise |
| Emergency stop | Push button or pull cord |
| Remote shutdown | Left, backward, push (switch knobs), up switches |

### 5.2.5 Principles of Software Ergonomics

Software ergonomics refers to the interface and interaction between the human and machine in terms of the software. The ergonomic design of software aims to enhance the user's ability to operate applications effectively, efficiently and with satisfaction. Consideration must be given to the user characteristics, the tasks to be performed and the environment in which the system will be used.

The International Standard relating to 'Human-centred design processes for interactive system' (ISO 13407: 1999) identifies and outlines the following key principles of software ergonomics:

- "Appropriate allocation of function between user and system, based on an appreciation of human capabilities and demands of the task
- Active involvement of users in order to enhance the new system and its acceptance
- Iteration of design systems to entail the feedback of users following their use of early design systems (ie: allow user feedback to inform ongoing modification of design systems)
- Multi-disciplinary design team to allow a collaborative process which benefits from the active involvement of various parties, each of whom have insights and expertise to share"

In order to apply these principles, a number of design activities with the focus on the user or human must be undertaken. This user-centred approach requires the following activities are undertaken:

- "Understand and specify the context of use
- Specify the user and organisational requirements
- Produce designs and prototypes
- Carry out user-based assessment"

The design must focus on the usability of the software, and so have regard for human sensory physiology, perception and motivation, cognition and communication, following the principles of:

- “Suitability for the task
- Self descriptiveness
- Controllability
- Conformity with user expectations
- Error tolerance
- Suitability for individualisation
- Suitability for learning”

(from ISO 14915-1:2002)

To enhance usability, the software should be easy for the user to adapt to their experience and knowledge, with information displayed in a format suited to the task and the user. The system should also provide feedback on performance.

International Standards provide detailed guidance regarding the ergonomics issues relating to software design, including design of information technology, multimedia user interfaces, software engineering etc. (Refer to ISO 13407: 1999 and ISO 14915 – 1:2002.)

# 6. PHYSICAL FACTORS OF THE WORK ENVIRONMENT

## SENSING THE ENVIRONMENT

As noted in Section 2, humans make physical contact with their environment through their senses. Information is conveyed to the brain through sense organs such as the eyes, ears and nose.

The stimulus has to be strong enough for the senses to detect before a person can be aware of any stimulation from the environment. The 'absolute threshold' marks the difference between being aware and not being aware of a stimulus and this may vary at different times and under different conditions.

A second threshold, termed the 'difference threshold', refers to detectable differences between two stimuli that can be observed by an individual. This discrimination between the stimuli is also termed the just noticeable difference (JND). The key question is, can the user discriminate one code/stimuli from another, and the JND needs to be established to determine this.

People's senses adapt to various stimuli in different situations. If the stimulus is constant and familiar the sense organs can become insensitive to it.

## 6.1 VISION & LIGHTING

### 6.1.1 The Eye & Visual Capabilities

#### a) Structure of the Eye

The eye operates like a camera catching and refracting light and converting it to a picture. The light passes through the cornea (the clear structure at the front of the eye) and through the pupil (the small aperture). The iris (the coloured part of the eye) controls the aperture of the pupil, allowing variable amounts of light to pass through.

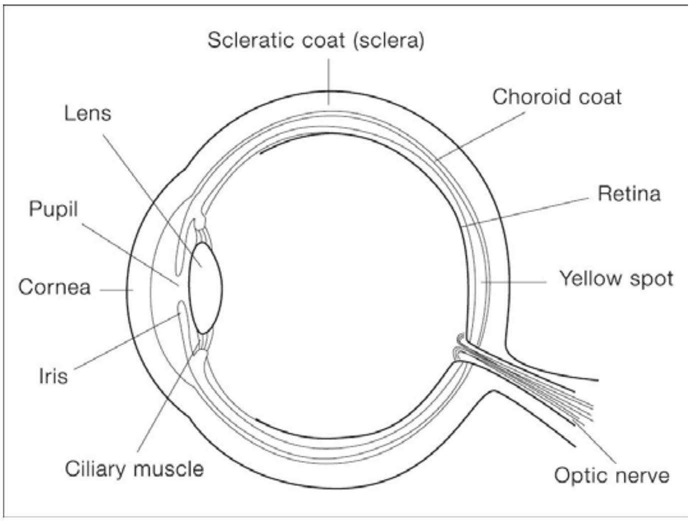
There are two muscles that control the iris and hence the size of the pupil. The iris constricts to make the pupil smaller in the following situations:

- High light levels
- Looking at near objects
- When the eye is irritated

The iris dilates, making the pupil larger in the following situations:

- Low light levels
- When you are alarmed or in pain

The light is focused by the crystalline lens onto the retina. The retina consists of a layer of nerves fibres, and the information it receives is transferred to the brain via the optic nerve. Only objects focused on a tiny area on the posterior surface of the eye, the fovea, are seen clearly. The rest of the retina, known as the peripheral retina, is used for peripheral or side vision. Normally the eye moves about very rapidly so that each part of the visual field falls on the fovea in turn, allowing the brain to gradually build up a sharp picture of the whole surrounding.




(Source: McPhee, (2005) – *reproduced with permission*)

***Figure 6.1 – Anatomy of the Human Eye***

The two types of cells in the retina that collect the light and transfer the information are the rods and cones.

- Rods - Rods are extremely sensitive to light, but they cannot detect shape or colour. Rods are only in the peripheral retina.
- Cones – These are most dense in the fovea, and detect blue light, green light and red light. There are also cones in the peripheral retina, but they decrease in density as the distance increases from the fovea.

While it is important for the whole eye to be healthy, the iris, pupil and retina play a large part in the collection and interpretation of light.

**b) Visual Acuity**

Visual acuity refers to the detection and discrimination of fine detail in visual stimuli. Visual acuity can be assessed used eye charts such as the Snellen Chart. A person with normal acuity can read the 6$^{th}$ line of the chart at a distance of 6 metres (hence the expression 6/6 vision). In the UK and USA the measure is 20$^{th}$ line of test chart at a 20 ft distance (20/20 vision).

To focus on objects at different distances the curvature of the lens of the eye is adjusted using the ciliary muscle, and this process is known as accommodation. The ciliary muscle is relaxed for long vision and contracts for near vision.

The ability to focus changes with age as the speed and range of accommodation reduces. With the ageing process the lens loses its elasticity, making focusing on near objects difficult. A person's 'near point' or the closest distance from the eye at which one can focus increases with age – from about 11cm at age 20 to about 50cm at age 50 – thus reducing the acuteness of the vision (ie: visual acuity).

To improve visual acuity one can increase illumination and/or increase contrast. The extra light on the work can improve visual acuity as it causes the pupil to contract and reduces the aperture of the lens. Glasses can also be prescribed to counteract visual problems.

**c) Colour Vision**

Light entering the eyes is converted into electrical impulses by photopigment in the cones in the retina, and this data is then sent to the brain via the optic nerve. The three different cone types allow us to see about 2 million different hues/shades of colour.

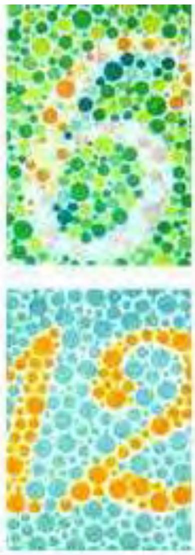
The colour that we see from objects is the result of subtractive colour mixing, with the colour we see being reflected back from the object's surface. All other colours are absorbed.
For example a red coloured surface reflects red and absorbs all other colours, while a black coloured surface absorbs all colours of the spectrum.

Coloured lights are the result of additive colour mixing. While light is a combination of all colours of the spectrum, and yellow is a combination of red and green light.

'Colour deficiency' occurs in approximately 8% of men and 0.5% of women, with mild, moderate and severe problems with being able to discriminate between colours, particularly the colours red and green. In this disorder one type of cone may be missing or not functioning to its full potential. Absolute colour blindness is rare.

Colour deficiency can be critical for certain occupations and when viewing visual displays involving these colours. Where colour vision is reduced, other visual aids such as the items' shape, size, position or brightness can often be used to assist in conveying the meaning of the colour (such as with traffic light location, marine markers etc).

The addition of labels over the colour further reduces any misinterpretation, such as the word ‘STOP’ over a red street sign.



(Source: Mosley’s Medical Encyclopedia)

***Figure 6.2 – Colour Vision Test***

**d) Vision in Low Light**

Eyes can operate in a very wide range of lighting conditions, with the photoreceptors adapting to the different levels. At low light levels we cannot see colour, and as lighting increases we can gradually detect colour and detail. The time for adaptation varies, taking between 2-3 minutes for eyes to adapt to light after being in the dark, to 60 minutes to adapt to the dark after being in the light. While there is rapid adaptation for the first 5 minutes, it takes 25 minutes to reach a level of approximately 80%.

When an individual works in a dark environment and needs to see detail without having their dark adaptation affected, the use of a red light is recommended as the rods are not sensitive to the long wavelength (red) light, yet the cones will have enough stimulation to be able to operate.

**e) Contrast Sensitivity**

Contrast sensitivity refers to the eyes ability to perceive small differences in luminance (light intensity) and so allows for the perception of shape and form, such as to detect an object against a background. Where there is minimal difference, such as black text printed on a dark blue background, visual performance (in terms of speed and accuracy) decreases. A low contrast may allow only the detection of a shape, while high contrast will allow the detection of detail. Sensitivity to contrast can be reduced in an environment with glare or if an individual's eye has cataracts.

Contrast sensitivity also includes the eyes' ability to detect light flicker. Light flicker refers to quick, repeated changes in light intensity - light that appears to flutter and be unsteady. People can see lights flashing on and off up to about 50 flashes or cycles per second (50 Hertz) – but after this level at higher frequencies most people can no longer distinguish between the individual flickers. At this frequency - the critical 'flicker fusion frequency' or 'flicker fusion threshold' - the flashes appear to fuse into a steady, continuous source of light. This happens because the response to the light stimulus lasts longer than the flash itself. Contrast sensitivity can be more important in many work situations than visual acuity as it allows for inspection work and product control.

**f) Glare**

Glare is usually associated with the presence of a bright surface or object in the field of view and is classified as:

- Disability glare – This causes a reduction in the ability to see, such as when a car's high beam headlights shine in the eyes of an oncoming driver

- Discomfort glare – This is due to excessive contrast between surface areas in the field of view and causes visual discomfort, such as the reflection of a lamp on the page when reading a glossy magazine

Eyes are unable to adapt to these extreme lighting conditions, so other measures are required to reduce the problem. Typical sources of discomfort glare at workplaces include:

- Unshielded lamps mounted too low, so in the normal filed of view
- Large windows in the field of view
- Excessively bright lighting
- Reflections off bright surfaces

To manage glare one should first consider eliminating the source of glare, followed by shielding the glare source, moving the glare source or re-orienting their position to avoid viewing the glare source. For example sunglasses reduce the luminance (brightness) of all objects in the visual field, and anti-reflective coatings or matt finishes can reduce reflections from troublesome surfaces.


(Source: www.eclipze.com.au – *copyright permission pending*)

***Figure 6.3 – Example of Disability Glare***

(Source: www.tintshield.com.au – *copyright permission pending*)

***Figure 6.4 – Example of Discomfort Glare***

**g) Veiling Reflections**

Veiling reflections refers to when reflections on an object being viewed are so bright that the contrast is reduced, making detail unreadable. The problem is related to glare. Common examples of this are reflections of light or windows on computer screens; gloss papers; and internal reflections on vehicle windscreens. Each of these problems with reflections can be eliminated or reduced through adjusting the angle of the light, screening the light, or using dark, matt surfaces and avoiding gloss finishes. Veiling reflections can be a problem in reading and interpreting displays.

### 6.1.2 Lighting For Work

**a) Illuminance & Luminance**

Lighting levels are usually measured in terms of the illuminance, which is the amount of light falling on a surface (luminous flux incident on a surface per unit area). It is generally measured with a light meter lying on or against the work surface, such as the horizontal work surface of a desk, or the vertical work surface of a whiteboard etc. The unit for illuminance is lumens per square metre, or lux (lx).

The maximum illuminance from a given source is obtained by moving close to, and directly under the source.

As well as light falling on surfaces (illuminance), light is emitted by surfaces and objects (luminance). This light can be measured by a light meter or photometer pointed at the surface and this is measured in candela per metre squared (cd $m^2$). The luminance or brightness of the surface or object will vary according to the intensity of the source light and the reflectivity of the surface.

Luminance = illuminance x reflectivity

Illuminance and luminance readings of a surface allow its reflectivity to be calculated. Work surfaces with a high reflectivity can cause annoying glare.

