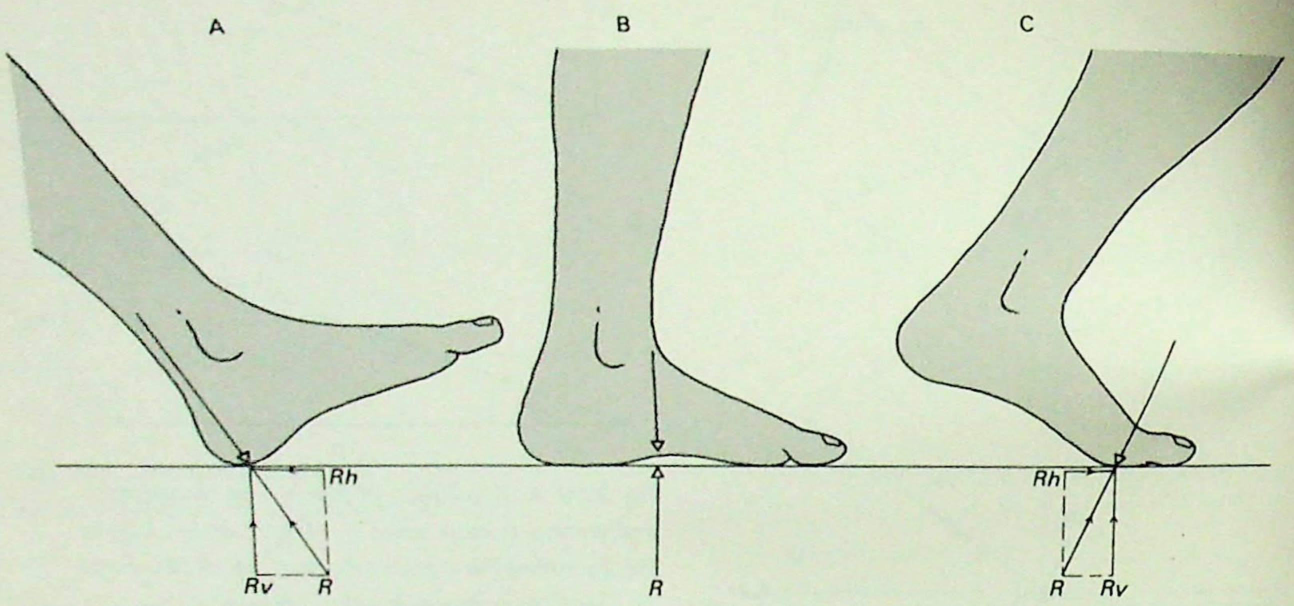

Fig. 2.12 Analysis of forces in walking. A, Heel strike; B, Stance; C, Toe-off. *R* – reaction force. *Rv* – vertical component of reaction force. *Rh* – horizontal component of reaction force.

which prevents the foot from sliding forward and checks the momentum of the body. In the propulsive (or toe off) phase, the horizontal force is responsible for allowing the driving force which propels the body forward.

Moments

A moment may be defined as the turning force resulting from the application of a force some distance away from the fulcrum of movement.

Figure 2.13A show a typical moment; Fig. 2.13B shows the same moment when applied to a cylinder, causing twisting. This presentation is often termed a *torque*. The effective value of the applied force is magnified as a result of being placed at a distance from the centre of motion:

Moment = Force × Distance

$M = Fd$

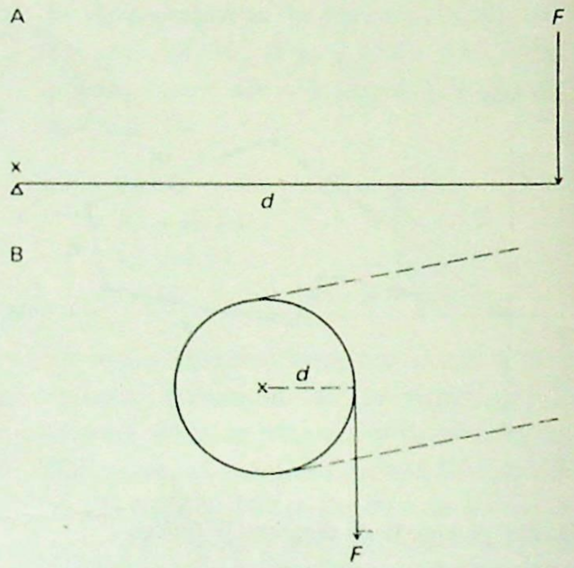

Fig. 2.13 A, Moment; B, Torque. *F* – force. *d* – distance. *x* – fulcrum.

The *moment arm* is the perpendicular distance from the axis of motion (fulcrum) to the applied force.

The *action arm* is the actual distance from

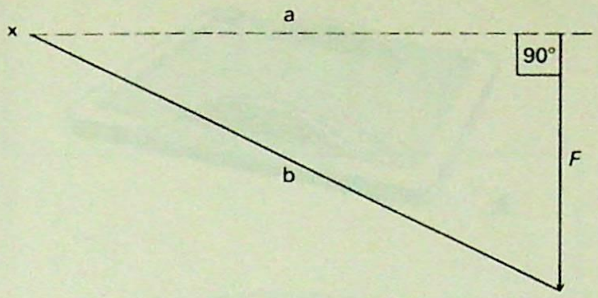

Fig. 2.14 The moment arm and the action arm may not be the same. x – fulcrum. *F* – force. a – moment arm. b – action arm.

the axis of motion to the point of application of the force along the bar, limb or lever.

The moment arm and action arm are frequently not the same (see Fig. 2.14). Figure 2.15 shows the upper limb being abducted. The length of the action arm will remain the same throughout a movement; the distance from the shoulder joint to the centre of gravity of the limb will remain constant. The length of the moment arm will change according to the degree of movement.

The following are examples of moments as encountered by the therapist.

(1) Moments of force are very common in the human body. The axis of motion, or fulcrum, occurs at a joint. The action arm is the limb or trunk segment and the force is supplied by body weight or muscular work. The example seen in Fig. 2.16 is that of the upper limb being taken into abduction. The shoulder joint acts as the fulcrum, the limb acts as the action arm, and the weight of the part acts as the force. This force acts through a point about one third of the way along the arm.

 The moment arm varies with the degree of abduction, for

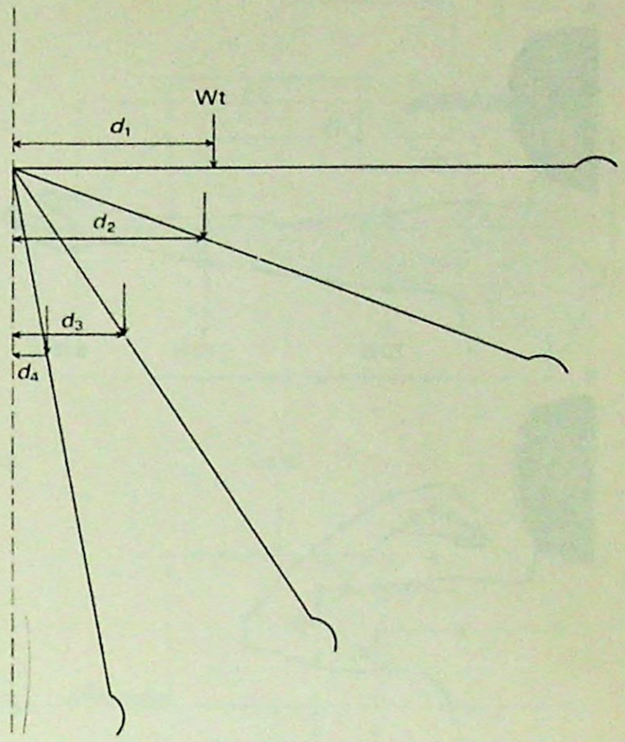

Fig. 2.15 Moments taken about the shoulder joint with the arm in varying degrees of abduction. d_{1-4} – distance, moment arm. Wt – weight.

