the United States (ANSI) and Britain (BSI). In addition, there are specific ergonomic standards which are applied in individual companies and in industrial sectors.

General and individual ergonomics

An important ergonomic principle is that equipment, technical systems and tasks have to be designed in such a way that they are suited to every user. The variability within populations is such that most designs, in the first instance, are suited to only 95 per cent of the population. This means that the design is less than optimum for five per cent of the users, who then require special, individual ergonomic measures. Examples of groups of users, who from an ergonomic perspective require additional attention, are short or tall persons, overweight people, the handicapped, the old, the young, and pregnant women.

Ergonomics for Beginners focuses primarily on the application of ergonomics in a more general sense. Individual requirements for special groups cannot be dealt with in a book of this size.

2 Posture and movement

Posture and movement play a central role in ergonomics. At work and in everyday life, postures and movements are often imposed by the task and the workplace. The body's muscles, ligaments and joints are involved in adopting a posture, carrying out a movement and applying a force. The muscles provide the force necessary to adopt a posture or make a movement. The ligaments, on the other hand, have an auxiliary function, while the joints allow the relative movement of the various parts of the body. Poor posture and movement can lead to local mechanical stress on the muscles, ligaments and joints, resulting in complaints of the neck, back, shoulder, wrist and other parts of the musculoskeletal system. Some movements not only produce a local mechanical stress on the muscles and joints, but also require an expenditure of energy on the part of the muscles, heart and lungs. In the following sections we shall begin by providing some general background on posture and movement. Thereafter, possibilities for optimizing tasks and the workplace are presented for commonplace postures and movements such as sitting, standing, lifting, pulling and pushing.

Biomechanical, physiological and anthropometric background

A number of principles of importance to the ergonomics of posture and movement derive from a range of specialist fields, namely biomechanics, physiology and anthropometrics. These general principles are discussed in this section and are applied in the subsequent sections (see p. 12 and p. 28) to some specific postures and movements.

Biomechanical background

In biomechanics, the physical laws of mechanics are applied to the human body. It is thereby possible to estimate the local mechanical stress on muscles and joints which occurs while adopting a posture or making a movement. A few biomechanical principles of importance to the ergonomics of posture and movement are outlined below.

Joints must be in a neutral position

When maintaining a posture or making a movement, the joints ought to be kept as far as possible in a neutral position. In the neutral position the muscles and ligaments which span the joints are stretched to the least possible extent, and are thus subject to less stress. In addition, the muscles are able to deliver their greatest force when the joints are in the neutral position.

Raised arms, bent wrists, bent neck and turned head, bent and twisted trunk are examples of poor postures where the joints are not in a neutral position.

Keep the work close to the body

If the work is too far from the body, the arms will be outstretched and the trunk bent over forwards. The weight of the arms, head, trunk and possibly the weight of any load being held then exerts a greater horizontal leverage on the joints under stress (elbow, shoulder, back). This obviously increases the stress on these muscles and joints. Figure 2.1 shows that the stress to the back increases when the arms are outstretched.

Avoid bending forward

The upper part of the body of an adult weighs about 40 kg on average. The further the trunk is bent forwards, the harder it is for the muscles and ligaments of the back to maintain the upper body in balance. The stress is particularly large in the lower back. Prolonged bending over for long periods must therefore be avoided wherever possible.

A twisted trunk strains the back

Twisted postures of the trunk cause undesirable stress to the spine. The elastic discs between the vertebrae are stretched, and the joints

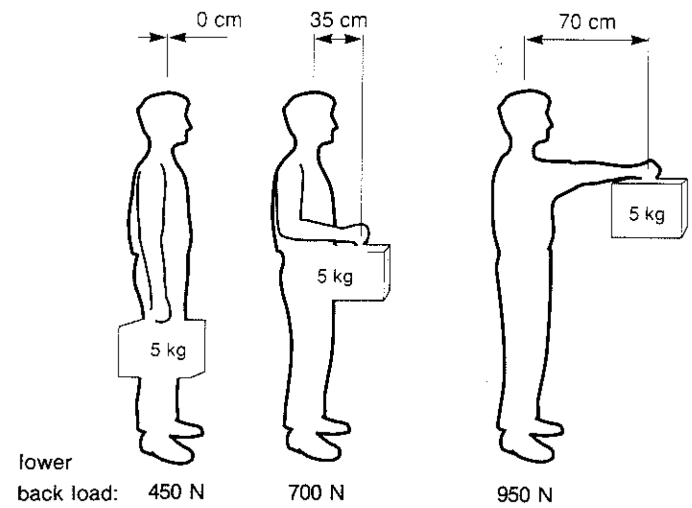


Figure 2.1 Increasing the distance between the hands and the body increases the stress on, among others, the lower back (10 N is about 1 kg force).

and muscles on both sides of the spine are subjected to asymmetric stress.

Sudden movements and forces produce peak stresses

Sudden movements and forces can produce large, short-duration stresses. These peak stresses are a consequence of the acceleration in the movement. It is well known that sudden lifting can cause acute back pain in the lower back. Lifting must occur as far as possible in an even and gradual manner. Thorough preparation is necessary before large forces are exerted.

Alternate postures as well as movements

No posture or movements should be maintained for a long period of time. Prolonged postures and repetitive movements are tiring, and in the long-run can lead to injuries to the muscles and joints. Although the ill-effects of prolonged postures and repetitive movements can be prevented by alternating tasks, it is best to avoid movements which involve regular lifting or repetitive arm movements. Likewise, standing, sitting and walking should also be alternated and it should be possible to carry out prolonged tasks either standing or sitting.

Limit the duration of any continuous muscular effort

Continuous stress on certain muscles in the body as a result of a prolonged posture or repetitive movement leads to localized muscle fatigue, a state of muscle discomfort and reduced muscle performance. As a result, the posture or movement cannot be maintained continuously. The greater the muscular effort (exerted force as a percentage of the maximum force), the shorter the time it can be maintained (Figure 2.2).

Most people can maintain a maximum muscular effort for no more than a few seconds and a 50 per cent muscular effort for no more than approximately two minutes as this causes muscular exhaustion.

Prevent muscular exhaustion

The muscles will take a fairly long time to recover if they become exhausted which is why exhaustion must be avoided. Figure 2.3

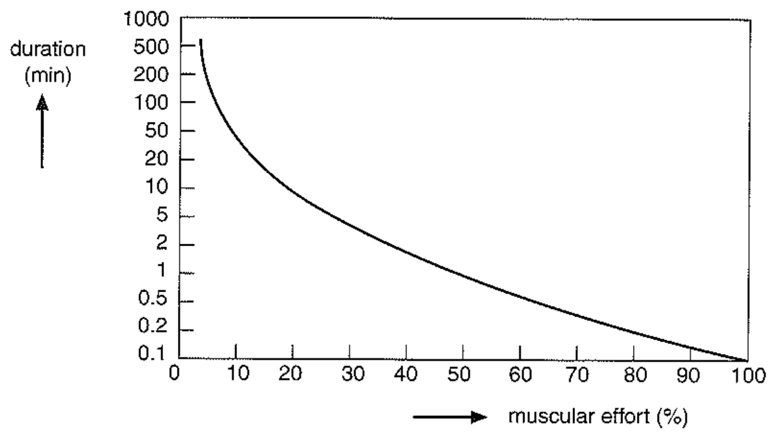


Figure 2.2 The duration of continuous localized muscular effort must be limited. The figure shows the relationship between muscular effort (exerted force as a percentage of maximum force) and the maximum possible duration (in minutes) of any continuous muscular effort.

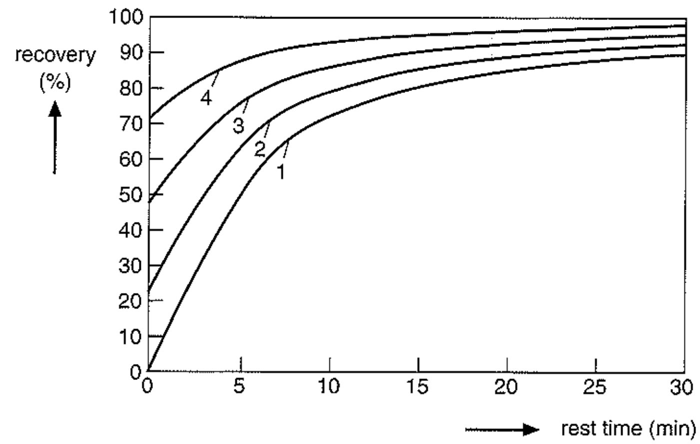


Figure 2.3 Recovery curves for muscles which have been exhausted (curve 1) or partially exhausted (curves 2 to 4) after continuous muscular effort.

shows an example of recovery curves after a muscle has been partially or totally exhausted from continuous effort.