The International Standards (eg: ISO/CIE 8995 parts 1 & 2) provide advice on the levels on illuminance and other lighting characteristics for different activities undertaken indoors and outdoors. They include guidance for general building areas plus for specific work tasks covering broad ranging workplaces such as: agriculture, manufacturing, education, transport, offices, power stations etc.

**b) Luminaires**

The term used for lighting installations or light fittings is ‘luminaires’ and these are fitted with various lamp types. Common lamp types are incandescent (such as conventional incandescent (heated filament) or tungsten halogen lamps) or gas discharge lamps (such as fluorescent lamps).

In determining the amount of light that must fall onto a work surface, it is necessary to distinguish between orientation lighting, normal working lighting and special lighting.

**c) Orientation Lighting**

Select a light intensity of 10-200 lux for orientation tasks. The minimum required intensity to detect obstacles is 10 lux. A light intensity of 10-200 lux is sufficient where the visual aspect is not critical, such as in corridors of public buildings, or for general activities in storerooms, provided no reading is required. A higher light intensity may be necessary for reading or to prevent excessive differences in brightness between adjoining areas. Where eyes need to adjust rapidly when moving between the areas, such as when driving into tunnels, reduce the differences in brightness.

**d) Normal Working Lighting**

Select a light intensity of 200-800 lux for normal visual tasks such as reading normal print, operating machines and carrying out assembly tasks. Where the details are small or hard to read, the person is older or has visual difficulties or where there are great contrasts of light such as near windows, more light will be needed.

**e) Special Lighting**

Select a light intensity of 800 - 3000 lux for special applications. It is sometimes necessary to use desk lighting to compensate for shadows or reflection on the work surface. Intensive activities requiring precision such as visual inspection tasks require much higher illumination levels to distinguish fine detail.

Avoid excessive differences in brightness within the visual field. Reflections, dazzling light and shadows can all cause difficulty in seeing. Use a combination of ambient (general) and localised or task lighting for localised tasks.

**f) Designing Lighting Systems**

To achieve the best lighting systems in a workplace, each of the following factors must be considered:

- Task – detail, large/small, stationary/moving, contrast
- Viewer – young or old, visual impediments
- Room or area – wide, narrow, high/low
- Environment – clean/dirty, maintenance, surface reflections
- Luminaire – open/closed, upward/downward, beam shape, environment
- Lamp – type, colour, life, lumen output, wattage
- Illuminance level – refer to relevant Standards
- Uniformity – layout, modelling/shadows (ensure lighting levels are uniform in work area – check for shadowing effects)
- Maintenance – of lamps, luminaries, room surfaces, windows
- Daylight – availability, energy conservation, good colour, user well being, glare

(Philip Saks, School of Electrotechnology, Regency Institute of TAFE 2000)

In summary, for any lighting system the aims are:

- For the task to be seen easily – with suitable maintenance illumination, and with no disability glare or veiling reflections
- Promote user comfort – with no discomfort glare

  and

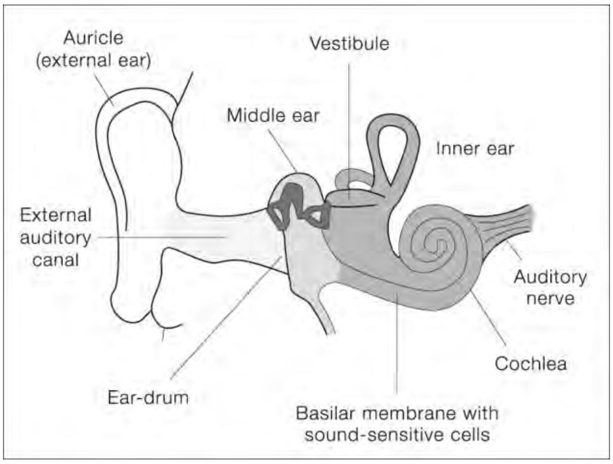
- Enhance safety – with adequate maintenance illumination levels, no flicker effects and with adequate colour rendering

## 6.2 NOISE

### 6.2.1 Ears & Hearing

The ear and auditory system consists of the external ear, middle ear (separated from the external ear by the ear drum), inner ear and the central auditory pathways. Sound travels to the ear in waves. These are transmitted via the auricle (visible part) and external auditory canal through the eardrum to small bones in the middle ear that vibrate. From there the vibrations are transmitted to the inner ear and to the sensory cells of the cochlear that respond to particular frequencies or pitches. The cells transform the sound waves to nerve impulses that are transmitted to the brain. The cells and hairs can be damaged when exposed to loud noise.

The ears also contain the semicircular canals that are necessary for balance and body orientation.




(Source: McPhee, (2005) – reproduced *with permission*)

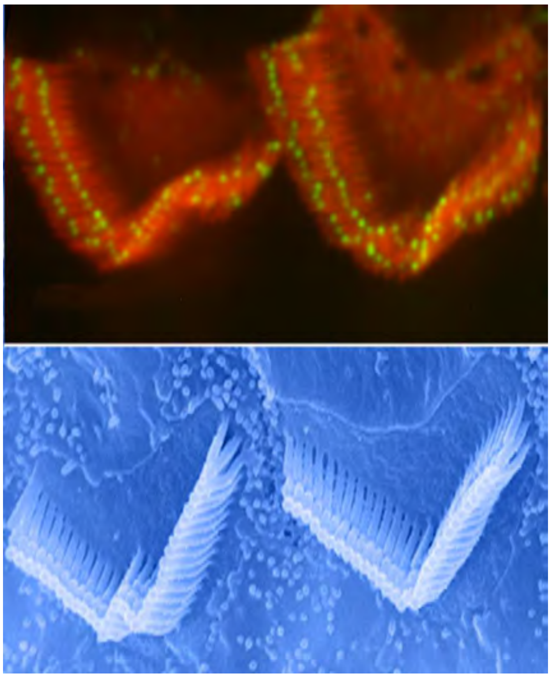
***Figure 6.5 – Anatomy of the Human Ear***

### 6.2.2 Noise

#### a) Hearing Problems

Noise tends to be described as a disturbing sound. Different kinds of noise affect hearing in different ways: the higher the pitch the worse the effects; the clearer the tone the greater the hazard; the higher the intensity the greater the damage.

Most noise control programs concentrate on reducing the total amount of noise (noise dose) that a person receives each day in order to conserve his or her hearing.



(Source: B Kachar, NI DCD – *reproduced with permission*)

***Figure 6.6 – Microscope of Outer Hair Cell of the Human Ear***

Noise induced hearing loss (NIHL), noise induced hearing damage (NIHD), and noise-induced permanent threshold shift (NIPTS) refer to the gradual reduction of the ability to hear sounds as the result of over exposure to loud noise. Hearing loss can affect understanding of speech, perception of a range of normal, daily 'signals' and appreciation of music. Prior to developing permanent hearing change and loss people usually experience a 'temporary threshold shift' (TSS).

The speed at which loss develops is affected by both the intensity of the noise and the duration of exposure to the noise.

The condition may develop following exposure to a very high level of noise for a short time (such as being near an explosion) but more commonly follows chronic exposure to noise.

The greater the length of exposure to damaging noise on a daily basis the greater is the risk of permanent hearing loss.

Tinnitus can be an early warning sign of noise induced hearing loss. This is an irreversible and distressing physical condition where the individual experiences noises such as ringing, whistling, humming or buzzing in the ears and/or head. The most common causes are exposure to excessive noise and ageing.

The current International Standard relating to acoustics and occupational noise exposure (ISO 1999: 1990) does not stipulate a specific formula for assessment of the risk of handicap, but specifies methods for predicting hearing impairment.

**b) Nuisance, Distraction and Annoyance Noise**

Noise can also be a nuisance without effecting hearing. Nuisance noise can be distracting, affect concentration and reduce productivity. It may also lead to early and unnecessary fatigue, and be dangerous where critical tasks are being performed. In environments that are too quiet ie: <30dB(A) any noise may become distracting or irritating. Usually a balance needs to be struck.

The experience of the noise is largely a subjective experience and the noise can be more annoying when the following factors are relevant:

- Loud noise of a high frequency
- Bad past experiences of the noise
- Not being accustomed to the noise
- Dislike of the source of the noise (be it a person or machine etc)
- Lack of familiarity with the noise
- If the noise is intermittent rather than regular

As well as feeling annoyed from noise, physiological studies have identified stress changes in the body such as raised blood pressure, accelerated heart rate, increased metabolism and increased muscular tension. Peoples' feelings and responses to noise should not be ignored, as they may also be a warning that noise is excessive.

**c) Measuring Noise**

Noise is measured in decibels (dB), including:

- 'A-weighting', or dB(A), is used to measure average noise levels as it approximates the sensitivity of the human ear at low noise levels. This is typically used to assess for the potential of hearing loss
- 'C-weighting', or dB(C), is used to measure peak, impact or explosive noises. This weighting is used to determine suitable personal hearing protection equipment in high noise environments

Even small differences between noise measurements have a large influence on the noise, as every 3dB change in noise level results in a doubling of the noise.

**d) Excessive Noise**

The following conditions can act as a guide if people are unsure if noise levels are unacceptable.

When noise levels are:

- Above 80 decibels (dB) people have to speak very loudly to be heard
- Between 85 and 90 decibels people have to shout to be heard
- Greater than 90 decibels people have to move very close together and shout to be heard

Apart from hearing loss and other direct health effects noise can be detrimental to communication and performance. For example, background noise often interferes with complex mental activities; noise can make it more difficult to learn dextrous tasks; and high levels of noise either continuous or unexpected, can impair mental performance.


(Source: HSE Noise at Work – *reproduced with permission*)

***Figure 6.7 - Examples of Typical Noise Levels***

As advised by the HSE, in a workplace, noise should be reduced where any of the following situations exist:

- The noise is intrusive for most of the working day
- Employees have to raise their voices to carry out a normal conversation when 2m apart for at least part of the day
- Employees use noisy powered tools or machinery for more than half an hour each day
- There are noises from impacts such as hammers, drop forging, pneumatic power tools, explosions etc
- The industry is noisy, such as: construction, demolition and road repair; woodworking; plastics processing; engineering; forging, pressing or stamping; canning or bottling; and foundries

Countries have different regulations and requirements regarding noise exposure and noise limits. For example in the United Kingdom the Noise Regulation has requirements for both level of exposure to noise averaged over a working day or week; and the maximum noise or peak sound pressure to which employees are exposed in a working day.

Lower exposure action values are:

- Daily or weekly exposure of 80 dB
- Peak sound pressure of 135 dB

Upper exposure action values are:

- Daily or weekly exposure of 85 dB
- Peak sound pressure of 137 dB

Levels of noise exposure which must not be exceeded:

- Daily or weekly exposure of 87 dB
- Peak sound pressure of 140 dB

(In the UK, the exposure limit values take into account any reduction in exposure provided by hearing protection).

There are certain steps in identifying and assessing workplace noise problems and deciding what needs to be done. Precise measuring and analysis equipment is used to identify or confirm which people in any workplace are at risk of hearing loss due to noise exposure.

**e) Controlling Noise Exposure**

There are five basic steps:

1. Identify areas of high noise levels.

2. Identify those workers who are at risk, and measure their daily exposure.

3. Conduct an education program, especially for those at risk, ensuring that supervisors and managers also attend.

4. Prepare a noise control program under the headings:

   - Engineering solutions (most preferred option)
   - Administrative solutions
   - Personal hearing protectors (least preferred option)

5. Determine the most effective program in terms of protection and cost.

Isolating the person from the noise through appropriate engineering controls can protect hearing (eg enclosing the workspace from surrounding machinery) or the noise from the person (eg enclosing the source of the noise). Personal protective equipment (PPE) such as earplugs or muffs is less effective but more easily implemented. This equipment may interfere with communication and can cause ear problems in hot, damp environments.

*i) Engineering Solutions*

The following general guidelines to control damaging and nuisance noise at source apply to all workplaces:

- To preserve hearing keep the noise exposure for each person below 80 decibels on average per day
- Minimise nuisance noise such as high pitch, unexpected or distracting noises for everybody
- Make sure that the general noise level is not too quiet eg <30 dB (A)

In order to achieve this, the following strategies may be employed:

- Use a quiet working method or isolate noisy stages of the process
- Use quiet machines and make sure they are well maintained
- Enclose or isolate noisy equipment
- Separate noisy and quiet work
- Use sound absorbing materials in the workplace such as the ceiling and screening

*ii) Administrative Solutions*

Sometimes it is possible to reduce exposures to noise by simply limiting the numbers of people in the area or restricting the times that noisy activities are carried out.

*iii) Use of Personal Hearing Protectors*

Hearing protectors are the least desirable method of controlling damaging noise. People have difficulty in wearing them in certain environments and where communication is important. However, sometimes they are the only reasonable option.