$M_1 = F \times d_1$ . . . through to:
$M_4 = F \times d_4$

 Greater effort is seen to be necessary to hold the arm in a position of 90° abduction. This is important in the planning of progressed exercises. The amount of effort may also be reduced by altering the length of the action arm and consequently the length of the moment arm (Fig. 2.16).

(2) A second example of the effect of moments is seen in the design of the re-education board as used by therapists (balance boards).

 Re-education boards are primarily used to re-educate balance and increase the strength of the muscles of the lower leg. They consist of a platform, which may

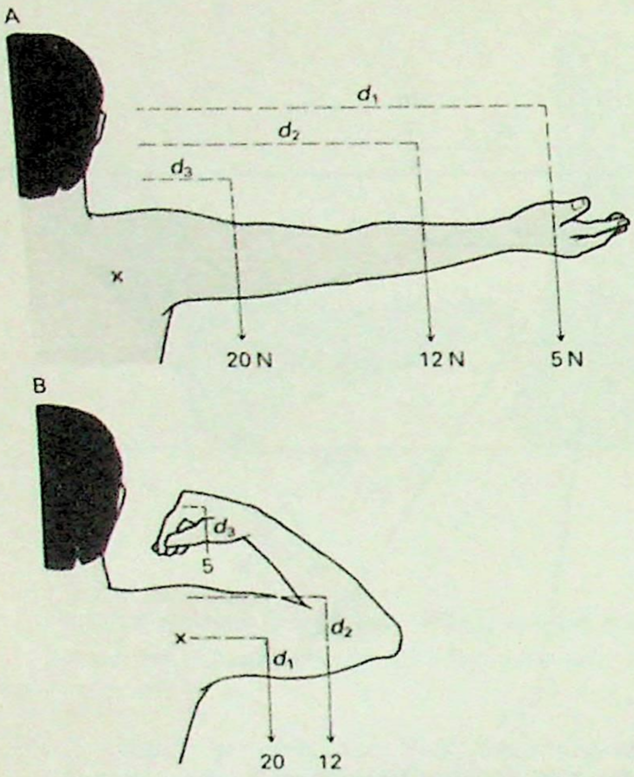

Fig. 2.16 The amount of effort may be reduced by shortening the length of the moment arm.

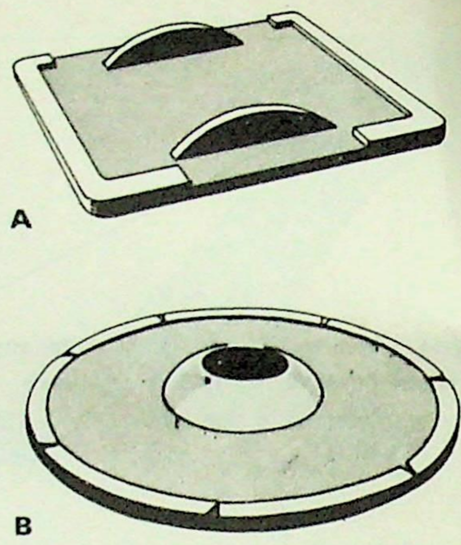

Fig. 2.17 A, A square re-education (wobble) board; B, A round re-education (wobble) board.

be either rectangular or circular, resting on curved supports (Fig. 2.17A and B). The aim of the exercise is that the subject should learn to balance on the board, holding the central position. Re-education boards are based on the principle of moments, as can be seen in Fig. 2.18. The moment F_1d_1 will equal F_2d_2 when the weight of the body is evenly balanced relative to the moments created. The position of the foot on the board will affect the moments as the distances either side of the axis alter.