In this example, an exhausted muscle needs to rest for 30 minutes to achieve a 90 per cent recovery. Muscles in a half-exhausted state will recover to the same degree after 15 minutes. Complete recovery can take many hours.

More frequent short breaks are better than a single long one

Muscular fatigue can be reduced by distributing the resting time over the task duration or working day. It is not sensible to accumulate break times until the end of the task or working day.

Physiological background

In exercise physiology, estimates are made of the energy demands on the heart and lungs resulting from muscular effort during movements. In addition to fatigue which results from continuous localized muscular effort (see Biomechanical background, p. 6), general body fatigue can develop from carrying out physical tasks over a long period. The limiting factor here is the amount of energy which the heart and lungs can supply to the muscles to allow postures to be adopted or movements to be carried out. A few physiological principles of importance to the ergonomics of posture and movement are discussed below.

Limit the energy expenditure in a task

The majority of the population can carry out a prolonged task without experiencing any general fatigue provided the energy demand of the task (expressed as the energy consumed by the person per unit of time) does not exceed 250 W ($1\,W = 0.06\,kJ\,min^{-1} = 0.0143\,kcal\,min^{-1}$). This figure includes the amount of energy, approximately 80 W, which the body needs when at rest. At the energy consumption level given above, the task is not considered heavy, and no special measures such as breaks, or alternation with light activities, are necessary for recovery. Examples of activities with an energy demand of less than 250 W are writing, typing, ironing, assembling light materials, operating machinery, a gentle walk or leisurely cycle ride.

Rest is necessary after heavy tasks

If the energy demand during a task exceeds 250 W, then additional rest is necessary to recover. Rest can be in the form of breaks or less demanding tasks. The reduction in activity must be such that the average energy demand over the working day does not exceed 250 W.

Table 2.1 lists some activities with a high energy demand. It is also true here that rest is most effective if the total rest time is spread over a number of break periods spaced regularly during the task, and not saved up until the end of the task or the end of the working day.

Table 2.1 Examples of activities with an energy demand in excess of 250 W. Additional measures are necessary to avoid exhaustion in the long term (breaks, alternation with lighter activities, etc.)

Activity	*Energy expenditure*
Walking while carrying a load (30 kg, 4 km hr^{-1})	370 W
Frequent lifting (1 kg, 1 × per sec)	600 W
Running (10 km hr^{-1})	670 W
Cycling (20 km hr^{-1})	670 W
Climbing stairs (30 deg, 1 km hr^{-1})	960 W

Anthropometric background

Anthropometry is concerned with the size and proportions of the human body. A few anthropometric principles of importance to the ergonomics of posture and movements are given below.

Take account of differences in body size

The designers of workplaces, accessories and suchlike must bear in mind differences in body size of the potential users. A table height which is suitable for a person of average stature can be unsuitable for a tall or short person. A table height which is adjustable over a sufficient range is the solution if the table is to be used by several people.

Sometimes only the shortest users must be considered, for example, in designing a control panel which has to be reached with the arms. In other cases, such as in choosing a door height, the tall users have to be considered instead.

Use the anthropometric tables appropriate for specific populations

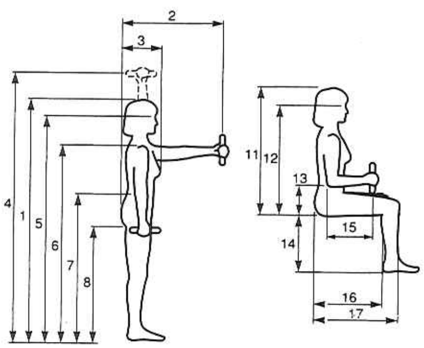
Data for body dimensions always refer to a particular population group and do not necessarily apply to other population groups. Table 2.2, for example, shows the body dimensions of British adults. The adult population of Great Britain is relatively tall in comparison with the average world population. The dimensions refer to unclothed, unshod persons. Some 3–5 cm must be added to the stature to account for shoe thickness. The data in the table do not apply to other population groups. To gain an idea of the extent of individual variation in body size, the data in Table 2.2 are given for:

- short adults (only 5 per cent of adult females are shorter)
- the average person
- tall persons (only 5 per cent of adult males are taller).

The average height of a British adult is 1.68 m, that of a short British adult is 1.51 m or less, and that of a tall British adult is over 1.85 m. The correlation between body dimensions in Table 2.2 is limited. For instance, a person with a short lower arm (dimension 15 is small) could have a long trunk (dimension 12 is large).

Table 2.2 Body sizes of short, average and tall British adults. All measurements are in centimetres, except for body weights, which are in kilograms

	short	*average*	*tall*
Standing			
1. Stature	150.5	167.5	185.5
2. Forward grip reach	65.0	74.3	83.5
3. Chest depth	21.0	25.0	28.5
4. Vertical grip reach	179.0	198.3	219.0
5. Eye height	140.5	156.8	174.5
6. Shoulder height	121.5	136.8	153.5
7. Elbow height	93.0	104.8	118.0
8. Knuckle height	66.0	73.8	82.5
Sitting			
11. Sitting height	79.5	88.0	96.5
12. Sitting eye height	68.5	76.5	84.5
13. Sitting elbow height	18.5	24.0	29.5
14. Popliteal height	35.5	42.0	49.0
15. Elbow-grip length	30.4	34.3	38.7
16. Buttock-popliteal length	43.5	48.8	55.0
17. Buttock-knee length	52.0	58.3	64.5
00. Body weight	44.1	68.5	93.7



Posture

Posture is often imposed by the task or the workplace. Prolonged postures can in time lead to complaints of the muscles and joints. In this section we take a look at the stress due to prolonged sitting and standing, as well as that due to hand and arm postures, such as would occur in the use of hand-held tools.

Select a basic posture that fits the job

The characteristic of the job determines the best basic posture: sitting, standing p. 20, combinations of sitting and standing (sit-stand work stations p. 23) or work stations with pedestal stools p. 24. Figure 2.4 provides a selection procedure for the best basic posture.

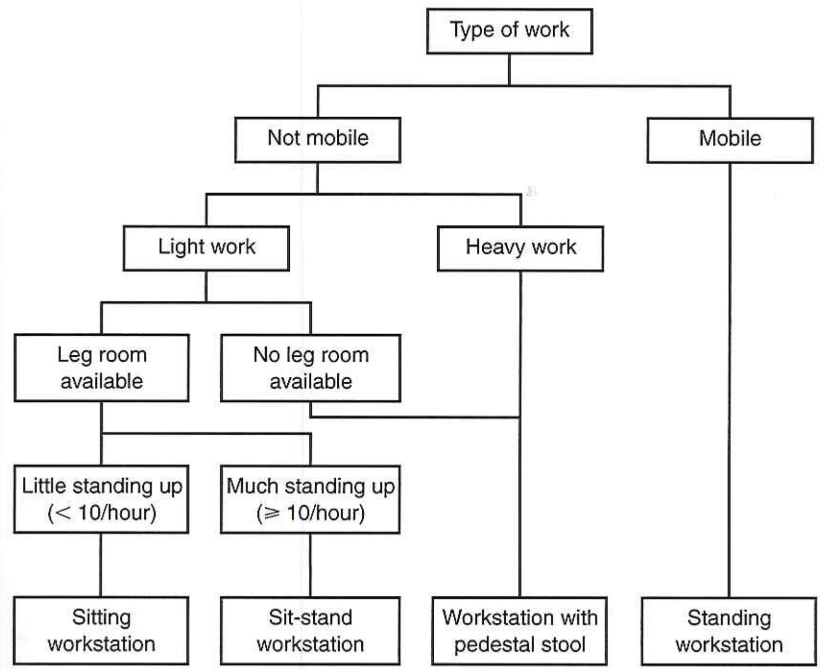


Figure 2.4 Selection procedure for basic posture.

Sitting

Working for long periods in a seated position occurs mostly in offices, but also occurs in industry (assembly and packaging work, sometimes for machine operation). Sitting has a number of advantages compared to standing. The body is better supported because several support surfaces can be used: floor, seat, back rest, armrest, work surface. Therefore, adopting this posture is less tiring than standing. However, activities which require the operator to exert a lot of force or to move around frequently are best carried out standing (see p. 20).