When choosing hearing protectors the pitch (frequency) of the noise must be taken into account. Different types of protective equipment have maximum damping effects in certain frequency ranges. Data on the characteristics of hearing protectors can be obtained from the suppliers. In order to encourage the use of hearing protectors, personal preferences in comfort and ease of use must be taken into account. Different types of ear protectors should therefore be available.

*NB: Emergency Signals is not included here, and can be found in Section 5.2.2 Danger and Information Signals.*

## 6.3 THERMAL ENVIRONMENT

### 6.3.1 Work in Hot or Cold Environments

Module W502 thermal environment provides detailed information regarding risk management for different thermal environments. This section provides an ergonomics context only. Work in the outdoors exposes employees to the extremes of weather and in particular temperature and may be complicated by the lack of facilities such as toilets, protection from the sun and wind and the provision of clean drinking water. In Australia, where heat is usually the main problem, there is also considerable exposure to cold either in the outdoors during winter or in cold stores.

There are six fundamental factors that define human thermal environments:

- Air temperature
- Radiant temperature
- Humidity
- Air movement
- Human activity; and
- Clothing

In hot conditions the body sheds heat to maintain thermal equilibrium. The cooling effect of evaporation of sweat from the skin becomes an important factor. The efficiency of this cooling depends on the humidity of the air, as a high humidity reduces the effectiveness of evaporative cooling.

Human activity and clothing also change an individual’s response to thermal environments. The amount of clothing will also affect cooling efficiency of evaporation due to its restriction of the air flow over the skin. Fabrics with low vapour permeability (those that don't "breathe") further increase the humidity of air near the skin.

**Table 6.1 – Steadman Apparent Temperature**

**Apparent temperature (AT) from temperature and relative humidity - after Steadman 1994**

| Relative Humidity (%) \ Temperature (°C) | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
| 5 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 44 | 45 | 46 | 47 | 48 |
| 10 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 41 | 42 | 43 | 44 | 45 | 46 | 48 | 49 | 50 |
| 15 | 17 | 18 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 33 | 34 | 35 | 36 | 37 | 38 | 40 | 41 | 42 | 43 | 45 | 46 | 47 | 48 | 50 | | |
| 20 | 17 | 18 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 28 | 29 | 30 | 31 | 32 | 33 | 35 | 36 | 37 | 38 | 40 | 41 | 42 | 43 | 45 | 46 | 47 | 49 | 50 | | | |
| 25 | 18 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 27 | 28 | 29 | 31 | 32 | 33 | 34 | 36 | 37 | 38 | 40 | 41 | 42 | 44 | 45 | 46 | 48 | 49 | | | | | |
| 30 | 18 | 19 | 21 | 22 | 23 | 24 | 25 | 26 | 28 | 29 | 30 | 31 | 33 | 34 | 35 | 37 | 38 | 39 | 41 | 42 | 43 | 45 | 46 | 48 | 49 | | | | | | |
| 35 | 19 | 20 | 21 | 22 | 23 | 25 | 26 | 27 | 28 | 30 | 31 | 32 | 34 | 35 | 36 | 38 | 39 | 40 | 42 | 43 | 45 | 46 | 48 | 49 | | | | | | | |
| 40 | 19 | 20 | 21 | 23 | 24 | 25 | 26 | 28 | 29 | 30 | 32 | 33 | 34 | 36 | 37 | 39 | 40 | 41 | 43 | 44 | 46 | 48 | 49 | | | | | | | | |
| 45 | 19 | 21 | 22 | 23 | 24 | 26 | 27 | 28 | 30 | 31 | 32 | 34 | 35 | 37 | 38 | 40 | 41 | 43 | 44 | 46 | 47 | 49 | | | | | | | | | |
| 50 | 20 | 21 | 22 | 24 | 25 | 26 | 28 | 29 | 30 | 32 | 33 | 35 | 36 | 38 | 39 | 41 | 42 | 44 | 45 | 47 | 49 | 50 | | | | | | | | | |
| 55 | 20 | 22 | 23 | 24 | 25 | 27 | 28 | 30 | 31 | 32 | 34 | 35 | 37 | 38 | 40 | 42 | 43 | 45 | 46 | 48 | 50 | | | | | | | | | | |
| 60 | 21 | 22 | 23 | 25 | 26 | 27 | 29 | 30 | 32 | 33 | 35 | 36 | 38 | 39 | 41 | 42 | 44 | 46 | 48 | 49 | | | | | | | | | | | |
| 65 | 21 | 22 | 24 | 25 | 27 | 28 | 29 | 31 | 32 | 34 | 35 | 37 | 39 | 40 | 42 | 43 | 45 | 47 | 49 | | | | | | | | | | | | |
| 70 | 21 | 23 | 24 | 26 | 27 | 28 | 30 | 31 | 33 | 35 | 36 | 38 | 39 | 41 | 43 | 44 | 46 | 48 | 50 | | | | | | | | | | | | |
| 75 | 22 | 23 | 25 | 26 | 28 | 29 | 31 | 32 | 34 | 35 | 37 | 38 | 40 | 42 | 44 | 45 | 47 | 49 | | | | | | | | | | | | | |
| 80 | 22 | 24 | 25 | 27 | 28 | 30 | 31 | 33 | 34 | 36 | 38 | 39 | 41 | 43 | 45 | 46 | 48 | 50 | | | | | | | | | | | | | |
| 85 | 23 | 24 | 26 | 27 | 29 | 30 | 32 | 33 | 35 | 37 | 38 | 40 | 42 | 44 | 45 | 47 | 49 | | | | | | | | | | | | | | |
| 90 | 23 | 25 | 26 | 28 | 29 | 31 | 32 | 34 | 36 | 37 | 39 | 41 | 43 | 45 | 46 | 48 | 50 | | | | | | | | | | | | | | |
| 95 | 23 | 25 | 26 | 28 | 30 | 31 | 33 | 35 | 36 | 38 | 40 | 42 | 43 | 45 | 47 | 49 | | | | | | | | | | | | | | | |
| 100 | 24 | 25 | 27 | 29 | 30 | 32 | 33 | 35 | 37 | 39 | 41 | 42 | 44 | 46 | 48 | 50 | | | | | | | | | | | | | | | |

AT above 50°C

(Source: Bureau of Meteorology, Australia - *reproduced with permission*)

All six factors need to be taken into account when designing work - especially in extreme conditions. Temperature is important but should not be used as the sole indicator for action. (Refer to module W502 Thermal Environment, for detail.)

**a) Body Temperature Regulation and Tolerance to Heat and Cold**

The human body has a relatively constant temperature, with the core temperature around 37 degrees Celsius, plus or minus 1 degree. This core temperature must be controlled to maintain body and brain function.

The effects of hot and cold environments vary between individuals. Some research indicates that distraction and /or arousal from feeling too hot or cold at work may reduce work performance and productivity, and could also result in increased absenteeism. Accident rates and unsafe work behaviours may also be affected by thermal comfort especially if people feel too hot.

There are large variations in individual responses to heat and cold and these will vary with the type of work being performed. Assess tolerable climatic conditions by using employee's opinions as well as observing their physiological responses (flushing, sweating, body temperature, skin temperature and heart rate), and changes in work performance. Decreased urine output, changes in behaviour and flushed skin may indicate dehydration and heat stress. Mild heat or cold stress will affect a worker's responses and their ability to perform work. Serious heat or cold stress can lead to strain and possibly death.

**b) Acclimatisation**

In hot climates the human body can acclimatise and become more efficient in sweating after about 5 days of work (based on a minimum of 2 hours work per day). The sweat is more dilute after acclimatisation, minimising salt loss, and the blood circulation is more efficient.

There is also some evidence of localised acclimatisation in the hands of workers in cold conditions, and this is possibly due to increased blood flow through the hands, (Stevenson, 1999, p.16.3).

**c) Humidity and Wind Speed**

In the heat, humidity can alter a person's perception of how hot it is and his or her ability to undertake strenuous work may be reduced. In high heat and low humidity conditions, fluid loss may be rapid. However, the thirst mechanism in humans is not very sensitive so people exposed to heat must be encouraged to drink more and frequently before they feel thirsty.

The main factor that produces coldness is wind speed. Therefore workers should be protected from wind in cold environments. Measures used for wind speed include the wind chill index (WCI).

### 6.3.2 Measuring the Effect of Heat and Cold

There are a variety of physiological and psychological methods to measure the impact of the thermal environment on workers.

The International Standard on risk assessment for the prevention of stress or discomfort in thermal working conditions advises that an assessment may be as simple as brief qualitative observations undertaken by workers with management, to the use of specialised measurements and evaluation over a few days by specialists in the field (again in consultation with the workers experiencing the discomfort or stress).

Any exact measure of heat and cold and their effects on an employee must take into account air temperature, radiant temperature, air velocity, humidity and the intensity of the work being performed. While there is no entirely satisfactory single measure of heat and cold stress various predetermined measures are available for different ambient and working conditions.

In neutral and cold climates the average resting body will lose about one litre of fluid per day while in warm environments about 2 litres.

Table 6.1 provides a scoring scale for the simplest 'Observation' method. In this table, the ideal score is zero, so the greater the deviation from this score, the greater the need for prevention measures.

***Table 6.2 – Steadman Apparent Temperature as a Wind Chill***

**Apparent temperature (AT) as a Wind Chill - after Steadman 1994**

| Wind Speed (km/h) \ Temperature (°C) | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 | 12 | 14 | 15 | 16 | 17 | 19 | 20 | 21 |
| 2 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 10 | 11 | 12 | 13 | 15 | 16 | 17 | 18 | 20 | 21 |
| 4 | -9 | -8 | -7 | -6 | -5 | -4 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 | 12 | 13 | 14 | 15 | 17 | 18 | 19 | 21 |
| 6 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 | 12 | 14 | 15 | 16 | 18 | 19 | 20 |
| 8 | -10 | -9 | -8 | -7 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 10 | 11 | 12 | 13 | 15 | 16 | 17 | 19 | 20 |
| 10 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 | 12 | 13 | 14 | 16 | 17 | 18 | 20 |
| 12 | -11 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 | 13 | 14 | 15 | 16 | 18 | 19 |
| 14 | -11 | -10 | -9 | -8 | -7 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 10 | 11 | 12 | 13 | 15 | 16 | 17 | 19 |
| 16 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 11 | 12 | 13 | 14 | 16 | 17 | 18 |
| 18 | -12 | -11 | -10 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 | 13 | 14 | 15 | 17 | 18 |
| 20 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 | 15 | 16 | 18 |
| 22 | -13 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 11 | 12 | 13 | 15 | 16 | 17 |
| 24 | -13 | -12 | -11 | -10 | -9 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 12 | 13 | 14 | 15 | 17 |
| 26 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 | 15 | 16 |
| 28 | -14 | -13 | -12 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 11 | 12 | 13 | 15 | 16 |
| 30 | -14 | -13 | -12 | -11 | -10 | -9 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 12 | 13 | 14 | 16 |
| 32 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -4 | -3 | -2 | -1 | 0 | 1 | 3 | 4 | 5 | 6 | 7 | 9 | 10 | 11 | 13 | 14 | 15 |
| 34 | -15 | -14 | -13 | -12 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 10 | 11 | 12 | 13 | 15 |
| 36 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 12 | 13 | 14 |
| 38 | -16 | -15 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -3 | -2 | -1 | 0 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 | 13 | 14 |
| 40 | -16 | -15 | -14 | -13 | -12 | -11 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 10 | 11 | 12 | 14 |
| 42 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 13 |
| 44 | -17 | -16 | -15 | -14 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -3 | -2 | -1 | 0 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 12 | 13 |
| 46 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 3 | 5 | 6 | 7 | 9 | 10 | 11 | 13 |
| 48 | -18 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 11 | 12 |
| 50 | -18 | -17 | -16 | -15 | -14 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -3 | -2 | -1 | 0 | 1 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 12 |
| 52 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 7 | 9 | 10 | 11 |
| 54 | -19 | -18 | -17 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 10 | 11 |
| 56 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -3 | -2 | -1 | 0 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 11 |
| 58 | -20 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 8 | 9 | 10 |
| 60 | -20 | -19 | -18 | -17 | -16 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 10 |
| 62 | -20 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -3 | -2 | -1 | 0 | 2 | 3 | 4 | 5 | 7 | 8 | 9 |
| 64 | -21 | -20 | -19 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -8 | -7 | -6 | -5 | -4 | -2 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 8 | 9 |
| 66 | -21 | -20 | -19 | -18 | -17 | -16 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | 0 | 1 | 2 | 3 | 5 | 6 | 7 | 9 |
| 68 | -21 | -20 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -11 | -10 | -9 | -8 | -7 | -6 | -4 | -3 | -2 | -1 | 0 | 2 | 3 | 4 | 6 | 7 | 8 |
| 70 | -22 | -21 | -20 | -19 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -8 | -7 | -6 | -5 | -4 | -2 | -1 | 0 | 1 | 3 | 4 | 5 | 6 | 8 |
| 72 | -22 | -21 | -20 | -19 | -18 | -17 | -16 | -15 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | 0 | 1 | 2 | 3 | 5 | 6 | 7 |
| 74 | -23 | -22 | -20 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -10 | -9 | -8 | -7 | -6 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 6 | 7 |
| 76 | -23 | -22 | -21 | -20 | -19 | -18 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -8 | -7 | -6 | -5 | -4 | -2 | -1 | 0 | 1 | 3 | 4 | 5 | 7 |
| 78 | -23 | -22 | -21 | -20 | -19 | -18 | -17 | -16 | -15 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | 0 | 1 | 2 | 4 | 5 | 6 |
| 80 | -24 | -23 | -22 | -21 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -10 | -9 | -8 | -7 | -6 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 5 | 6 |

Apparent temperature with no radiational heating and relative humidity fixed at 70%

Formula from *Norms of apparent temperature in Australia*, **Aust. Met. Mag**, Vol 43, 1994, 1-16.