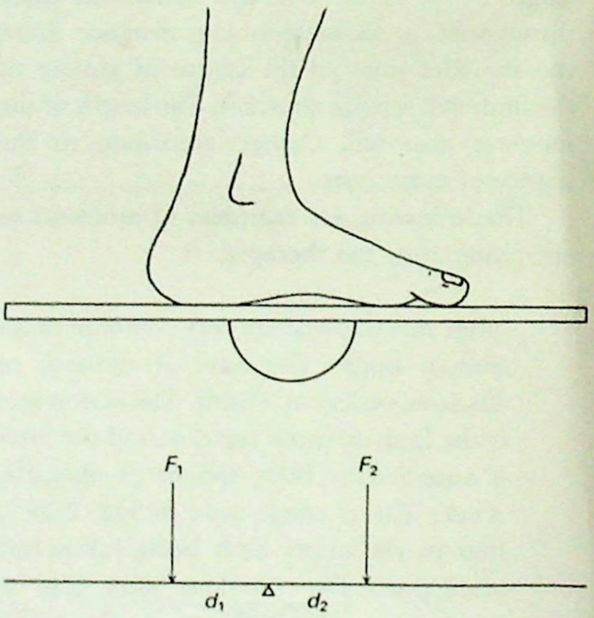

Fig. 2.18 Moments about the fulcrum of a re-education board. When the weight is balanced $F_1d_1 = F_2d_2$. F – force. d – distance.

Force couple

Two forces of equal magnitude acting together in opposite directions and displaced from

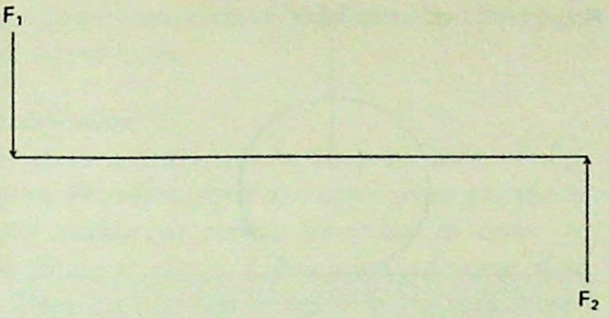

Fig. 2.19 A force couple. $F_1 = F_2$. F – force.

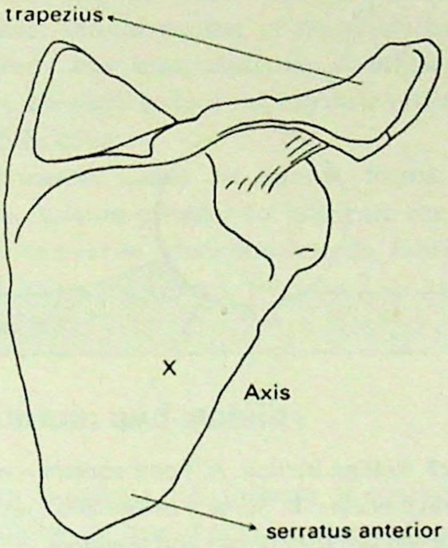

Fig. 2.20 A force couple producing lateral rotation of the scapula.

one another are called a force couple (Fig. 2.19). A force couple may be regarded as a pair of moments acting at an axis of rotation which may be placed at any point along the length.

Couples, composed of a muscle force and a joint reaction force, are present during limb movements.

The forces acting on the scapula in order to bring about the lateral rotation necessary for full abduction of the upper limb constitute a force couple and are shown in Fig. 2.20. The axis of motion falls through the body of the scapula and the forces are provided by serratus anterior inferiorly and trapezius superiorly.