Alternate sitting with standing and walking

Although sitting is usually more favourable than standing, sitting for long periods should be avoided as it has a number of disadvantages. Many manual activities carried out while seated (e.g. writing or assembly work) require the person to keep the hands in view. This means that the head and trunk have to be bent forward. The neck and back are then subjected to prolonged stress which can lead to neck and back complaints. Bending the trunk forward also means that the back rest of the chair is no longer used. The back is subject to further stresses if the trunk has to be twisted and the seat cannot swivel. Manual work often requires working with unsupported raised arms, which can lead to shoulder complaints.

Tasks which require prolonged sitting (for example, at a VDU screen) should be alternated with tasks which can be carried out in a standing position, or where walking is necessary. A sit-stand workplace (p. 23), or a chair that promotes active sitting allow the user to alternate between sitting and other postures during the task.

The height of the seat and back rest of the chair must be adjustable

There are many ergonomically-sound chairs on the market. The most important general feature of such chairs is that the height of the seat and back rest is adjustable.

- It must be possible to adjust the height of the seat while sitting, in a continuous, smooth motion rather than in steps. For British adults, the minimum adjustment range should be at least 13 cm between the heights of 39 and 52 cm, based on popliteal height differences (measure 14 in Table 2.2 plus 3 cm for shoe thickness).
- The height of the seat must be chosen in such a way that when the feet are properly supported, the upper legs are also properly supported, without the back of the knee being cramped.
- The backrest must provide support mainly to the lower back (for British adults, the minimum adjustment range should be at least 10 cm between the heights of 20 and 30 cm, based on differences in the lumbar height, not shown in Table 2.2). Avoid misusing a low back rest as a high back rest.
- The lower part of the back rest must be given a convex shape in order to preserve the curve of the lower back.

In addition, the chair should swivel. This reduces the need to twist the body.

Limit the number of adjustment possibilities

Adjustment possibilities must be restricted to only the most important components of the chair; as a minimum, the seat height and the height of the back rest. If too many features are adjustable, settings will be used either incorrectly or not at all.

Provide proper seating instructions

Users of adjustable chairs must receive regular instruction in the optimum adjustment of the chair, say every six months. This also applies to other adjustable elements of the workplace, such as the table.

Specific chair characteristics are determined by the task

In addition to its general characteristics, an ergonomically-sound chair will also display specific features which depend on the task. A chair with armrests can be selected if these do not hinder the activities, as armrests can partly support the weight of the arms and trunk, and are also useful when rising from the chair. Armrests should be short to allow close proximity to the table. Castors can be useful if a chair has to be moved frequently but none should be present if pedals have to be operated. If the trunk is mostly upright or tilted somewhat backwards, the seat ought to be tilted backwards a few degrees. For tasks where the body is unavoidably bent forward, a limited forward tilt (maximum 20 degrees), is advantageous, as it can prevent the lower back from curving. Figure 2.5 shows an example of an ergonomically-sound chair for VDU work. Here, the seat and back rest are adjustable, the back rest supports also the lower back, and the short armrests and castors provide additional comfort.

The work height depends on the task

The chair is only one of several factors determining whether the working posture is correct. The position of the hands as well as the focal point are also of great importance to the posture of the head, trunk and arms. The correct height for the hands and focal point

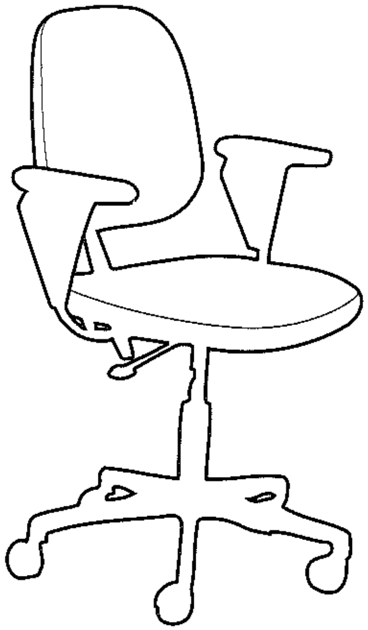


Figure 2.5 An ergonomically-sound chair for VDU work. The height of the seat and back rest (with support for the lower back) can easily be adjusted. The chair swivels, has short, adjustable armrests and is fitted with castors.

depends on the task, individual body dimensions and individual preference. During most tasks the hands have to be used and viewed simultaneously. Then, the work height is a compromise between the optimum height for the arms and the optimum position of the head and trunk. In the first instance, a low table is better since the arms have to be raised to a lesser extent and it is easier to apply a force. In the second instance, a high table is better because it means less bending forward and a better view of the work.

General guidelines for the work height are given in Table 2.3 for three types of tasks. These guidelines apply both when sitting or standing.

The height of the hands and focal point need not always be the same as the table or work surface height. The work surface might have to be lowered, to take into account the thickness of the workpieces, tools or accessories (e.g. a keyboard). The work surface and

Table 2.3 Guidelines for the height of the hands and focal point, for carrying out various tasks while seated or standing

Type of task	*Work height*
Use of eyes: frequent, Use of hands/arms: infrequent	10–30 cm below eye height
Use of eyes: frequent, Use of hands/arms: frequent	0–15 cm above elbow height
Use of eyes: infrequent, Use of hands/arms: frequent	0–30 cm below elbow height

the objects on it should not be too thick otherwise legroom will be restricted.

Work tables used for a given type of seated task not involving objects of different thickness must be adjustable over a range of at least 25 cm because of differences between individuals. Where a number of tasks have to be carried out which require different work heights, the adjustment range must be even greater.

A good starting position for the height of a VDU workstation is one where the hands are kept at elbow height. The height of a VDU table with a keyboard thickness of 3 cm (measured at the position of the middle row of keys) must be adjustable between 54 and 79 cm for British adults (based on differences in sitting elbow height, see measures 13 and 14 in Table 2.2). It must be possible to make the adjustment easily from the seated position.

The heights of the work surface, seat and feet must be compatible

In a seated workplace which can be adjusted individually, the vertical distances between the feet, seat and working surface must be compatible. The height of the feet is mostly fixed because they rest on the floor. The chair and table must then be adjustable and set according to the guidelines of Table 2.3.

Use a footrest if the work height is fixed

If the work height cannot be adjusted by the individual user, such as at a machine, a relatively high work surface must be chosen to suit tall users. The seat height is then adjusted to the work surface. The height of the feet should then also be adjusted, using a suitable footrest, which would be not simply a bar, but a slightly sloping surface.

Avoid excessive reaches

It is necessary to limit the extent of forward and sideways reaches to avoid having to bend over or twist the trunk. Workpieces, tools and controls which are in regular use should be located directly in front of, or near the body.

Figure 2.6 shows the reach envelopes in three planes. The most important operations should take place within a radius of approximately 50 cm. This value applies to both seated and standing work. Application of the guidelines on reaches is given in Chapter 3, which covers the design of control panels.

Select a sloping work surface for reading tasks

If the activities allow it, use should be made of a sloping work surface for reading tasks and other tasks where the work has to be kept in view, such as writing and assembly work without tools. A sloping work surface brings the work to the eye instead of the other

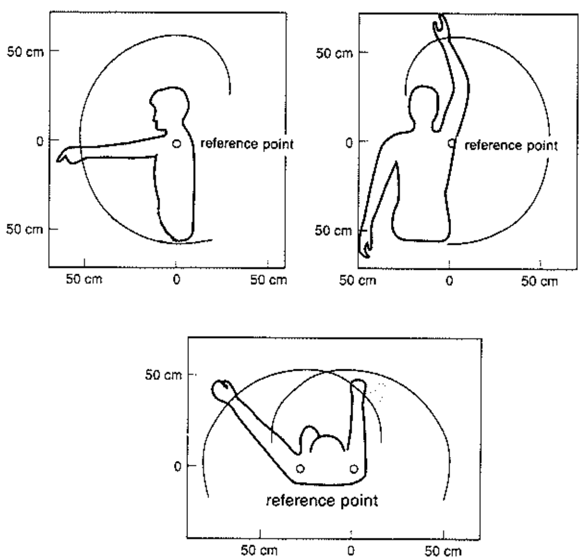


Figure 2.6 Guidelines for convenient maximum reaches in seated or standing work.

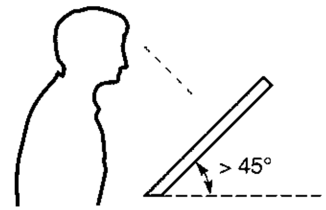


Figure 2.7 In tasks which require no manual work, such as reading, bending the head and trunk forward can be reduced by using a sloping work surface of at least 45 degrees for viewing.