(Source: Bureau of Meteorology Australia - *reproduced with permission*)

***Table 6.3 – Scoring Scales for the "Observation" Method of Thermal Risk Assessment (Ideal score in each category is '0')***

***(Note: Score each environmental condition independently)***

| Score | Environmental Condition | | | | | | |
|---|---|---|---|---|---|---|---|
| | Air Temperature | Humidity | Thermal Radiation | Air Movements | Physical Work Load | Clothing | Worker Opinion |
| -3 | Generally freezing | | | | | | Shivering, strong discomfort of whole body |
| -2 | Generally ≥0°≤10°C | | | Cold strong air movements | | | Strong local discomfort; overall sensation of coolness |
| -1 | Generally ≥10°≤18°C | Dry throat/eyes > 2-3 hr | Cold on face > 2-3 min | Cold light air movements | | | Slight local cool discomfort |
| 0 | ≥18°≤25°C | Normal | No radiation discernible | No air movements | Office work; easy, low muscular constraints; occasional movements at normal speed | Light, flexible, not interfering with the work | No discomfort |
| 1 | ≥25°≤32°C | Moist skin | Warm on face > 2-3 min | Warm light air movements | Moderate work with arms or legs: use of heavy machines, steadily walking | Long, heavier, interfering slightly with the work | Slight sweating and discomfort; thirst |
| 2 | ≥32°≤40°C | Skin completely wet | Unbearable on face > 2 min | Warm strong air movements | Intense work with arms and trunk: handling of heavy objects, shovelling, wood cutting, walking rapidly or while carrying a heavy load | Clumsy, heavy, special for radiation, humidity or cold temperatures | Heavy sweating, strong thirst, work pace modified |
| 3 | Generally ≥40°C | | Immediate burning sensation | | Very intense work at high speed: stairs, ladders | Special overalls with gloves, hoods, shoes | Excessive seating, very tiring work, special clothing |

(Source: UOW – adapted from ISO 15265:2004)

Other approaches to establishing the thermal comfort or stress of individuals are outlined in The International Standard ISO 10551. This includes a number of subjective judgement scales and phrases where workers are asked to provide their opinion and experiences that incorporate the following judgement types: perceptual; affective evaluation; thermal preference; personal acceptability; and personal tolerance.

The results of any subjective judgement scales can then be compared against a Predicted Mean Vote (PMV) and a Predicted Percentage of Dissatisfied (PPD) based on data collected earlier. (Refer to ISO 7730 for further details.)

**a) Heat**

Physical work raises the body's temperature and the increased heat is transferred to the atmosphere. If conditions impede transfer of this heat the body's temperature will start to rise. Such conditions occur with higher air temperatures (>30° C) especially in combination with higher humidity (>50%) and little airflow. If the worker is wearing heavy protective clothing and there is radiant heat from the sun the heat load on the body can be even greater.

The body cools itself mainly through evaporation of sweat. However, this fluid needs to be replaced by higher levels of water intake otherwise dehydration will occur. In high humidity the effectiveness of sweating is reduced. The body temperature may then start to rise and heat exhaustion and heat stroke can set in. Heat stroke can be fatal.
Heat disorders can occur for any of the following reasons:

- Individual factors such as dehydration or lack of acclimatisation
- Inadequate appreciation of the dangers of heat by supervisors or individuals at risk

The wet-bulb globe temperature (WBGT) is the empirical index of heat stress on people at work and is covered in detail in module W505 Thermal Environment.

**b) Control of Exposure to Heat**

As with most other areas of OHS, risks arising from exposure to heat can be controlled through engineering and administrative controls including training. The National Institute of Occupational Safety and Health (NIOSH) in the USA has devised the following control methods.

Engineering controls include:

- Reducing the heat source by moving workers or reducing temperatures
- Convective heat control through cooling air and increasing air movement (air temperature cooler than skin temperature to facilitate heat loss from body)
- Radiant heat control by reducing surface temperatures, shielding etc (blocking radiant heat source)
- Evaporative heat control through increasing air movement (fans), decreasing water vapour pressure (air conditioning), wet clothing

Work practices include:

- Limiting exposure time and/or temperature eg: working at cooler times of the day, cool rest areas, extra personnel for job rotation and frequent breaks, increasing water intake
- Reducing metabolic heat through mechanisation, job redesign, reduced work times, increased personnel
- Enhancing tolerance times through heat acclimatisation; physical fitness; ensuring water and electrolyte losses are replaced

Health and safety training including recognising the signs of heat illness; first aid and contingency plans; personal precautions; use of protective equipment; recognition of effects of non-occupational factors such as alcohol; and a buddy system.

Screening for heat intolerance including previous illness and physical unfitness.

Additional programs include:

- Heat alert programs including planning for work in hot weather through timetabling and adequate information, facilities and personnel
- Auxiliary body cooling and protective clothing including cooled garments and appropriate training
- Understanding performance degradation when wearing all types of protective clothing including those that reduce heat loss or impair vision or hearing

The mnemonic SHAFTS can be used to advise people how to increase tolerance to heat. The letters stand for:

Sensible (ie appropriate) behaviour
Hydrated
Acclimatised
Fit
Thin; and
Sober (avoidance of alcohol and other drugs)

**c) Working in the Sun**

Apart from the heat, the sun is now regarded as a major risk for skin cancer in outdoor workers especially those of European origin.

The use of sun hats and other protective clothing, sun screens for the skin, sunglasses, the provision of clean drinking water and recognition of the need to take regular breaks from physical work in high temperatures should be mandatory in most outdoor jobs. These protective measures may alter the way the work is done and will need to be taken into account in the design of the work and the protective clothes, time schedules and payments for work done.

(Source: Qld Health 2006 –reproduced with permission)

***Figure 6.8 – Workers Wearing Head Gear for Protection from the Sun***

**d) Cold**

In air environments cold stress generally produces discomfort before any effect on health occurs. There is a strong behavioural reaction to cold and a person may avoid feeling cold with clothing, activity and/or shelter. Clothing helps reduce heat loss while activity raises the body's heat production. However if there are higher levels of activity sweating may occur and on rest heat loss and discomfort are made worse by damp clothing.

Cold can affect psychological responses including behavioural responses to increased discomfort. It can directly affect performance such as decreased arousal, reduced memory capacity, and perception. Changes can occur in mood and personality especially if the body's core temperature drops.

The effect of cold on the hands of individuals varies enormously under different conditions. These arise from a number of factors including size, structure and shape of the hand and fingers; contact force; surface temperature of the item being handled; material properties; surface mass; and the thermal condition of the whole body, the hands and fingers.

**e) Control of Exposure to Cold**

Workers in cool or cold climates, in cold storage facilities and in food preparation areas will need adequate protective clothing that takes into account the need to manipulate product, controls and tools safely and quickly. Therefore the wearing of bulky clothing, boots and gloves needs to be considered in the design of the job as well as for hand tools, access to and operation of machinery and the use of seating. Each job should be assessed for its particular requirements and reviewed on a regular basis.

The use of PPE such as gloves can minimise any harmful effects of handling cold items. Decreases in manual dexterity after contact with cold material may be offset by problems with dexterity when wearing gloves. However the design of gloves including thermal insulation and gripping qualities and their appropriate use needs to be carefully reviewed.

Issues that need to be addressed for workers in cold environments include:

- Whether or not it is necessary for the workers to be in the cold environment in the first place. Are alternatives available such as the use of robotics or separating workers from the cold environments?
- Adequacy of clothing to protect from cold and the likelihood of sweating when workers are active (clothing must be adequately insulated; refer to W502 Thermal Environment, Section 9.3 Clothing Insulation Index)

- Work practices encompassing appropriate behaviours eg: wearing adequate protective clothing, length of exposure, activity, care when working with certain substances
- Monitoring air temperature, air velocity and equivalent chill temperature
- Screening workers who may have a reduced tolerance to cold

## 6.4 VIBRATION

Vibration refers to the oscillatory motions of solid bodies. Vibration arises from various mechanical sources with which humans have physical contact. Vibration energy can be passed onto operators from vehicles on rough roads; vibrating tools; vibrating machinery; or vibrating work platforms and may give rise to adverse health effects. These health effects can range from discomfort and interference with activity to injury and disease. The magnitude of the effect of vibration depends on the severity and length of exposure. The two main types of vibration exposure are:

- Hand transmitted vibration, and
- Whole-body (WBV)

Much is known about the effects on humans of hand transmitted vibration but there has been less research into the long-term effects of WBV.

(a) Hand-arm vibration (b) Whole-body vibration

(Source: ASCC, 2007 – *reproduced with permission*)

***Figure 6.9 – Examples of Types of Vibration Exposure***

### 6.4.1 Hand-Transmitted Vibration

#### a) Causes and Effects

Hand-transmitted vibration, or hand-arm vibration, refers to the vibration transmitted from work processes into worker's hands and arms. If exposure to vibration is regular and frequent, such as being a routine aspect of a job, there can be permanent damage to the body.

There are a range of conditions that can be caused by vibration, referred to collectively as Hand-Arm Vibration Syndrome (HAVS).

These conditions and disorders include: disorders of the circulation of the fingers aggravated by cold (vibration white finger); tingling, numbness and/or reduced sensitivity and dexterity of the fingers such as from carpal tunnel syndrome; and muscle, joint and bone disorders.

Once the conditions have become established they are not reversible so prevention through reduction of exposure duration and intensity is extremely important.

Once the condition is established people affected may be too disabled to undertake their job as a result of having functional limitations including: reduced grip strength; reduced dexterity; low tolerance to working in cold or damp conditions; pain and sleep disturbance; and decreased sensitivity.

(Source: www.whitefinger.co.uk – *copyright permission pending*)

***Figure 6.10 – The Effect of Vibration on Blood Circulation, known as "Vibration White Finger"***

**b) Workers at Risk**

Workers most at risk of exposure to hand-transmitted vibration are those operating hand held power tools with a frequency between 25 and 150 Hz. Examples of these tools include: jackhammers or road breakers; hand guided powered equipment such as powered lawnmowers; and powered machines which process hand-held materials such as pedestal grinders.

Industries with high rates of hand-transmitted vibration problems include building and maintenance of roads and railways, construction, foundries, forestry, heavy engineering, mines etc.

(Source: HSE 2005: – *reproduced with permission*)

***Figure 6.11 – Example of Type of Equipment Posing Risk of Hand-Arm Vibration***

**c) Assessing Exposure**

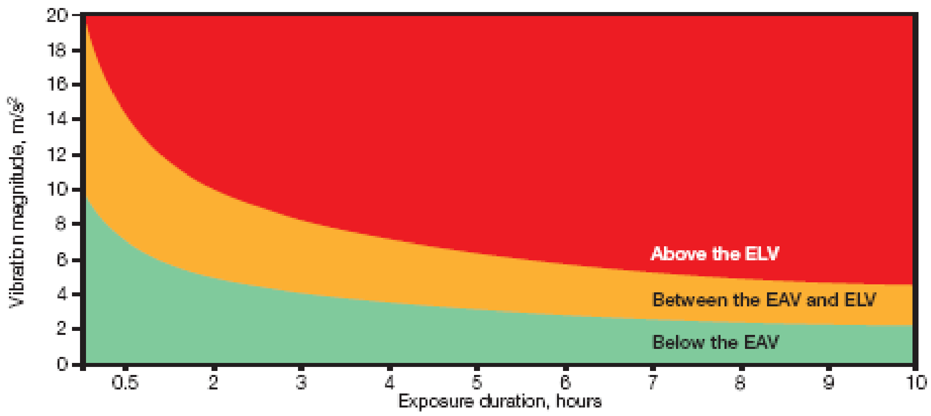
Human exposure to vibration is measured by magnitude of acceleration, frequency, direction and exposure time. The International Standard (ISO 5349-1) recommends that the total daily exposure duration is calculated, and the daily vibration is determined by calculating the magnitude of the vibration (expressed in metres per second squared) and the duration per day, to determine the workers 'daily vibration exposure' (referred to as *A*/8, the average over an 8 hour shift). Where various vibrating tools are in use in one day, each tool is assessed.