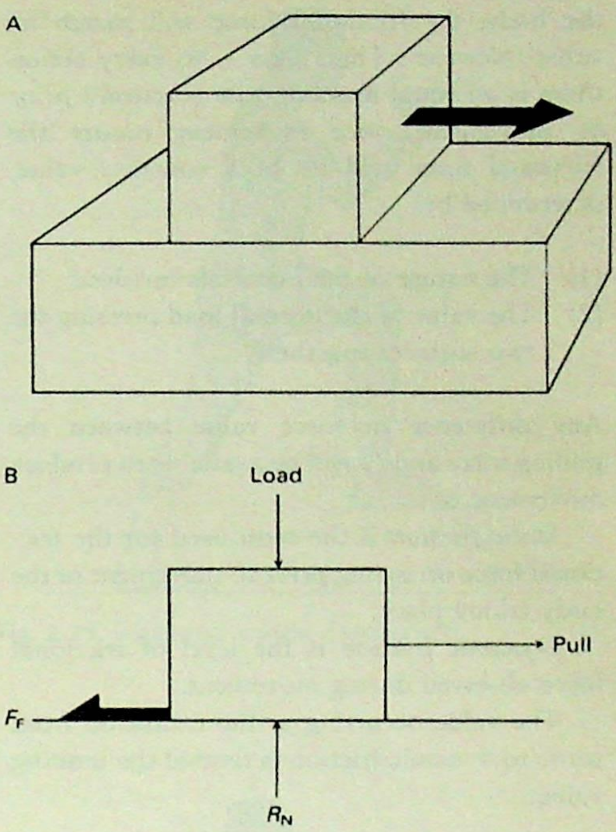

Fig. 2.21 A, Shear force occurring as two bodies slide relative to one another. B, Free body diagram of forces occurring in (A). R_N – reaction normal. F_F – friction force.

Friction

Friction occurs when one body slides in relation to another (Fig. 2.21A and B); the frictional force (F_F) is a shear force occurring between two adjacent surfaces which are in contact. As the pulling force is applied to he body, the frictional force will match its value (Newton's Third Law – 'to every action there is an equal and opposite reaction') prior to movement; once movement occurs the frictional force will be of a constant value, determined by:

(1) The nature of the materials involved
(2) The value of the normal load pressing the two surfaces together.

Any difference in force value between the pulling force and F_f will be available to produce movement.

Static friction is the term used for the frictional force occurring prior to movement of the body taking place.

Dynamic friction is the level of frictional force observed during movement.

The value occurring at the transition from static to dynamic friction is termed the limiting value.

Types of friction

(1) *Dry*: the surfaces of the materials are dry and clean.
(2) *Boundary*: the surfaces of the material are coated with contaminants, e.g. grease, dust and other debris.
(3) *Viscous* (fluid): fluid is present between the surfaces.

The principles considered above are for dry friction; those for boundary and viscous friction are basically the same except that the additional material will modify the surfaces and therefore the frictional values.

Rolling friction

When a body rolls, no frictional resistance will occur as point contact only is made. In order for 'rolling friction' to occur, deformation of either the body or the surface must take place,