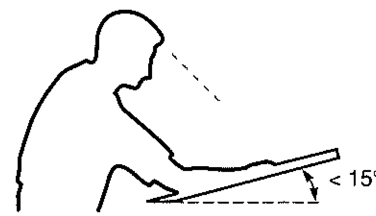


Figure 2.8 Viewing manual work.

way round, thereby improving the posture of the head and trunk. Because the height of the front of the table or machine remains the same, the arms do not have to be raised any further. Successful use of a sloping work surface requires measures to prevent workpieces or accessories from sliding off (non-slip work surface, rim, etc.) or alternatively, only part of the work surface should slope. Sloping work surfaces can often be created easily by raising the back of the table or machine or by using a lectern. For reading purposes, the position of the work surface which is viewed, must be tilted by at least 45 degrees (Figure 2.7).

For tasks where the hands have to be used and kept in view, such as in writing, the work surface must be placed at an angle of approximately 15 degrees (Figure 2.8). A greater slope is not desirable because of insufficient support for the arms and because objects may slide off.

Allow sufficient legroom

Sufficient legroom must be provided under the work surface (Figure 2.9). The width clearance must be at least 60 cm. The required depth

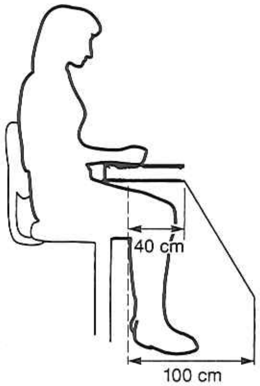


Figure 2.9 Required legroom for sitting.

clearance must be at least 40 cm at the knees and 100 cm at the feet, which should allow the user to sit close to the work without bending the trunk forward.

It is desirable to be able to stretch the legs once in a while when sitting for long periods. To this effect the depth clearance at the feet should be at least 1 m.

To have sufficient room between the underside of the working surface and the top of the legs, the thickness of the working surface (and objects on it) must be as small as possible. The thickness of a writing surface, for example, should not exceed 3 cm.

Standing

Activities where considerable force has to be exerted or where the work place has to be frequently changed, should be carried out in a standing position.

Alternate standing with sitting and walking

It is not recommended for the whole working day to be spent in a standing position. Standing for long periods tires the back and legs. An additional stress can arise when the head and trunk are bent, leading to neck and back complaints. Furthermore, working with the arms unsupported, in a raised position, leads to stress on the shoulders, which may result in shoulder complaints.

Tasks which have to be carried out over long periods in a standing

position should be alternated with tasks which can be carried out while seated, or with tasks where walking is required. People should also be given the opportunity to sit down during natural breaks in the work (e.g. in the case of operating a machine or in sales work in shops). A sit-stand workplace or a pedestal stool will allow the user to vary postures during the task (see pp. 23 and 24).

The work height depends on the task

The work height for standing work depends, as for seated work, on the task, on individual preference, and on individual body dimensions. Table 2.3 contains the guidelines for the optimum work height for different types of standing tasks carried out at a work surface.

The height of the work table must be adjustable

It must be possible to adjust the height of a work table which is intended for use by several people (as a result of part-time working, team work or task rotation), or whenever different tasks (e.g. with varying sizes of workpieces) must be carried out at the same table. It must be possible to conveniently adjust the table from the normal working position. A table meant for standing work which is used for a given task, and on which no objects of different thickness are used, must have an adjustment range of at least 25 cm in order to cater for individual differences in body size. Users must be instructed in the optimum height of the table.

Do not use platforms

The use of platforms for standing work is not advisable. The major disadvantages of platforms are that they constitute a trip hazard, are cumbersome to clean, and hamper transport along floors. They also require additional work space, and are not practical if their height has to be regularly adjusted for different people or to different working heights.

Provide sufficient room for the legs and feet

Sufficient room must also be kept free under the work surface or machine for the legs and feet in standing work. This allows the person to be close to the work without bending the trunk. Enough clearance is also required for changing the position of the legs once in

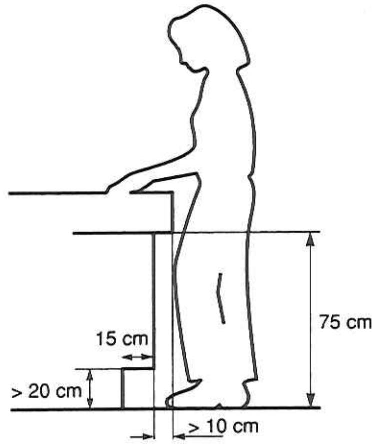


Figure 2.10 Minimum foot and leg-room required for standing work (dimensions in cm).

a while. Figure 2.10 illustrates the required minimum recesses under the work surface or machine.

Avoid excessive reaches

Forward and sideways reaches must be limited in order to avoid having to bend forward or twist the trunk. Workpieces, tools and controls which are in regular use should be located directly in front of, and near, the body. Convenient maximum reaches are given in Figure 2.6.

Select a sloping work surface for reading tasks

If the activities allow it, a sloping work surface should be used for reading tasks just as in the case of seated work. The same is true also for other tasks where the work must be kept in view, such as writing. Guidelines for a sloping work surface are given in Figures 2.7 and 2.8.

Change of posture

This section describes ways of relieving prolonged postures. These techniques relate to the provision of a varied task package, the

implementation of a sit-stand workplace and the use of a pedestal stool.

Offer variation in tasks and activities

The design and organization of activities should ensure that everyone is given variation in tasks and activities so that no prolonged postures occur. The principle of job enrichment can be usefully applied (see Chapter 5).

Introduce sit-stand work stations

If tasks have to be carried out over a long period, the workplace should be adapted to allow the work to be carried out either standing or sitting. To this effect a work height is selected which is suitable for standing work (see Standing, p. 20). In addition, a special high chair also allows the work to be carried out while seated. Leg-room has been left under the work surface and a footrest is provided (Figure 2.11).

Alternate sitting postures

A prolonged seated posture can be varied by using different types of chairs. There are chairs available that promote 'active sitting'. The chairs offer possibilities to change posture and have adjustable seats

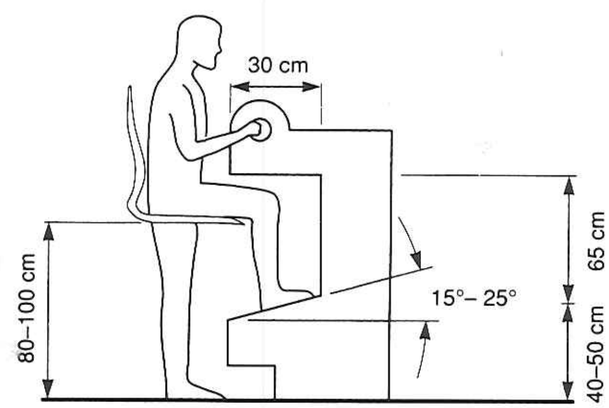


Figure 2.11 Guidelines for the dimensions of a workplace at which seated and standing work can be alternated.

and backs, allowing movements of the body. Despite the use of these chairs, it is still advisable to alternate sitting with standing and walking.

Make occasional use of a pedestal stool in standing work

A pedestal stool can be used once in a while to vary a standing work posture. A pedestal stool consists of a seat which is adjustable in height (65–85 cm), and is tilted forwards between 15 and 30 degrees. It allows semi-supported postures to be adopted, which somewhat relieve the stress on the legs. A pedestal stool cannot be used for long periods and is only suited to standing activities where large forces or extensive movements are not required. The floor on which it rests must provide sufficient friction to prevent the support from sliding away (Figure 2.12).

Hand and arm postures

Working for long periods with the hand and arm in a poor posture can lead to specific complaints of the wrist, elbow and shoulder. A continuously bent wrist can lead to local nerves becoming inflamed and trapped, resulting in wrist pain and a tingling sensation in the fingers. Another ailment is tennis elbow, which is a local inflamma-

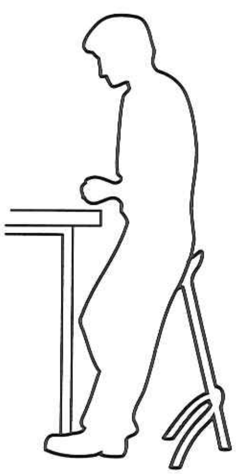


Figure 2.12 A pedestal stool can be used to change posture when standing for long periods.

tion of a tendon attachment due to a combination of a bent elbow and bent wrist.

Neck and shoulder complaints occur in prolonged work with unsupported, raised arms. These problems arise especially from handling tools. In addition to posture, application of a force and repetitive movement ('Repetitive Strain Injuries or RSI') play a role in the development and aggravation of these conditions. Correct hand and arm postures can be promoted by selecting a correct working height for the hands (see Table 2.3) and by using the right tools (see below).