In the UK, the regulations provide:

- Exposure action values (EAV) - the daily amount of vibration exposure above which employers are required to take action to control exposure. For hand-transmitted vibration the EAV is a daily exposure of 2.5 m/s squared A(8)

- Exposure limit value (ELV) – the maximum amount of vibration an employee may be exposed to in any single day. For hand-transmitted vibration the ELV is a daily exposure to 5 m/s squared *A*(8).

The Figure below describes this law in the UK.




(Source: HSE 2005 – *reproduced with permission*)

***Figure 6.12***

**d) Reducing Risk**

Management of vibration should focus on using alternative methods that eliminate exposure to vibration or by mechanising or automating the task. An example is provided by the HSE: break up concrete using an attachment on an excavating machine in preference to using a handheld concrete breaker. When handheld equipment must be used, ensure it is the lowest vibration possible and can achieve the required task in the shortest time, so not prolonging the workers' exposure to risk.

Where high-vibration tools must be used, it is important to reduce each worker's exposure and to have several short periods in preference to one long period of vibration exposure.

A wide range of other controls must also be considered as each can impact on risk. The ISO (5349-1) and HSE suggest the following additional controls:

- A maintenance program, to avoid unnecessary vibration and to keep equipment in good order
- Avoiding tools with handle shapes that result in high pressures on the skin in the area of contact
- Selecting tools that require small contact forces (ie grip and feed forces)
- Keeping the mass of the tool to a minimum provided other parameters (such as vibration magnitude or contact forces) are not increased
- Purchasing policy for replacing old equipment and tools
- Improving workstation design, such as using jigs and counterbalancing tools
- Clothing to keep workers warm and dry
- Avoiding use of tools that expel cold gases or fluids over the operator's hand

For a useful screening tool, go to the HSE site:
http://www.hse.gov.uk/vibration/hav/advicetoemployers/inscrquest.pdf

### 6.4.2 Whole Body Vibration

#### a) Causes and Effects

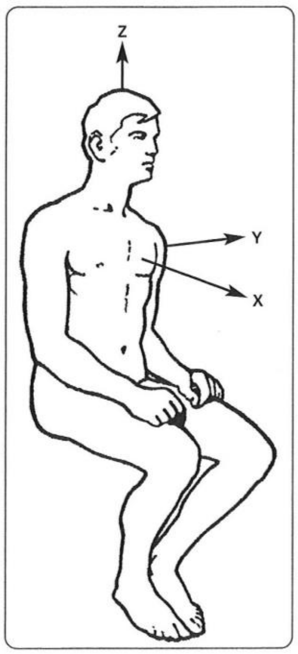
Whole-body vibration (WBV) refers to shaking or jolting of the human body through a supporting surface. The vibration may be transmitted through the feet in standing work or, more likely, through the seat in seated work especially when operating machinery or driving vehicles.

Medical problems as a result of WBV can include: disorders of the joints and muscles, especially the spine; cardiovascular, respiratory (breathing), endocrine (hormonal) and metabolic (conversion of food → energy) changes; problems with the digestive system; impairment of vision and/or balance; and reproductive changes in females. It is now believed that it may be a significant risk factor for the development of low back pain such as from early degeneration of the lumbar spine and from herniated lumbar discs.

There appears to be three different scenarios where symptoms arise. The first is prolonged sitting and exposure to vibration; the second is where injuries result from a one-off severe jolt in an otherwise reasonable ride; and the third situation is where the onset of pain occurs after an extended period of moderate to severe jolts and jars.

Measurement of Whole Body Vibration is in 3 planes:

- Z Vertical (up and down)
- Y Horizontal (side to side)
- X Horizontal (fore – aft)




(Source: McPhee (2001) – *reproduced with permission*)

***Figure 6.13 – Measuring WBV in 3 Planes***

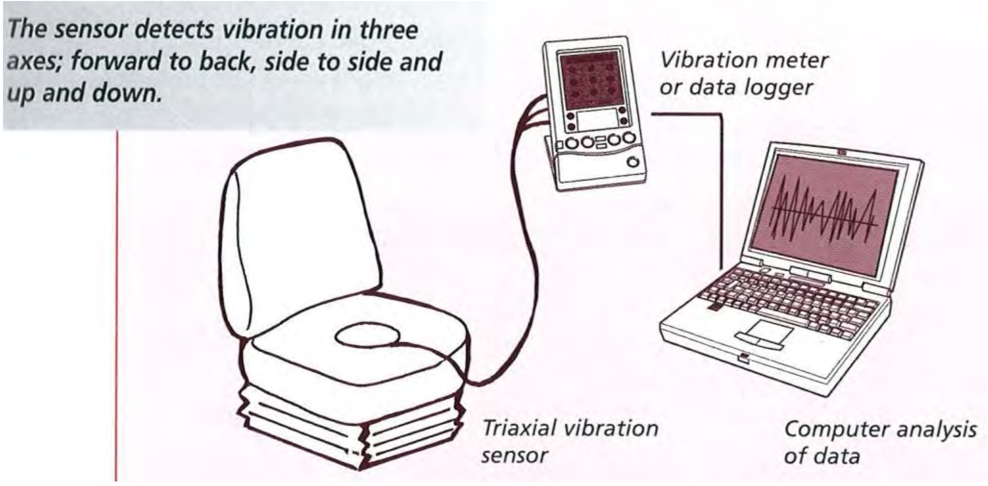
**b) Workers at Risk**

Workers most likely to be exposed to WBV are operators and drivers of off-road machinery such as in the construction, mining, forestry and agriculture industries. People driving vehicles designed for smooth surfaces over rough surfaces, such as cracked or uneven surfaces in a yard, may also be exposed to a high levels of WBV. Road transport drivers are less at risk unless the vehicle has poor suspension or is driven on poor surfaces or off-road. The likelihood of developing injuries from WBV is also affected by age and previous injury. Older (over 45 years) and younger workers (late teens), pregnant women, and people with a history of back or neck pain are most susceptible to WBV affecting their back or neck.

WBV exposure arises from rough work surfaces, vehicle activity and engine vibration and there are a range of factors that can either accentuate or reduce the impact of these.

**c) Assessing Exposure**

WBV exposure can be measured using a vibration transducer such as an accelerometer. The International Standard (ISO 2631-1, 1997) and its equivalent Australian Standard (AS 2670.1-2001) use a combination of methods to assess WBV including the measurement of jolts and jars commonly experienced in off-road vehicles, to determine if the exposure poses a risk to health. The ‘steady state’ vibration is measured using the root mean square value (r.m.s.) methods while shocks or jolts and jars are assessed using either the ‘Vibration Dose Value’ (VDV) which is sensitive to high peaks; or the ‘running r.m.s. method.




(Source: McPhee (2001) – *reproduced with permission*)

***Figure 6.14 – Measuring WBV***

Vibration health exposures are classified as either being:

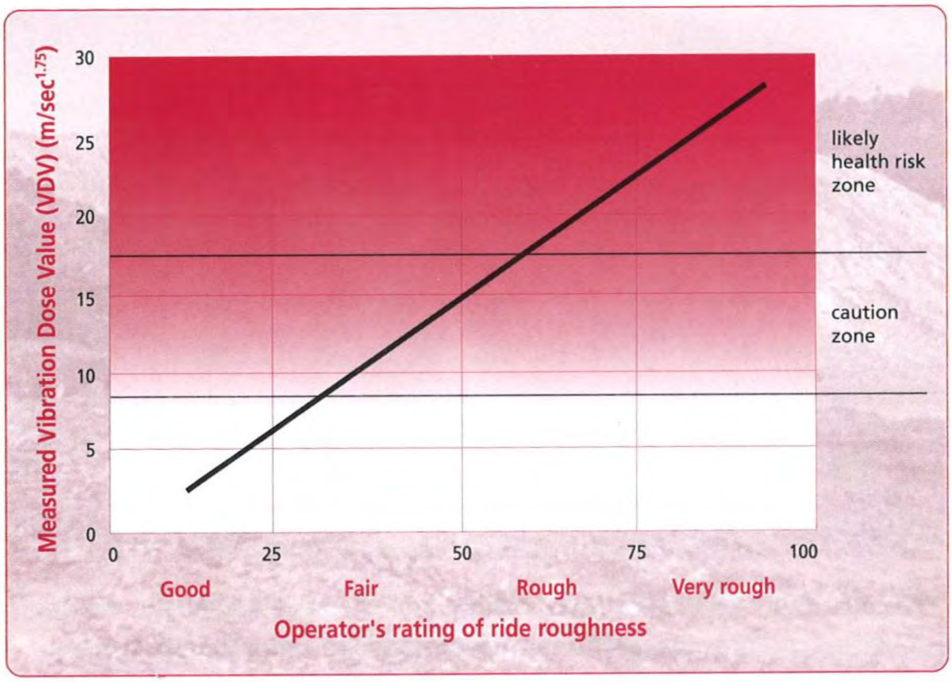
- In the likely health risk zone (likely health risk)
- In the caution zone (potential health risk)
- Below the caution zone (acceptable vibration level).

Important points about the standard:

- The standard provides guidance, not strict limits on exposure and health effects as the data is insufficient to provide set criteria
- Vibration exposure is dependent upon duration and level of vibration reaching the operator
- The health effects of WBV are cumulative and may take years to become evident (apart from one-off severe jolts which can cause immediate damage)
- The recommended exposure times do not predict possible immediate damage caused by a one-off jolt
- In some situations, prolonged sitting may be a bigger issue for the operator than the vibration, and this ergonomics consideration could be overlooked by only applying the standard.

**d) Operator Perception and VDV (Vibration Dose Value)**

In a study undertaken with the Australian coal industry (McPhee et al. 2000) the correlation between VDV and driver opinion on ride roughness was explored. The VDV was found to be a good indicator of what drivers, operators and passengers consider to be a rough ride. It is believed that rides with a VDV of ≥ 17 are likely to cause injury if exposure is prolonged and/or repeated.




(Source: McPhee (2001) – *reproduced with permission*)

***Figure 6.15 – Drivers Subjective Road Roughness Rating***

In mining many rides exceed time limits for the likely health risk zone using different methods of analysis. The type of vehicle, its speed and condition (particularly its age and suspension system), and the condition of roads strongly influence ride roughness.

***Table 6.5 - Comparison of International Standard Time Limits for the Caution and Likely Health Risk Zones for Average Vehicle Rides in the Coal Mining Industry***

| Vehicle Type | International Standard | |
|---|---|---|
| | Time to reach | |
| | Caution zone | Likely health risk zone |
| Open-cut Mine Vehicles | | |
| Track dozer: ripping & pushing hard partings | 10 minutes | 2 hours |
| Dump truck: loading overburden | 6 hours | 24 hours |
| Loader: loading coal | 1.5 hours | 5.5 hours |
| 4 wheel drive personnel carrier: Passenger | 6 minutes | 1.5 hours |
| Underground Mine Vehicles | | |
| Equipment transport without suspension: driver | 1-20 minutes | 6 minutes – 1 hour |
| 4 wheel drive personnel troop carrier: passenger | 1.5 hours | 6 hours |
| Personnel rail carrier: passenger | 2 hours | 7 hours |

(Source: McPhee et al: 2000 – *reproduced with permission*)

**e) Subjective Assessment**

McPhee et al's study (2000) used two subjective assessment tools for measuring Whole-Body Vibration (WBV). First, a Scale of Vibration Discomfort (British Standards Institution, 1987); and second, an alternative scale developed by the researchers with a simple line rating scale (Figure 6.14), which for analysis was divided into four equal parts (good, OK, fair, poor). The British Standards scale was found to have poor correlation with actual vibration measures, while the researcher's own scale, found good correlation with vibration data collected in the study.