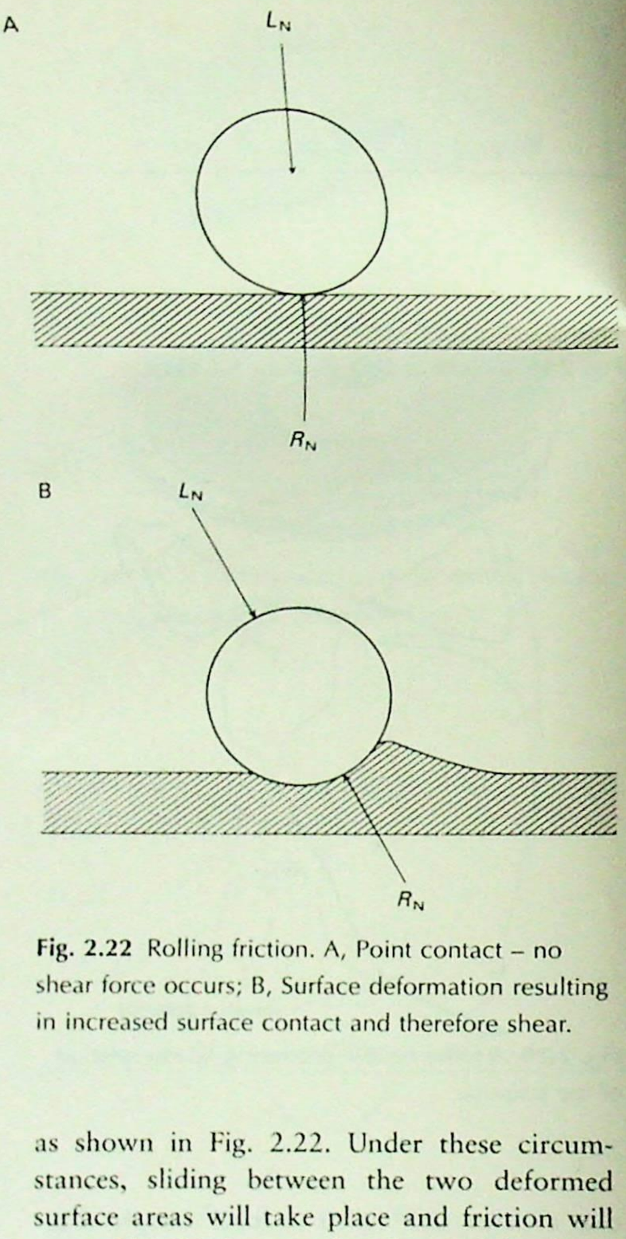

Fig. 2.22 Rolling friction. A, Point contact – no shear force occurs; B, Surface deformation resulting in increased surface contact and therefore shear.

as shown in Fig. 2.22. Under these circumstances, sliding between the two deformed surface areas will take place and friction will occur. This friction may be of any of the above types.

Friction can be of great value to the therapist. Shoes should always have soles of a material which will not slip easily; ferrules on crutches and sticks should be in good condition and the brakes on most wheelchairs depend on friction for their effect. Conversely, friction can be damaging to skin if the part is dragged over rough surfaces such as bedclothes and the edges of wheelchairs.

Lubrication

Friction is important in the prevention of slipping. However, there are times when the therapist wishes to reduce its value in order to facilitate an action. Lubrication is the use of an additional material to separate surfaces. Much shear resistance is due to the uneven nature of the surfaces of materials and the consequent tearing resulting during motion. Lubricants, therefore, act to even out the surfaces. Lubricants should consist of materials having a relatively low intermolecular co-efficient of friction. This will reduce the intrinsic resistance of the lubricant.

Lubricants come in many forms; for example, talcum powder to lubricate the skin as it slides over re-education boards, fabric for use in blanket pulls across the gym floor and oil in massage.

Equilibrium and stability

In order to discuss the concepts of equilibrium and stability the line of gravity, centre of gravity and base of support need to be defined.

Line of gravity

A human body consists of a number of segments, each of which contributes a percentage weight to that of the whole. Each segmental weight may be represented by a resultant force acting through a single point (Fig. 2.23). These segmental resultants may be summated in order to give the resultant force exerted by the weight of the whole body. This resultant is known as the line of gravity (Fig. 2.24).

Centre of gravity

The point through which this line would pass with the body orientated in any direction is

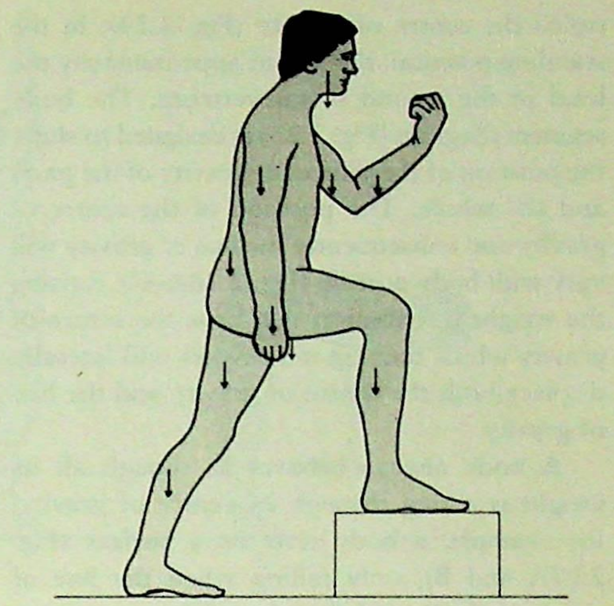

Fig. 2.23 Segmental weight distribution.