Select the right model of tool

A particular tool is often available in different models. Select a model which is best suited to the task and posture, so that the joints can be kept as far as possible in the neutral position. Figure 2.13 shows the correct and incorrect use of different types of electric drills and screwdrivers.

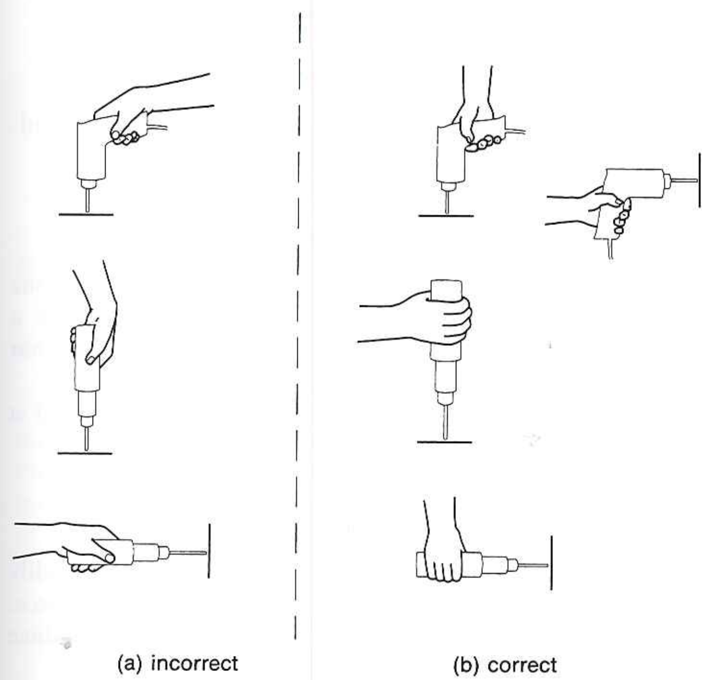


Figure 2.13 When using hand-held tools, the wrist should be kept as straight as possible. The figure shows the correct and incorrect use of two types of rotating tool.

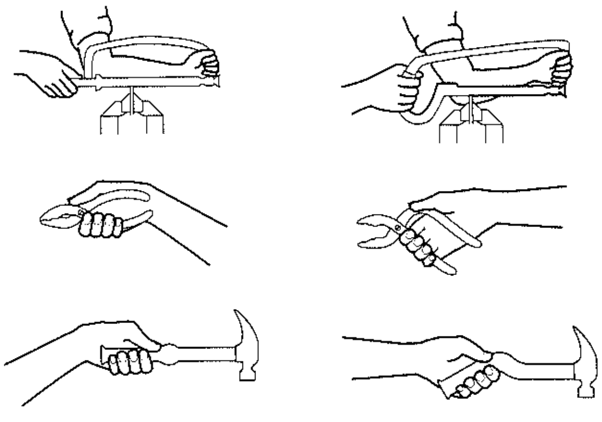


Figure 2.14 Correct location of handgrips on tools avoids having to bend the wrist.

Do not bend the wrist, use curved tools instead

Bending the wrist can be prevented by correctly locating the handgrips on a tool (Figure 2.14).

Hand-held tools must not be too heavy

If the tool cannot rest on a surface, and is normally used with one hand, its weight should not exceed 2 kg. If the tool can rest on a surface, heavier weights are allowed, but the maximum weights that apply to lifting (p. 30) must be taken into consideration.

Heavy tools which are frequently used can be suspended on a counterweight (Figure 2.15).

Maintain your tools

Proper maintenance of tools can contribute to a reduction in bodily stress. Blunt knives, saws or other equipment require greater force. Proper maintenance of motorized hand-held tools can also reduce wear, noise and vibration (see Chapter 4).

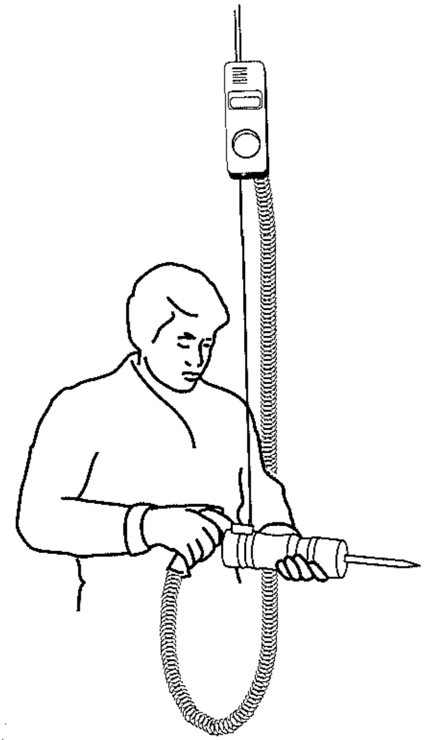


Figure 2.15 The weight of heavy hand-held tools can be supported by a counterweight.

Pay attention to the shape of handgrips

The shape and location of handgrips on trolleys, loads, machines, equipment and suchlike must take into consideration the position of the hands and arms. If the whole hand is used to exert a force, the handgrip must have a diameter of approximately 3 cm and a length of approximately 10 cm (Figure 2.16).

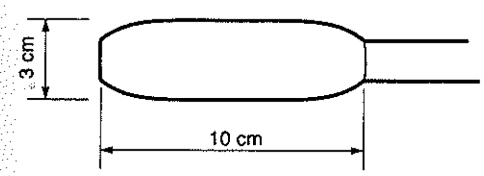


Figure 2.16 Shape of handgrips on hand-held tools.

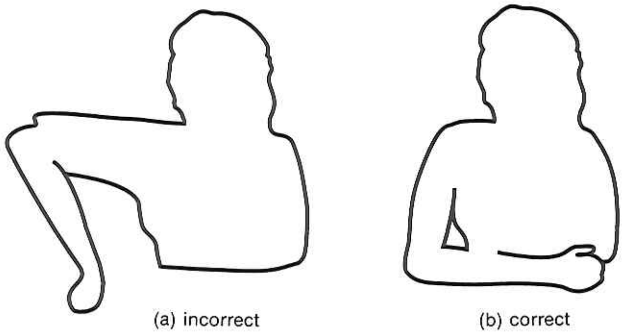


Figure 2.17 Hand and elbow positions above shoulder height are to be avoided.

The handgrip must be somewhat convex to increase the contact surface with the hand. The use of pre-shaped handgrips is not advised: the fingers are constrained, too little account is taken of individual differences in finger thickness and the grips are not suitable for use with gloves.

Avoid carrying out tasks above shoulder level

The hands and elbows should be well below shoulder level when carrying out a task (Figure 2.17). If work above shoulder level is unavoidable, the duration of the work must be limited and regular breaks must be taken.

Avoid working with the hands behind the body

Working with the hands behind the body should be avoided (Figure 2.18). This kind of posture occurs when sliding away objects, for example, at check-outs in supermarkets.

Movement

Various tasks require moving the whole body, often while exerting a force. Such movements can cause high, localized mechanical stresses which in time can lead to bodily aches and pains. Movements can also be stressful in the energetic sense for the muscles, heart and lungs. In this section we examine the stress from lifting, carrying, pulling and pushing.

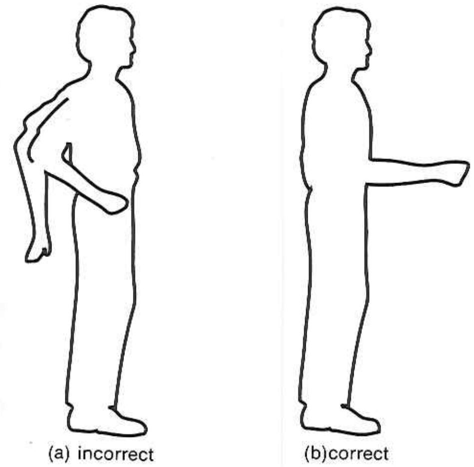


Figure 2.18 Avoid positions where the hands and elbows are held behind the body.

Lifting

Manual lifting is still frequently needed in spite of mechanization and automation. Lifting is seen as a major cause of lower back complaints. Many lifting situations still do not satisfy ergonomic requirements. This section contains guidelines and measures for lifting. These measures relate to the production technique (mechanical or manual), the work organization (task design, lifting frequency), the workplace (position of load with respect to the body), the load (shape, weight, presence of handgrips), lifting accessories, and the working method (lifting by several persons, individual lifting technique).

Restrict the number of tasks which require displacing loads manually

Production systems must be designed to use mechanization as a way of restricting the extent of manual lifting. In this case, however, attention must be paid to new problems relating to posture and movement. These could include prolonged manual operation of machines or lifting accessories, or the necessity for heavy maintenance work on machines which are difficult to access. Other problems can also develop as a result of mechanization, for example, noise and vibration, monotony, and reduced social contacts.