☺ Best Ever Ride ________________________________ Worst Ever Ride ☹

(Source: McPhee et al: 2000 – *reproduced with permission*)

***Figure 6.17 - Simple Comfort Rating Scale for Whole Body Vibration***

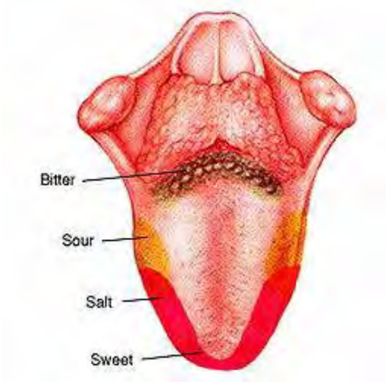
### f) Reducing Risk

Ways of reducing the impact of WBV include regular monitoring of vibration levels to ensure they are within an acceptable range; operator training; limiting speed; prompt communication and correction of road problems; effective road maintenance programs; appropriate design of vehicles including the isolation of the cab in vehicles where vibration can be excessive; effective maintenance of vehicles; task variation and regular breaks out of the seat.

## 6.5 SMELL, TASTE & TACTILE SENSES

### 6.5.1 Olfactory Ability (Smell) & Taste

The nose both transmits sensations of smell via the olfactory nerve, and filters and alters the temperature of the air that an individual inhales. An individual's sense of smell adapts quickly to some smells. Taste is achieved through taste buds on the tongue that respond to the sensations of sweetness, salt, bitterness and sour tastes. Some of these smells and tastes may tell a worker that there is a problem.




(Source: Mosby's Medical Encyclopedia)

***Figure 6.18 – The Human Tongue***

Many hazardous substances do not emit any warning such as a smell or a taste. For example fumes from carbon monoxide can result in people feeling unwell including experiencing tiredness, drowsiness, headaches and breathlessness. In the worst situations, carbon monoxide can kill without warning in just hours. Other odours such as hydrogen sulphide have a low odour threshold, so are easily detected at low levels, despite the gas being colourless. However while hydrogen sulphide is easy to smell at low levels, at very high concentrations or with prolonged periods of exposure people suffer from a temporary paralysis of the olfactory nerves, making them unable to smell the gas. This illustrates how the reliance on smell is not appropriate to managing hazardous substances at the workplace.

Workers may need respiratory protection in environments where unpleasant or noxious smells cannot be eliminated. Dangerous, unnecessary and/or unpleasant smells will need to be controlled where the sense of smell is needed as an early detection monitor.

(Source: BlueScope Steel Pty Ltd – *reproduced with permission*)

***Figure 6.19 – Example of Respirator***

### 6.5.2 Skin & Touch

The skin is the largest visible part of an individual (at 1.4-2 square metres) and is also the body's largest organ. It protects tissues underneath from physical and chemical damage as well as protecting the body from drying out and abrupt changes in temperature.

The skin contains:

- *Sweat glands* - help maintain an even body temperature
- *Fine blood vessels* - assist in temperature control, nutrition and waste removal
- *Nerve endings* – act as sensory receptors for heat, cold, pain, pressure and touch
- *Sebaceous glands* - secrete substances to keep the skin supple and protect it from harmful bacteria

Exposure of the skin to some substances and physical agents, such as the sun, may cause skin irritation, non-allergic contact eczema and burning. Protection of the skin is achieved best through elimination of or isolation from the substances and agents, and less effectively with PPE.

Wearing gloves has a significant impact on tactile sensation, and there is a linear relationship between increasing glove thickness and tactile sensitivity, with the bare hand being most sensitive, followed by gloves of increasing thickness. Impaired sensation affects motor control as more grip and load force is generated when workers wear multiple glove layers, and this use of force is increased if the gloves are more slippery than bare skin.

Tactile information is very important for tasks requiring high levels of manual dexterity such as manipulating small items.

## **6**.6 CLOTHING & PROTECTIVE EQUIPMENT

### 6.6.1 Introduction

This section of the module briefly examines the ergonomics considerations for personal protective equipment (PPE). As outlined in the risk management section, PPE is a last option control measure and whatever hazards and risks may be present in a workplace should be controlled according to the hierarchy of controls, ie: the priority is to control at the source; then if this is not possible, mitigate through engineering controls, or use of assistive devices, etc. The option of PPE is the last and least preferred risk control strategy.

Having said that, PPE is commonly used in industry, and the range of PPE is broad. PPE can be used in circumstances such as emergency situations and rescue scenarios; or when a worker is required to work in a hazardous area for situations such as maintenance; or where engineering controls are inadequate and supplementary protection is required. Essentially, PPE is used to protect the human at work by protecting the body (clothing), the skin, the visual system (protective eyewear), the face (full face shields), the respiratory system (masks), the feet (safety footwear), the hands (gloves), the head (helmets) and the auditory system (hearing protection).


(Source: BlueScope Steel Pty Ltd – *reproduced with permission*)

***Figure 6.20 – Use of Various PPE at Steelworks***

PPE is designed to fulfil a function of protection, and if not designed appropriately, may not only fail to meet criteria for protection, but not fit criteria for comfort and wearability. In fact, the PPE may actually impede the function of other PPE worn at the same time, impair task performance and actually create extra workload for the employee. A good example of this is the use of PPE by women in a workforce traditionally having male employees. The equipment is designed for the men, and therefore fit and comfort is an issue for the women with PPE being too big, not sealing correctly, falling off and ultimately failing to fulfil its role of protection, not to mention being uncomfortable and impeding work performance. PPE should be trialled and tested with the user group prior to purchase and use.

The use of PPE should not take place as an 'add on' to safety. Howie (2005) recommends that a PPE program be established in workplaces to manage ongoing and adequate protection for workers in a systematic way. Intrinsic to this approach is consideration of the ergonomics of PPE, specifically:

- Involving personnel in equipment selection
- Matching equipment to each individual worker/wearer
- Ensuring that PPE is mutually compatible (eg: ear muffs do not interfere with head wear protection)
- Training in the correct use of PPE
- Minimising wear periods
- Supervision of correct use
- Documented maintenance, inspection and replacement program
- Provision of equipment at no cost to the worker

### 6.6.2 Risk Perception and PPE Use

In addition to physical ergonomics requirements of PPE, the compliance factor also needs to be considered. In Section 2.3.4 we discussed perception of risk, and the role this plays in the wearing of PPE. The relevant factor to consider in the wearing of PPE is that humans tend to perceive risk as being lower than it actually is, and when the consequences of not wearing PPE is seen as a reward (such as avoiding sweating and fogging of eyewear in a hot and humid environment), then the human is likely to not comply with wearing the equipment.

Again referring to Section 2.3.4, risk perception is lowered when the hazard is encountered routinely (this is usually the case when PPE is used – eg: noisy mining environment); the hazard is understood, affects everyone and is cumulative (eg: hearing loss).

### 6.6.3 I.S. EN 13921:2007. Personal Protective Equipment – Ergonomic Principles

This European Standard was established in November, 2007. The purpose of the standard is to provide specification of ergonomic requirements for developers of PPE product standards. It provides an excellent overview of the ergonomic considerations for PPE, as well as guidelines for assessment of these considerations. A summary of the standard is provided here.

The standard addresses the key ergonomic requirements in terms of:

a) Integration of performance and ergonomic requirements
b) How to determine the best ergonomic solution
c) Adjustment and fit of PPE
d) Comfort of PPE
e) Anthropometric variability
f) Biomechanical aspects of PPE (eg: extra load on body due to PPE)
g) Thermal effects of PPE
h) Sensory effects of PPE

**a) Integration of Performance and Ergonomic Requirements**

Often more than one piece of PPE is worn by workers. This may lead to incompatibility issues in terms of fit and function. The standard recommends that consideration of the use of multiple PPE and testing of the combinations of PPE be undertaken.
The purpose of this is to ensure the technical protective aspects of the equipment is adequate, as well as checking that the combination of equipment does not cause sensory of social isolation of the worker.

Additionally, to ensure adequate hazard identification, consideration of the following is recommended:

- Tasks being performed in the workplace (or home)
- The equipment used
- Duration of usage
- Environments in which PPE may be used

**b) How to Determine the Best Ergonomic Solution**

The standard discusses the ‘compromise between protection, practicality and any potentially adverse impact of wearing the PPE.’ Considerations include the duration of wear (short time, full shift, etc); the different situations where the PPE may be used and the use of other PPE at various times; and the ‘reasonable balance’ between the hazard, the ‘burden’ of wearing the PPE, the level of protection provided, and how long it is to be worn.

Testing of PPE should be undertaken, individually and in combination. The testing should be representative of the user group and mimic the usual work task in the following ways:

- Measure understanding of manufacturer instructions and warnings
- Test donning, adjusting and removing PPE
- Test the ability of the user to undertake usual work activities: movements and communication
- Test the range of specific activities and situations in which PPE is to be used

Additionally the physiological ‘burden’ of wearing the PPE should be considered by taking measures such as:

- Heart rate
- Oxygen consumption
- Alveolar gas composition (to determine changes in $CO_2$ and $O_2$ levels)
- Breathing rate
- Body temperature change
- Blood flow

- Sweat rate
- Fatigue/muscle strain

**c) Adjustment and Fit of PPE**

Certain work tasks may cause the PPE to displace and consideration should be given to the maximum ‘tolerable displacement.’ Possible issues include:

- Information and instructions for fitting and adjustment
- Stability, adjustability (and ‘robustness’) of adjustments
- Determining correct fit of PPE

**d) Comfort of PPE**

PPE should be as comfortable as possible, and not cause the wearer any discomfort, irritation, or future injuries. Indicators for discomfort include:

- Any contact between the PPE and the skin of the wearer. The sensitivity of the skin to rubbing and pressure should be checked
- The duration of PPE contact with the skin should be considered
- Check the PPE for sharp, hard edges and/or pinch points for skin, hair, etc. (check this for the equipment and the fastenings/closures)
- The chemical composition of the fabric or material and its by-products may affect the human body
- If allergic reactions may be caused by materials in contact with skin surfaces
- Check that the size, mass, physical characteristics and position of adjustment and closure mechanisms do not impact negatively on the user

- Determine whether the outside surface of the PPE could hurt other people in work area
- Ensure adequate testing of equipment is undertaken (visual and manual examination may not be sufficient)

**e) Anthropometric Variability**

Depending on the hazard, PPE may need to fit the body very closely to provide adequate protection, additionally, the movements and activities the worker must perform whilst wearing the PPE must be taken into account. Considerations for anthropometric variability include:

- The nature of the hazard the PPE is used for
- The part(s) of the body requiring protection
- The physical activities and movements needing to be performed by the user
- The user group characteristics and variability

**f) Biomechanical Aspects of PPE**

The actual wearing of PPE can increase the physical workload of the worker and/or impede their ability to complete required work tasks. The biomechanical considerations of PPE should be considered:

- The static loading the PPE or combination of PPE can place on the worker. For example it is better to wear the PPE as close to the person's centre of gravity as possible; as well as avoiding assymetrical loading of the worker or placing heavy/bulky PPE on the limbs.
- Dynamic or inertial forces on the body with PPE or combination PPE use; for example heavy, or bulky material can limit movements at joints and so require extra effort by the worker to perform a task to overcome the resistance produced by the PPE.

- Positioning PPE that may place a load on the body to the best biomechanical advantage. Compression of nerves or blood vessels by straps or other aspects of the PPE must be avoided. Compression over the skin may lead to abrasion and in addition to discomfort may reduce the acceptability of the PPE. Particular attention must be paid to the pulse points in the neck, groin and wrist for impact on circulation.

  Another important consideration is the impact of the PPE on any WBV the worker may experience. The PPE may alter and exacerbate the effects of WBV.

**g) Thermal Effects of PPE**

PPE can affect the thermal comfort of the worker as it impacts on the heat exchange between the human and their environment. The interaction of three factors needs to be considered: The environment, the work activity being performed, and the clothing/PPE being worn by the worker. Both protection and thermal comfort must both be considered by product designers. It is recommended that the range of environmental conditions for defined work activities and ability to work comfortably be determined.

Specific guidance is provided for thermal characteristics of PPE either used singly or in combination, such as:

- Thermal insulation
- Water vapour resistance (low resistance assists heat loss)
- Water vapour permeability (high permeability assists heat loss)
- Air permeability (low for cold or windy conditions; high for hot environments)
- Water absorption
- Water desorption
- Consideration for full body PPE and flow through ventilation

### h) Sensory Effects of PPE

As outlined in Section 2.2, our senses inform the human about their environment, and provide feedback after we have acted on information. To produce the correct response, the worker must perceive the signal correctly. PPE can impede the sensory information we rely on to make appropriate decisions and take action.