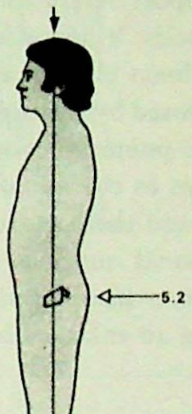

Fig. 2.24 Centre and line of gravity. The centre of gravity of the standing human is at the level of the second sacral vertebra. The line of gravity falls from the vertex, through the centre of gravity, in front of the ankles and within the base.

called the centre of gravity (Fig. 2.24). In the standing position, this lies at approximately the level of the second sacral vertebra. The body segment diagram (Fig. 2.25) is designed to show the position of the centres of gravity of the parts and the whole. The position of the centre of gravity and consequently the line of gravity will vary with body posture (Fig. 2.26A–G). Raising the weight distribution will raise the centre of gravity whilst moving it sideways will laterally displace both the centre of gravity and the line of gravity.

A body always behaves as though all its weight is acting through its centre of gravity; for example, a body rests on a surface (Fig. 2.27A and B), only falling when the line of gravity falls beyond the edge of the supporting surface (Fig. 2.27C).

Base of support

The base of support refers to the supporting area beneath a body. It includes both the parts of the body in direct contact with the surface and the area enclosed by the contact points. For the therapist, the points of contact in question will be such areas as the feet in standing, buttocks in sitting, and the heels, calves and back in lying. Additional supports such as sticks and walking frames also function as points of contact enclosing an enlarged base.

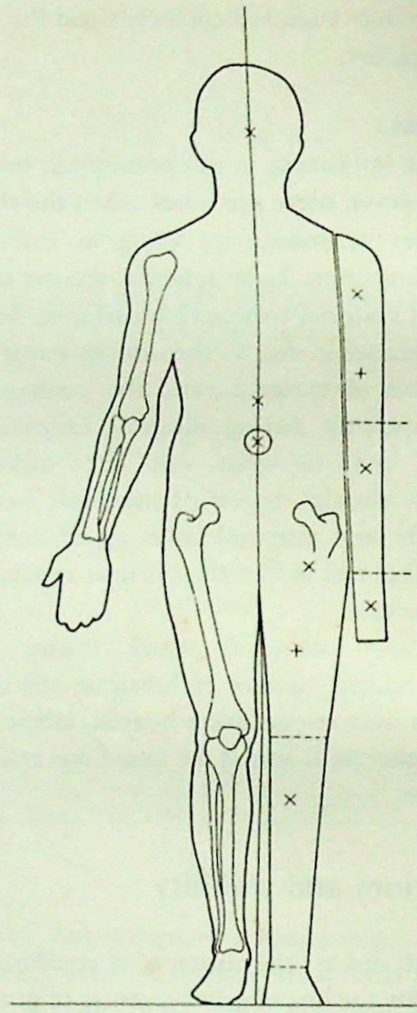

Fig. 2.25 Body segment diagram showing centres of gravity. ⊗ – of whole body. + – of limb. × – of segment.

Equilibrium

When a body is at rest in equilibrium there is:

(1) No tendency to move in any direction, i.e. resultant force = 0

(2) No tendency to rotate in any direction, i.e. resultant moment = 0.

A body may be defined as being in equilibrium but its hold on its position may be more or less precarious. This is referred to as its degree of stability.

Types of equilibrium

Stable equilibrium

The body returns to its original starting position following the application of a displacing force. The centre of the body is usually low and considerable effort is required in order to raise