If it is not possible to avoid heavy or frequent lifting, these activities must be alternated with other (light) activities, for example, by applying job enrichment (see Chapter 5).

In lifting, but also in other physical activities, it is important that the work pace should be set by the person involved. It is essential to avoid situations where the rate of lifting is imposed by a machine, by colleagues or by a supervisor.

Create optimum circumstances for lifting

If manual lifting of heavy loads (up to 23 kg) is necessary, then lifting conditions have to be optimized:

- it must be possible to hold the load close to the body (horizontal distance from hand to ankles about 25 cm);
- the initial height of the load before it is lifted should be about 75 cm;
- the vertical displacement of the load should not exceed 25 cm;
- it must be possible to pick up the load with both hands;
- the load must be fitted with handles or hand-hold cut-outs;
- it must be possible to choose the lifting posture freely;
- the trunk should not be twisted when lifting;
- the lifting frequency should be less than one lift per five minutes;
- the lifting task should not last more than one hour, and should be followed by a resting time (or light activity) of 120 per cent of the duration of the lifting task.

Ensure that people always lift less, and preferably much less, than 23 kg

Only in the above-mentioned optimum lifting situation may a person lift the maximum load of 23 kg. Lifting conditions, however, are virtually never optimum, in which case the maximum allowable load is considerably less (see below). The load should not exceed a few kilogrammes if it has to be picked up far away in front of the body and has to be displaced over a large vertical distance.

Use the NIOSH method to assess lifting situations

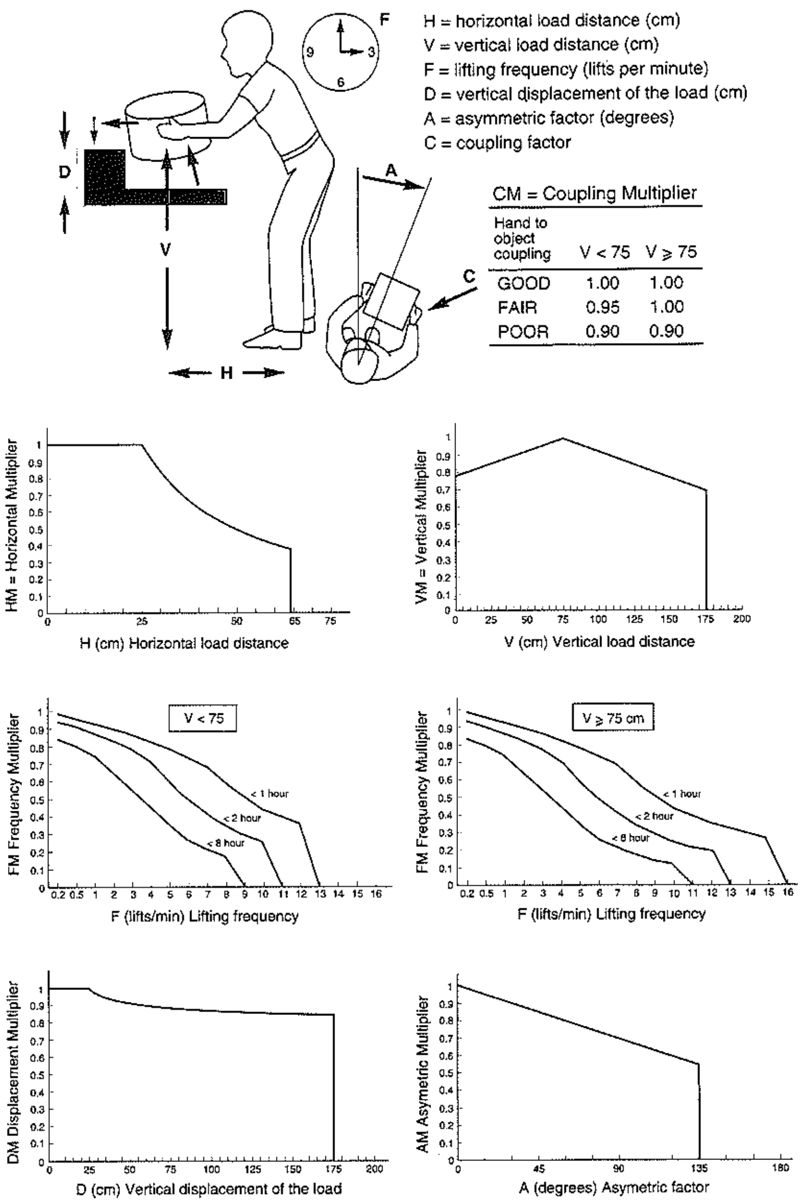
In practice, optimum lifting conditions are seldom met, and therefore the permitted load is much less than 23 kg. The method developed by the American National Institute for Occupational Safety and Health (NIOSH) can be used to determine the maximum load in unfavourable lifting conditions. This takes into account the horizontal and vertical distance between the load and the body, the trunk rotation, the vertical displacement, the lifting frequency and duration, and the coupling between hands and load. It assumes among other things that the lifting posture can be freely chosen and that the load is lifted with both hands. The NIOSH equation is devised in such a way that the weight is acceptable for the majority of the population (99 per cent of men and 75 per cent of women) that the compressive load on the lower back is less than 3400 N (340 kg force), and that the energy expenditure for 1–2 hours repetitive lifting is less than 260 W for lifts below the bench height (75 cm) and less than 190 W for lifts above the bench height. In the NIOSH method, the unit weight of 23 kg is reduced for unfavourable lifting conditions by using a series of multipliers according to the formula:

Recommended weight limit
$= 23\,\text{kg} \times HM \times VM \times DM \times FM \times AM \times CM$

Figure 2.19 shows the multipliers for the horizontal load distance (horizontal multiplier, HM), the vertical load distance (vertical multiplier, VM), the vertical displacement of the load (displacement multiplier, DM), the frequency (frequency multiplier, FM), the asymmetric factor (asymmetric multiplier, AM), and the coupling factor (coupling multiplier, CM). If the lifting situation does not satisfy the requirements of the NIOSH method (e.g. if the lifting posture cannot be freely chosen, or if the load is lifted with one hand), the method will result in values that are too high. Because of the complexity of the analysis, several software packages have been developed to analyse lifting situations including combinations of different lifting tasks, using the NIOSH method. These can also help to develop improvements based on the results of the analysis.

Individual loads should not be too light

The weight of a load (e.g. the unit weight of a packaging) has to be chosen carefully. On the one hand the NIOSH recommendation should not be exceeded under normal conditions. On the other hand the loads should not be too light otherwise more frequent lifting becomes necessary. If individual loads are too light there is also a danger that several loads may be lifted simultaneously.



Hand to object coupling	V < 75	V ≥ 75
GOOD	1.00	1.00
FAIR	0.95	1.00
POOR	0.90	0.90

Figure 2.19 The maximum load can be determined for unfavourable lifting conditions by using the NIOSH equation.

Make the workplace suitable for lifting activities

The design of tables, shelves, machines and suchlike, onto which loads have to be placed or from which loads have to be lifted, must result in optimum lifting conditions being achieved.

- It must be possible to approach the load properly when lifting and setting it down.
- Foot and legroom must be sufficient to allow a stable position for the feet and to be able to bend the knees.
- Twisting the trunk should not be necessary.
- The height and location of the load on the work surface must be such that when lifting the load or setting it down, the hands are at the optimum height of approximately 75 cm, and close to the trunk.

It can generally be said that the measures described here have considerable influence on the admissibility of lifting activities. It is often possible to achieve more through a higher and closer position of the load than by reducing its weight.

Loads should be fitted with handgrips

A load should be fitted with two handgrips so that it can be grasped with both hands and lifted (Figure 2.20b). Grasping the load with the fingers (Figure 2.20a) should be avoided because far less force can be exerted.

The position of the handgrips should be such that the load cannot twist when lifted.

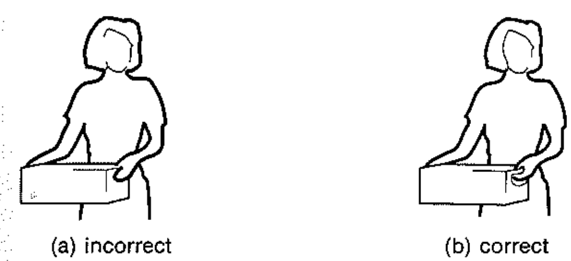


Figure 2.20 No handgrips (a) and correct (b) handgrips for lifting loads.