- Vision: PPE can lead to reduced quality or quantity of visual information. Consideration must also be given to workers who need to wear corrective eyewear underneath their PPE
- Hearing: PPE can affect the ability of the worker to perceive essential (danger alarms), and useful (co-workers speech); additionally, the hearing protection can be uncomfortable
- Smell: inherent qualities of the PPE may produce strong smells or taste (for example plastics, rubber). These may mask dangerous smells or tastes in the work environment; additionally, these qualities may be harmful to the health of the worker, and or lead to non-compliance wearing the PPE
- Touch/tactile: wearing gloves can decrease the tactile sensation in the hands and impede work performance; additionally, the gloves provide another source of tactile information and this can impede the work performance by increasing the tactile discrimination load on the worker

# 7. STANDARDS & SOCIAL ASPECTS

## 7.1 STANDARDS

The International Standards Organisation (ISO) aims to encourage international standardisation and to facilitate the exchange of goods and services through the elimination of technical barriers to trade.

To assist professional and other people who are interested in the design and function of workplaces and workplace equipment, the International Standards cover a wide range of topics of relevance to the well-being and behaviour of people at work. These Standards provide the user – be they a manager, an employee, an OHS professional or an ergonomist - with detailed technical guidance to compliment other information sources.

To develop these Standards, the ISO has approximately 250 technical committees providing professional and industry advice. Technical Committee No.159 advises in the area of ergonomics, including:

- General ergonomics principles
- Anthropometry and biomechanics
- Ergonomics of human-system interaction
- Ergonomics of the physical environment

This Technical Committee in ergonomics deals with products, work systems and work equipment which are used all over the world.

This committee (ISO/TC 159) list the key benefits and aims of standardisation of ergonomics in business environments as:

- "To enhance health, safety and well-being of the users as well as meet the overall performance
- To prepare standards in the field of ergonomics, in order to meet the requirements for ergonomics and efficient products under the conditions of free trade

- To improve the usability of products; and
- To deliver a consistent set of ergonomics requirements as a reliable basis for a world-wide machine design (as ISO standards world-wide)" (http://isotc.iso.org/livelink/livelink/fetch/2000/2122/687806/ISO_TC_159__Ergonomics_.pdf?nodeid=1162319&vernum=0)

The committee has a list of priorities, including: making standards more consistent internationally; working of the ergonomics of new technologies; working across the borders of occupational work; considering ergonomics for people with special requirements such as access; and considering the ergonomic implications of the ageing population.

One of the key Standards regarding occupational workplace ergonomics is the ISO 6385:2004 as this aims to provide an ergonomic framework by outlining the key principles to consider in workplace and work systems design and redesign.

## 7.2 TRAINING, EXPERIENCE AND SKILL DEVELOPMENT

Training is an integral component of a workplace safety management system. The employer has a duty of care for their employees (see Section 7.3.1), and essential in fulfilling this duty of care, is appropriate training for their employees.

Workplace training is an ongoing process. Few individuals start a job without needing further training or development of skills to perform the job. Continuing technological changes, differences between workplaces, promotional opportunities and multiskilling mean that employees are constantly required to learn new skills and understand different processes and procedures in order to perform optimally at work.

Training can be provided to employees in order to increase their knowledge and skills. It can be on-the-job, in a classroom at the workplace or off-site and can involve individuals learning different types of skills, such as technical (computer software), interpersonal (mentoring or different management techniques) or problem solving.

Adults learn best from their own experience and then move from this into new areas of knowledge and skill. It may be best to train adult learners in practical situations if they are not comfortable in a classroom. Some people like to see, others to hear and others to do. The best training provides a combination of these opportunities.

There is a wide range of skills that users may bring to a job. No two users of the same equipment will operate it in the same way. If it is important that equipment is used in a systematic and standardised way then much more training or relearning will be required. Cultural differences may also affect equipment operation and task execution (eg: carrying loads on head and shoulders vs in arms).

In complex and highly specific systems much time and money may be needed for training, evaluation of the work system and retraining. Airline pilots are a good example of how training can help people to use complex systems competently. However, pilots are also very carefully selected and well paid. Asking for the same amount of effort and accuracy from workers with little training and paid one quarter of the salary may mean that employers or managers may be disappointed in the workers' performance.

### 7.2.1 Acquisition of Physical Skills

Physically skilled work involves quick and accurate muscular contraction, co-ordination of the different muscle groups involved, precision, concentration and visual control. Usually skilled work involves use of the hand(s) and in particular the fingers.

When a skill is being learned there are two phases: learning the movements and then adapting the body tissues involved. At first movements are done consciously and as training progresses the conscious part gradually reduces and the actions begin to become automatic. As the skill develops the movements change from jerky and unco-ordinated to smooth and flowing. In the first stages of skill acquisition extra muscle work occurs. Less energy is required for a skilled person doing exactly the same job as an unskilled person. As time progresses the body tissues adapt to the work by increasing muscle size/bulk or cardiovascular fitness (eg: workers who perform heavy lifting tasks develop strong thigh muscles).

Short training sessions, breaking the job up into parts and providing strict controls and good examples can improve skill acquisition. Short training sessions are necessary because a high degree of concentration is required and people tire quickly under these circumstances. Breaking the job into parts allows more difficult or critical parts to get more attention during the training and allows the practice of parts before putting the whole together. It is important that the best technique is developed. This is facilitated if accurate feedback and supervision are provided during the learning process.

### 7.2.2 Skill Development and Individual Differences

Differences between individuals should be taken into account when any type of training scheme is developed or offered to employees. Key differences in employees include:

- Knowledge they posses before training begins
- The way that they learn new skills
- The speed with which they learn new skills
- Confidence in dealing with unfamiliar situations

Thus the type of training methods employed should be adapted to the learning needs of each individual. The main aim of skill acquisitions is that individuals achieve a satisfactory level of competence.

### 7.2.3 Training Needs Analysis

The first stage of the training process is a review of training needs. This analysis should be performed on three levels:

1. *Organisational* – what training should be performed in the organisation and where is it needed?
2. *Task/ job* (usually called a task or job analysis) – what skills or abilities are required to perform a specific task or job?
3. *Personal* – what are the training needs of each individual?

### 7.2.4 Types of Training

There are several types of training that can be conducted:

- *Knowledge teaching* - the provision of knowledge to employees regarding a specific operation or system. This aids in teaching individuals the reasoning behind safe operating procedures or other safety measures

- *On-the-job training* – job rotation and the use of mentoring relationships or apprenticeships where new employees learn the skills required to perform their job from more experienced workers

- *Simulator training* – workers practise their skills on a simulated situation eg aircraft pilots, military personnel and medical staff

- *Part-task* – workers are taught part of a task that often can require special practice or can be a particular skill that should be developed before comprehensive training is begun eg medical training

- *Team-based training* – training is provided to groups of individuals who often work in teams. As a member of a team individuals are required to perform their respective jobs successfully and to co-ordinate their efforts to meet team goals

- *Refresher training* – involves workers re-learning skills and can involve on-the-job drills eg evacuation drills or simulated exercises eg: first aid training. Refresher training is essential for workers to sustain skills that are used infrequently but are necessary especially in emergencies

Whichever training method is used, it should be evaluated. This is can be done in a number of ways (such as practical demonstrations, written reports, etc) but must test the skills and knowledge acquired with regard to what is required by the task.

***Training Aids***

Training aids are helpful for individuals who have acquired new skills to enhance their performance. They can include:

- Reference or procedural manuals
- Checklists
- Charts, notices or labels
- Decision trees or decision charts
- An in-house expert or outsourced technical support who can provide support when needed

### 7.2.5 Education and Training in Ergonomics

Education of stakeholders is important for a successful ergonomics program. By definition ergonomics requires that the people doing the work must be involved in the design of that work if solutions are to be successful. As well, if money, time, and expertise are used to produce an ergonomically sound workplace, then employees should understand *why* it has been so designed and *how* it can best be used. Training should encompass both of these elements.

Ergonomics training can be formal or it may be incorporated into participative activities such as design reviews, risk assessments, focus groups and quality circles. It may also be learned on-the-job through using checklists and tools developed to identify hazards and solve problems.

## 7.3 HEALTH INFORMATION

### 7.3.1 Health Information, Legal Duty of Care

Employers have a responsibility and duty of care for their employees. This duty of care requires employers to identify all relevant hazards in their workplaces, undertake a risk assessment of the hazards, develop a risk control strategy and monitor the control effectiveness.

An essential part of this process is to inform the employees about any risks to their health and safety in current work practices and in any changes to work practices that may be introduced. Underpinning this is a process of consultation with the workforce. An example of health information to the workforce would be a Material Safety Data Sheet when using potentially hazardous materials/substances. Such information should be provided as part of an overall training program within the employer's safety management system.

### 7.3.2 Supervision and Records

To adequately fulfil this duty of care, the employer must provide adequate and suitable supervision and instruction, as well as maintain records as part of their overall safety management system. The supervision must include information and instruction to the workers on how to perform their job safely, as well as what control strategies have been put in place to protect their health and safety. Basic to this information is instruction on emergency procedures and first aid facilities.

### 7.3.3 Measuring Health and Illness

As stated above in Section 7.3.1, workers require training and information regarding any health risks with their work and the action the employer is taking to mitigate the risks. They also require advice on the actions they can take to further mitigate the risks – such as wearing prescribed PPE.

Where the employer's safety management systems have identified health risks to the workforce, they should conduct regular health surveillance/biological monitoring to check that the controls put in place are actually working. This system must be documented so that individual workers can be monitored over time. Some forms of health surveillance may be required under legislation, such as certain States and Territories in Australia under the guidelines for the Control of Workplace Hazardous Substances.

From an ergonomics monitoring viewpoint, reviewing injury statistics (after the fact), or 'near miss' reports and hazard reports (before injury sustained) are an excellent way to determine if ergonomics controls are working, in particular for musculoskeletal injuries. Further details regarding measuring the impact of ergonomics is in the following section.

## 7.4 MEASURING THE IMPACT OF ERGONOMICS

There are several measurement tools and techniques that may be used to measure the impact of OHS and ergonomics outcomes.

### 7.4.1 Positive Performance Indicators (PPIs)

PPIs can give information about the effectiveness of activities especially within OHS management systems. Ergonomics is one of the areas where these indicators can be useful. However, they will not tell the whole story nor will they in themselves improve performance - they are merely flags indicating progress or the lack of it.

Nevertheless PPIs allow an organisation to set standards that are above the minimum and allow efforts towards preventive health and safety programs to be recognised and encouraged.

When benchmarking and making comparisons with other organisations or industries it is important that different measures can be compared. Therefore they need to be reliable (consistent), repeatable, comparable (with other areas or organisations) and valid (measure what they say they are measuring). This can be very complex when systems are so different. As a result organisations often resort to lost time injury frequency rates (LTIFRs) which are a negative performance indicator (NPI) (see below) but which can be applied across a range of industries.

Aspects that lend themselves to the development of PPIs for ergonomics include those used to define OHS systems.

***Table 7.1 – Applying PPIs to Ergonomics***

| Systems Area | Possible Measures of Performance |
|---|---|
| 1. Commitment | % of jobs with OHS and ergonomics responsibilities defined |
| 2. Documentation | Level of awareness and use of manuals by the workforce<br>Frequency and timeliness of document updates |
| 3. Purchasing | % of purchase orders with OHS (ergonomics) requirements specified |
| 4. Safe working systems | % of systems controls compared with individual controls<br>% of risk assessments results that have been included in systems management plans |
| 5. Identifying, reporting and correcting deficiencies | Frequency of reviews and % of actions achieved<br>% of incidents/problems where remedial action was taken within an appropriate time frame |
| 6. Monitoring, recording and reviewing | % of OHS standards conformance<br>Level of record keeping required by regulation against potential recorded events |
| 7. Developing skills and competencies. | % of employees assessed as conforming to competency standards |

(Source: McPhee – *reproduced with permission*)

PPIs are process indicators and the way they can be used is often not understood very well. The development of PPIs is still in the early stages in many organisations even though there are often significant positive actions that can be measured and documented.

### 7.4.2 Negative Performance Indicators (NPIs)

NPIs such as the LTIFR only tell what has happened in the past and that something went wrong. It gives no indication of what has been done well. Simply measuring negative outcomes such as injury rates or the costs of workers' compensation claims may not give a true indication of what is happening now and how effective current risk control measures are. In fact they may give wrong information when they fluctuate or when there are subtle differences in reporting criteria. They may also allow the concealing of injuries to provide an apparently better result. Most importantly they are very limited in predicting high consequence, low probability accidents.

However, they measure actual failures and they allow statistics to be compared across industries and from company to company. Organisations can benchmark themselves against others and this comparison can be useful to a limited degree.

### 7.4.3 Injury/illness Rates

When used in conjunction with some or all of the above measures, injury /illness rates can provide valuable information concerning program implementation. It is important to recognise that there may be a latent period before the rates begin to improve due to the time it takes to implement a mature, effective safety program.