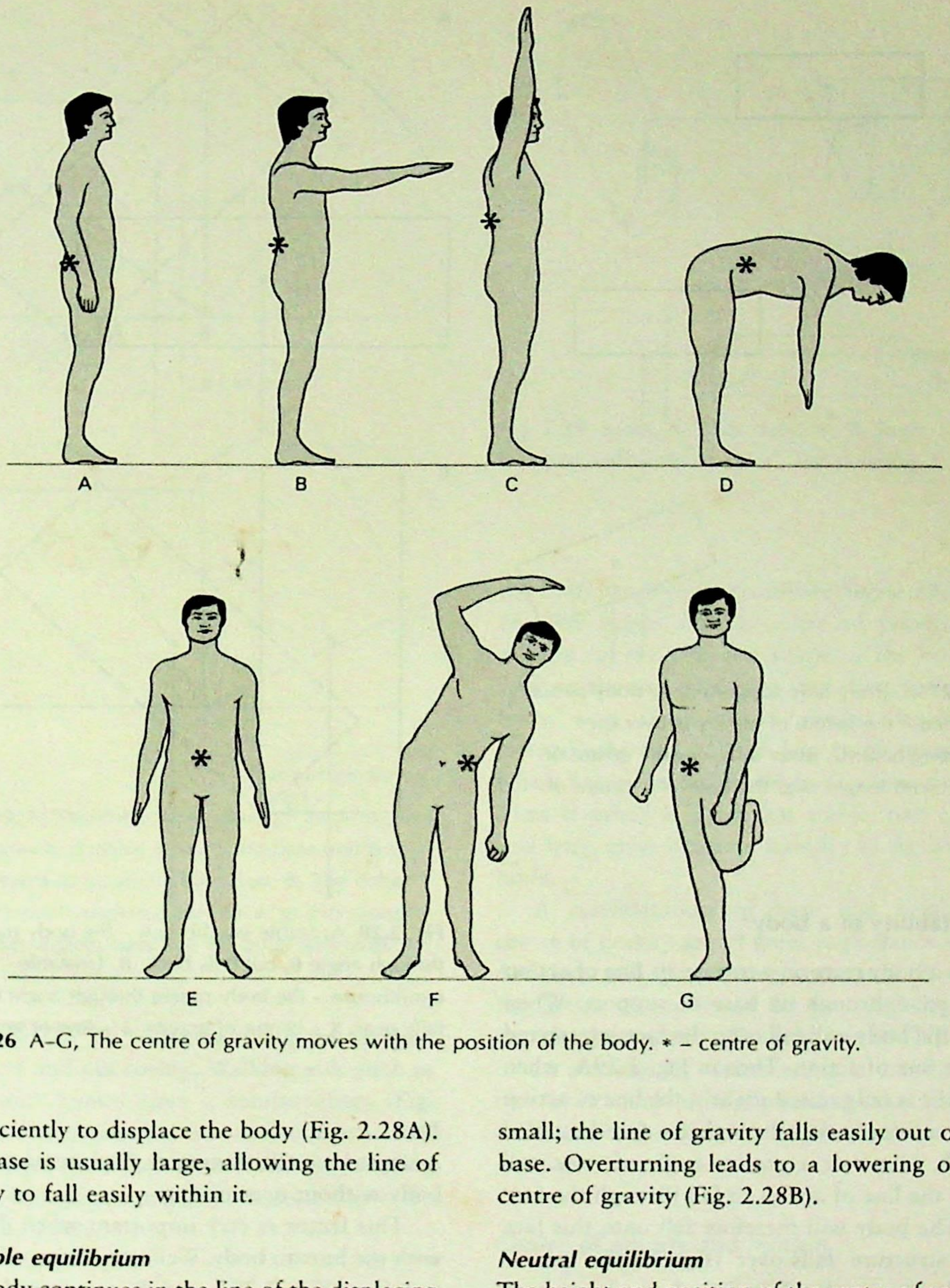

Fig. 2.26 A–G, The centre of gravity moves with the position of the body. * – centre of gravity.

it sufficiently to displace the body (Fig. 2.28A). The base is usually large, allowing the line of gravity to fall easily within it.

Unstable equilibrium

The body continues in the line of the displacing force leading to overturning. The centre of gravity tends to be high initially and the base small; the line of gravity falls easily out of the base. Overturning leads to a lowering of the centre of gravity (Fig. 2.28B).

Neutral equilibrium

The height and position of the centre of gravity remains the same despite displacement; rolling is the prime example.