Ensure that the load is of the correct shape

The size of the load must be as small as possible so that it can be held close to the body. It must be possible to move the load between the knees if it has to be lifted from the floor. The load should not have any sharp edges nor be hot or cold to the touch. For special loads, such as a container of hazardous liquid, or a hospital patient, additional attention should be paid to the lifting process, for instance, by taking special safety precautions and planning the lifting operation.

If a person is to lift loads of a weight unknown in advance to him or her, it is desirable to label the loads in advance showing their weight and possibly advise caution.

Use correct lifting techniques

Sometimes a person can more or less freely choose the lifting technique. In such instances, prior training will ensure that the best possible posture is adopted during the lift. On the other hand, the benefits of information and training should not be overestimated. In practice, improved lifting techniques are often not feasible because of restrictions at the workplace. In addition, ingrained habits and movements can only be changed after intensive training and repetition.

Training should address the following aspects:

- assess the load and establish where it must be moved to. Consider using the help of others or the use of a lifting accessory;
- where lifting has to be done without any additional help, stand directly in front of the load. Make sure the feet are in a stable position. Bring the load as close as possible to the body. Grasp the load with both hands, using the whole hand, not just a few fingers;
- hold the load as close as possible to the body while lifting. Make a flowing movement with a straight trunk. Avoid twisting the trunk. If necessary, move the feet.

The latter recommendation is of great importance in reducing back stress (Figures 2.21 and 2.22). Bending or twisting of the trunk while lifting, contribute significantly to injuries of the lower back. The load in Figure 2.21 is approximately 20 kg; bending the trunk forward, as in (a) results in a back stress nearly 30 per cent greater than in (b).

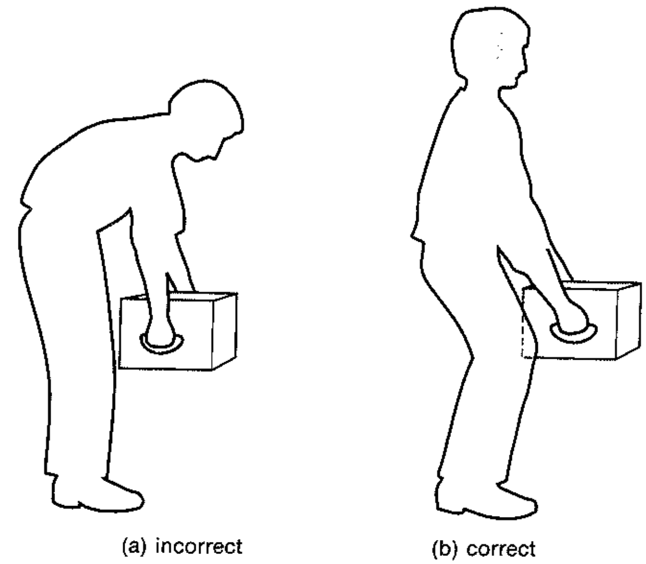


Figure 2.21 Lifting with a bent trunk and a large horizontal distance between load and lower back (a) is more hazardous than lifting with the back straight and a small horizontal distance between load and body (b).

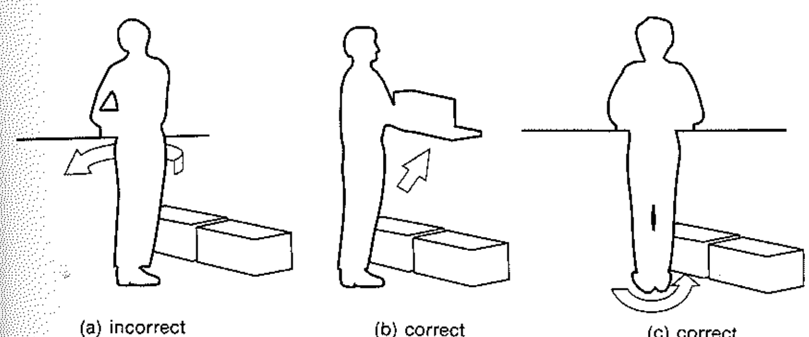


Figure 2.22 Twisting the trunk while lifting (a) must be avoided by a better choice of lay-down surface (b), or by moving the feet (c).

Heavy lifting should be done by several people

Several people can work together if the load is too heavy to be lifted by one person. The partners must be of approximately the same height and strength, and must be able to work well together. One of them must co-ordinate the lifting as this will prevent unexpected movements.

Use lifting accessories

Many lifting accessories are available to help lift and move loads. The different types include, for example, levers, raising platforms, and cranes. Figure 2.23 gives an example of a special device for lifting kerbstones (a), a dedicated mobile lift for moving patients (b), and two universal accessories: a mobile lifting table (c) and a crane (d).

Carrying

After a load has been lifted it must sometimes be moved manually. In general, walking with a load is both mechanically stressful and

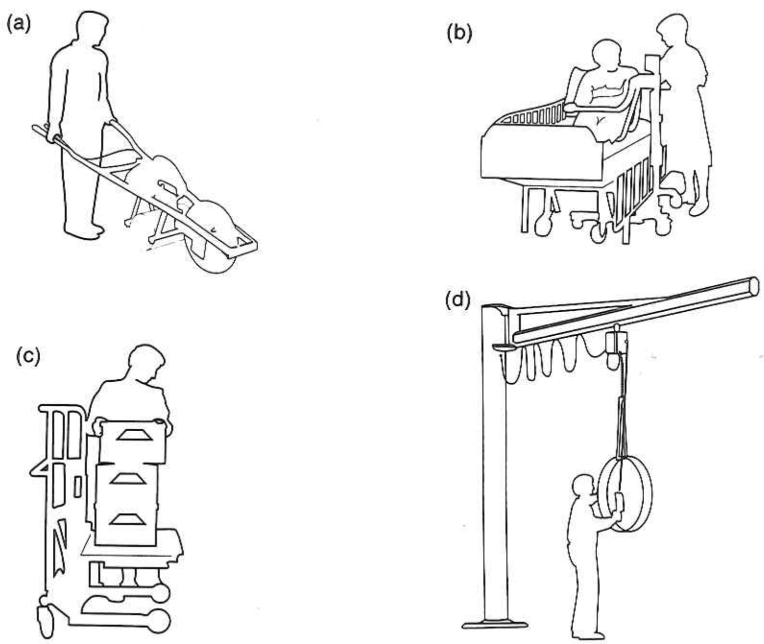


Figure 2.23 Examples of lifting accessories.

energetically demanding. As a result of holding the load, the muscles are subjected to continuous mechanical stress; this particularly affects the muscles in the arms and back. Displacing the whole body and the load consumes energy.

Limit the weight of the load

The permissible weight of a carried load is determined mostly by the lifting which precedes the carrying. Guidelines for lifting are given in the section on lifting (p. 29).

Hold the load as close to the body as possible

To limit both mechanical stress and energy consumption, the load must be kept as close as possible to the body. Small, compact loads are therefore preferable to larger loads. By using accessories such as a backpack or a yoke, it is possible to hold the load even closer to the body.

Provide well-designed handgrips

The load should be fitted with well-designed handgrips that have no sharp edges. Alternatively, an accessory such as a hook may be used instead.

Avoid carrying tall loads

A person lifting a tall load will tend to bend the arms to prevent the load from hitting his or her legs. This causes additional fatigue to the muscles in the arms, shoulders and back. The vertical dimension of the load must therefore be limited (Figure 2.24).

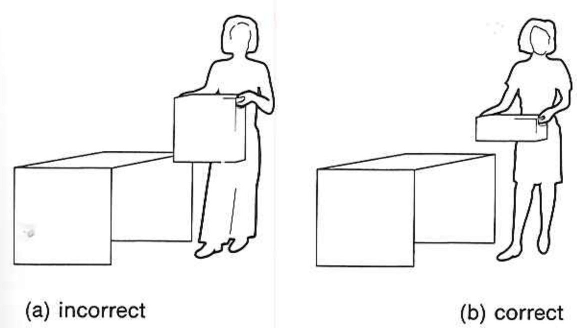


Figure 2.24 Carrying of tall loads should be avoided.

Avoid carrying loads with one hand

When only one hand is used to carry a load, the body is subject to an asymmetric stress; well-known examples of this are carrying a school bag, suitcase or shopping bag. The solution is to carry two lighter loads (one in each hand) or use a backpack.

Use transport accessories

There is a large number of provisions and accessories such as roller conveyors, conveyor belts, trolleys and mobile raising platforms which make it unnecessary to carry loads manually. Whenever one of these is selected, the user must be aware of any possible new problems resulting from the lifting, pulling and pushing required to place the load on the device or move it (trolley, etc.).