### 7.4.4 Program Evaluation

Evaluation of an ergonomics program needs to measure how well program implementation is progressing as well as whether or not the program objectives were achieved.

What is measured will depend on what is considered necessary to determine if the program is on track. You can:

1. **Determine if the process is working**. For instance, if the program involves consultation with users, the identification of problems and development of solutions these can all be measured simply by determining if they have been done and what they have achieved
2. **Estimate or assess the risks** associated with poor ergonomics in broad terms and then reassess these after changes have been implemented. People involved can be asked about the degree of difficulty of the job, the number of near misses or other incidents and perhaps the number of times accidents or injuries have actually occurred
3. **Ask how workers feel about solutions** and if they have been effective or not

However, in many cases it is difficult to show that injuries have been reduced by the changes made. This is because there are so many causes of most injuries and in some cases they develop over time (eg: chronic musculoskeletal injuries). It takes time and sophisticated measurement techniques to establish that particular interventions have lead to a reduction of injuries.

It is important to develop methods of evaluating positive indicators of work being done that address areas requiring improvement. Then these indicators and resulting improvements can be measured over time. The use of both positive and negative performance indicators give the most balanced approach to evaluation and can act as effective safety program drivers if used carefully.

### 7.4.5 Strategic Planning

Performance can be measured from strategic plans. The mission statement of an organisation can be used to measure performance. The board can be measured by the goals outlined for the organisation.

The manager can be measured by the objectives and the staff can be measured by action plans. Key performance indicators (KPIs) (see below) can be identified from strategic plans.

### 7.4.6 Key Performance Indicators

KPIs are derived from the use of statistics in process control in manufacturing. The basic concept of statistical process control is that variation in outcomes is inevitable and that the control of this variation determines the quality of the outcome. If there is reduction of variation in one or more stages of the process, then there will be a consistent reduction in the variation of the outcome of the process. Recently this concept has been applied successfully to business processes. The result has been that the whole business process outcome has been developed by the improvement of key variables within the process. This method can also be applied to the process of OHS and ergonomics in organisations.

### 7.4.7 Program Audits

These give a comparison over time of improvements in implementation. They involve the using of a series of predetermined questions to establish how much work has been done to implement and maintain a program. Information provided at audit is verified through document reviews, random sampling, discussions with staff, observation of behaviours and activities and physical conditions surveys.

As with all audits there are always problems in getting the balance right. The evaluation of a program is never black and white – there are always shades of grey. These are hard to evaluate in questionnaires. However they need to be recognised and some credit given where progress has been made but the outcome has not been achieved fully. Therefore the development and use of the audit tools is critical to how much useful information can be derived.

### 7.4.8 Accident and Incident Investigation

Accident and incident investigations are part of every OHS program. They are undertaken to find the real and not immediately obvious causes of an accident and to assess the risk of recurrence. Based on this information appropriate control measures can be developed. These may involve changes to the structure of the OHS program as well as fixing the immediate damage or providing the injured person with appropriate medical treatment.

Poor ergonomics is often overlooked in accident investigations because it is not always immediately obvious and its analysis may require specialist input.

Information obtained as a result of the investigations can also be pooled to determine trends and used to assist program implementation planning.

### 7.4.9 Cost-Benefit Models

Justifying expenditure to improve OHS has been difficult in the past. Often direct compensation and medical expenses were the only indicator that poor OHS practices were costly. However, now it is possible to calculate the real costs of injuries to companies using methods and programs that are available commercially. These range in complexity from full company accounting systems to methods that apply to individual jobs or groups of workers.

The feasibility, availability and cost of changes needed to improve ergonomics may be considered in relation to the size and cost of the problem. Sometimes it may be necessary to justify the cost of change or of different changes (termed cost effectiveness) or the costs of doing nothing at all. This is where conducting a cost-benefit or cost effectiveness analysis can be useful.

Such analyses are best conducted prior to and after changes have been made. Where they are conducted beforehand payback periods can be estimated for budgets. If the payback period is short (3-12 months) this can be used to justify expenditures.

Cost-benefit and cost effectiveness programs require some basic information in the following five areas:

1. Actual number of productive hours worked per employee per year
2. Salary or wage costs per hour worked
3. Employee turnover and training costs
4. Productivity and product/service quality losses due to absent employees
5. Cost of implementation of intervention(s)

Costs per hour of OHS problems can then be calculated. To this, costs of solutions can be added and a payback period can be estimated. Not all the information is essential but the more that can be supplied and the more accurate it is, the better the true costs and benefits can be predicted.

The costs of wasted product, increased time to undertake the tasks, inadequate or poor quality workmanship, and damage to equipment and product as may have identified in the process can also be added to the OHS costs.

Refer also to Section 3.2 on methods of evaluating ergonomics solutions.

# 8. REFERENCES


Australian Safety and Compensation Council (2007)
Code of practice for the prevention of musculoskeletal disorders from performing manual tasks at work.
Canberra: Australian Government Publishing Service

Bernard, B. P. (1997) Musculoskeletal Disorders and Workplace Factors. A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back.
Cincinnati: National Institute for Occupational Safety and Health

Bongers, P. M., Kremer, A.M., Laak, J. (2002) Are Psychosocial Factors, Risk Factors for Symptoms and Signs of the Shoulder, Elbow, or Hand/Wrist?: A Review of the Epidemiological Literature.
American Journal of Industrial Medicine 41: 315-342

Bridger, R. S (2003) Introduction to ergonomics (2nd Ed.)
London; New York: Taylor & Francis

Buckle, P. W., Devereux, J. J. (2002) The nature of work-related neck and upper limb musculoskeletal disorders.
Applied Ergonomics 33 (3): 207-217

Burgess-Limerick, R. (2003) Squat, stoop, or something in between? International Journal of Industrial Ergonomics 31(3): 143-148

Burgess-Limerick, R., Straker, L., et al. (2004) Manual Tasks Risk Assessment Tool (ManTRA) V 2.0.
Human Factors and Ergonomics Society of Australia, Cairns, Qld, Australia

Chaffin, D. B. (1988) Biomechanical modelling of the low back during load lifting.
Ergonomics 31(5): 685-697

Chaffin, D. B., Gallay, L. S. et al. (1986) An evaluation of the effect of a training program on worker lifting postures.
International Journal of Industrial Ergonomics 1(2): 127-136

Chengalur, S., Rodgers, S., Bernard, T. (2004) Ergonomic design for people at work Eastman Kodak Company (2nd Ed.)
New York: Wiley

Colombini, D., Occhipinti, E., Grieco, A. (2002) Risk assessment and management of repetitive movements and exertions of upper limbs : job analysis, Ocra risk indices, prevention strategies, and design principles.
Amsterdam ; Boston : Elsevier

Daltroy, L. H., Iversen, M. D. et al. (1997) A Controlled Trial of an Educational Program to Prevent Low Back Injuries.
New England Journal of Medicine 337(5): 322-328

David, G., Woods, V., Buckle, P. (2005) Further development of the usability and validity of the Quick Exposure Check (QEC).
Guildford, Robens Centre for Health Ergonomics EIHMS, University of Surrey

European Agency for Safety and Health at Work (2000)
Work-related musculoskeletal disorders: prevention report.
http://osha.europa.eu/en/publications/reports/204/view

Gagnon, M. (2005) Ergonomic identification and biomechanical evaluation of workers' strategies and their validation in a training situation: Summary of research.
Clinical Biomechanics 20(6): 569-580

Geller, E.S. (2001) The psychology of safety handbook (2nd Ed.)
Boca Raton, Fla.; London: Lewis Publishers

Grandjean, E, Kroemer, K. (1997) Fitting the task to the human.
London: Taylor & Francis

Härmä, M. (1996) Ageing, physical fitness and shiftwork tolerance.
Applied Ergonomics 27(1): 25-29.

Helander, M. (2006) A Guide to human factors and ergonomics (2nd Ed.)
Boca Raton, FL: CRC Press

HSE (2005) Control the risks from hand-arm vibration
http://www.hse.gov.uk/pubns/indg175.pdf

HSE (2006) Getting to grips with manual handling
http://www.hse.gov.uk/pubns/indg143.pdf

HSE. Manual Handling Assessment Charts.
http://www.hse.gov.uk/pubns/indg383.pdf

HSG 48. Reducing error and influencing behaviour.
Norwich: Health and Safety Executive, (2007 Reprint)

Ilmarinen, J. (2006) The ageing workforce--challenges for occupational health.
Occupational Medicine (Lond) 56(6): 362-364

Jager, M., Luttmann, A. (1999) Critical survey on the biomechanical criterion in the NIOSH method for the design and evaluation of manual lifting tasks.
International Journal of Industrial Ergonomics 23: 331-337

Kahneman, D., Tversky, A. (1984) Choices, values, and frames.
American Psychologist 39(4): 341-350

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorenson, F., Andersson, G., Jogensen, K., (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms.
Applied Ergonomics 18(3): 233-237

Lavender, S. A., Andersson, G. B. J. et al. (2003) The effects of initial lifting height, load magnitude, and lifting speed on the peak dynamic L5/S1 moments.
International Journal of Industrial Ergonomics 31(1): 51-59

Marras, W.S., Karwowski W. (2006) Occupational ergonomics handbook (2nd Ed.)
Boca Raton, FL: Taylor & Francis

Marras, W., Lavender, S., Leurgans, S., Rajulu, S. (1993) The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders
Spine, 18 (5): 617-628

McGill, S. (2002) Low back disorders: evidence-based prevention and rehabilitation
Champaign, IL: Human Kinetics

McPhee, B. (2001) Bad Vibrations. A handbook on whole body vibration exposure in mining
Sydney: Joint Coal Board Health and Safety Trust

McPhee, B. (2005) Practical Ergonomics. Application of ergonomics principles in the workplace
Sydney: Coal Services Health and Safety Trust

Pheasant, S. (1991) Ergonomics, work and health
London: Macmillan

Ranney, D. (1997) Chronic musculoskeletal injuries in the workplace Philadelphia: W.B. Saunders

Sanders, M., McCormick, E. (1987)
Human factors in engineering and design. (6th Ed.)
New York: McGraw-Hill

Sandman, P. N., Weinstein, N. D., Miller, P. (1994) High Risk or Low: How Location on a "Risk Ladder" Affects Perceived Risk.
Risk Analysis 14(1): 35-45

Snook, S. H. (1985) Psychophysical considerations in permissible loads.
Ergonomics 28(1): 327-330

Snook, S. H., Ciriello, V.M. (1991) The design of manual handling tasks: revised tables of maximum acceptable weights and forces.
Ergonomics 34(9): 1197-1213

Standards

AS 2670.1: 2001 Evaluation of human exposure to whole-body vibration - General requirements.

IS EN 13921: 2007 Personal Protective Equipment – Ergonomic Principles.

IS EN 894-1:1997 Safety Of Machinery - Ergonomics Requirements For The Design Of Displays And Control Actuators - General Principles For Human Interactions With Displays And Control Actuators.

ISO 10551 Ergonomics of the thermal environment - Assessment of the influence of the thermal environment using subjective judgement scales.

ISO 11228-1: 2003 Ergonomics-Manual Handling-Part 1: Lifting and Carrying.

ISO 11228-3: 2007 Ergonomics Manual Handling Part 1,2,3.

ISO 11429: 1996 Ergonomics - System of auditory and visual danger and information signals.

ISO 13407: 1999 Human-centred design processes for interactive systems.

ISO 14915-1: 2002 Software ergonomics for multimedia user interfaces - Part 1: Design principles and framework.

ISO 15265: 2004 Ergonomics of the thermal environment - Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions.

ISO 1999: 1990 Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment.

ISO 2631-1: 1997 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements.

ISO 5349-1: 2001 Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements.

ISO 6385 Ergonomic Principles in the Design of Work Systems.

ISO 7730: 2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

ISO 9241-5: 1998 Ergonomic requirements for office work with visual display terminals (VDTs) - Part 5: Workstation layout and postural requirements.

ISO/CIE 8995-1:2002: Lighting of work places - Part 1: Indoor
ISO/CIE 8995-1:2002: Lighting of work places - Part 2: Outdoor

Stanton, N., Hedge, A., Brookhuis, K., Salas, E., Hendrick, H. (2005) Handbook of Human Factors and Ergonomics Methods.
Boca Raton, Fla.; London: CRC

Stanton, N. and Young, M. (1999) A guide to methodology in ergonomics: designing for human use
London: Taylor & Francis

Stevenson, M. (1999) Notes on the Principles of Ergonomics
Sydney: University of Sydney Printing Service

Wickens, D., Hollands, J. (2000) Engineering psychology and human performance. (3rd Ed.)
Upper Saddle River, NJ: Prentice Hall