Pulling and pushing

Many types of trolley have to be moved manually. Pulling and pushing trolleys places stress mainly on the arms, shoulders and back. The design of the trolley must take this into account (Figure 2.25).

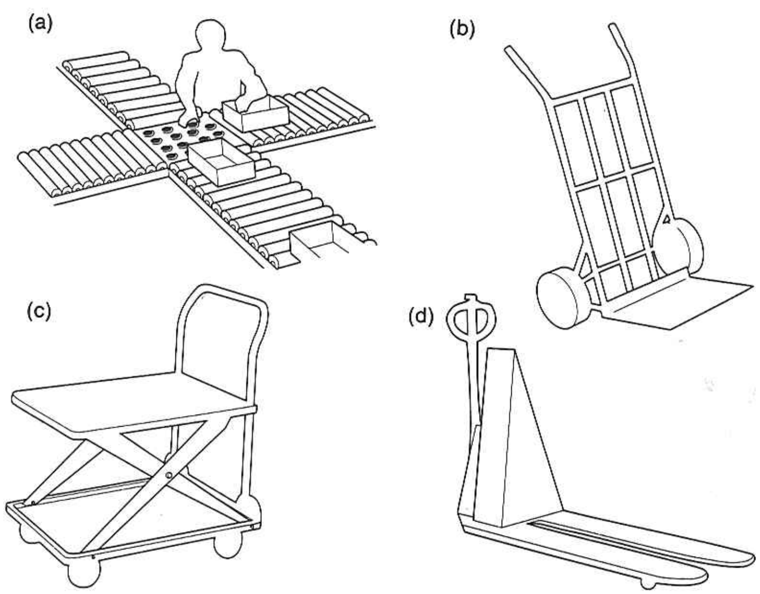


Figure 2.25 Transport accessories which replace manual carrying: (a) roller conveyor, (b) sack barrow, (c) mobile raising platform, (d) forklift.

Limit the pulling and pushing force

When setting a trolley in motion by pulling or pushing, the exerted manual force should not exceed approximately 200 N (about 20 kg force). Although the maximum possible force required is often considerably higher, this limit should be adhered to in order to prevent large mechanical stresses, mainly to the back. If the trolley is kept moving for more than one minute, the permissible pulling or pushing force drops to 100 N.

In practice this means that trolleys with a total weight (including load) of 700 kg or more should certainly not be displaced manually. The permissible weight depends on the type of trolley, the kind of floor, the wheels, and so forth. Many types of motorized trolley are available which can be used as an alternative.

Use the body weight when pulling or pushing

A correct pulling and pushing posture is one which uses the body's own weight. When pushing, the body should be bent forwards and when pulling, it should lean backwards. The friction between the floor and the shoes must be sufficiently large to allow this. There must also be sufficient clearance for the legs to be able to maintain this posture. In pulling and in pushing, the horizontal distance between the rearmost ankle and the hands must be at least 120 cm. When pulling, there must also be room under the trolley to place the forward foot directly below the hands (Figure 2.26).

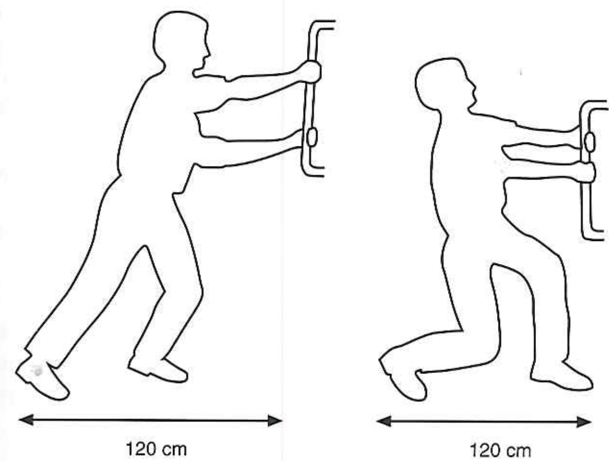


Figure 2.26 Using the weight of the body when pushing or pulling trolleys.

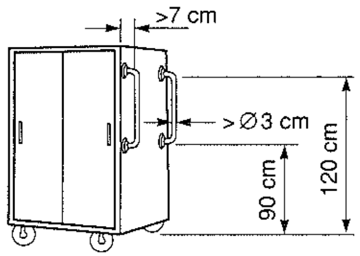


Figure 2.27 Recommended handgrip designs for pulling and pushing trolleys.

Provide handgrips on trolleys

Trolleys and suchlike should be fitted with handgrips so that both hands can be fully utilized to exert a force. The dimensions (in cm) of handgrips for pushing and pulling are given in Figure 2.27. The handgrips must be cylindrical. Vertical handgrips, at a height of 90–120 cm, have the advantage that the hands can be placed at the right height when maintaining a correct pulling or pushing posture.

A trolley should have two swivel wheels

Trolleys used on a hard floor surface must be fitted with large, hard wheels, which are able to limit any resistance due to unevenness of the floor. Two swivel wheels should be fitted to achieve good manoevrability. These should be positioned on the side that is pushed or pulled, i.e. where the handgrips are located. Having four swivel wheels is not advisable because this makes it necessary to steer continuously.

The loaded trolley must not be higher than 130 cm so that most persons can see over the load while pulling or pushing.

Ensure that the floors are hard and even

If possible, avoid having to lift trolleys over any raised features such as kerbs. If this is unavoidable, the trolleys should be fitted with horizontal handgrips. The weight to be lifted may not exceed the limits given above for lifting (p. 31).

SUMMARY CHECKLIST

Biomechanical, physiological and anthropometric background

Biomechanical background

1 Are the joints in a neutral position?
2 Is the work held close to the body?
3 Are forward-bending postures avoided?
4 Are twisted trunk postures avoided?
5 Are sudden movements and forces avoided?
6 Is there a variation in postures and movements?
7 Is the duration of any continuous muscular effort limited?
8 Is muscle exhaustion avoided?
9 Are breaks sufficiently short to allow them to be spread over the duration of the task?

Physiological background

10 Is the energy consumption for each task limited?
11 Is rest taken after heavy work?

Anthropometric background

12 Has account been taken of differences in body size?
13 Have the right anthropometric tables been used for specific populations?

Posture

14 Has a basic posture been selected that fits the job?

Sitting

15 Is sitting alternated with standing and walking?
16 Are the height of the seat and back rest of the chair adjustable?
17 Is the number of adjustment possibilities limited?
18 Have good seating instructions been provided?
19 Are the specific chair characteristics dependent on the task?
20 Is the work height dependent on the task?
21 Do the heights of the work surface, seat and feet correspond?
22 Is a footrest used where the work height is fixed?

23 Are excessive reaches avoided?
24 Is there a sloping work surface for reading tasks?
25 Is there enough legroom?

Standing

26 Is standing alternated with sitting and walking?
27 Is work height dependent on the task?
28 Is the height of the work table adjustable?
29 Has the use of platforms been avoided?
30 Is there enough room for the legs and feet?
31 Are excessive reaches avoided?
32 Is there a sloping work surface for reading tasks?

Change of posture

33 Has an effort been made to provide a varied task package?
34 Have combined sit-stand workplaces been introduced?
35 Are sitting postures alternated?
36 Is a pedestal stool used once in a while in standing work?

Hand and arm postures

37 Has the right model of tool been chosen?
38 Is the tool curved instead of the wrist being bent?
39 Are hand-held tools not too heavy?
40 Are tools well maintained?
41 Has attention been paid to the shape of handgrips?
42 Has work above shoulder level been avoided?
43 Has work with the hands behind the body been avoided?

Movement

Lifting

44 Have tasks involving manual displacement of loads been limited?
45 Have optimum lifting conditions been achieved?
46 Has care been taken that any one person always lifts less, and preferably much less, than 23 kg?
47 Have lifting situations been assessed using the NIOSH method?
48 Are the weights to be lifted not too light?
49 Are the workplaces suited to lifting activities?

50 Are handgrips fitted to the loads to be lifted?
51 Does the load have a favourable shape?
52 Have good lifting techniques been used?
53 Is more than one person involved in heavy lifting?
54 Are lifting accessories used?

Carrying

55 Is the weight of the load limited?
56 Is the load held as close to the body as possible?
57 Are good handgrips fitted?
58 Is the vertical dimension of the load limited?
59 Is carrying with one hand avoided?
60 Are transport accessories being used?

Pulling and pushing

61 Are pulling and pushing forces limited?
62 Is the body weight used during pulling and pushing?
63 Are the trolleys fitted with handgrips?
64 Do the trolleys have two swivel wheels?
65 Are the floors hardened and even?