CHAPTER 4

ONTOGENESIS: INDIVIDUAL DEVELOPMENT

In ontogeny, as in phylogeny, man grows and moves spirally
(Dart, 1950: 268).

The human foetus, as it grows in the womb, passes through a cycle that roughly parallels the whole of human evolution, from fish to Homo sapiens. However, the baby does not develop its upright posture until after it has been born
(Barker, 1985: 20).

Good posture ..... are not characterized by beauty but rather by a capacity to meet the environment and to conquer it successfully (Goff, 1953: 78)

4.1 INTRODUCTION

The upright posture in man is, despite its long history, still not an automatic activity such as breathing (Kruger, 1988). Even when all the physical conditions, like the development and maturation of tissues, postural reflexes and voluntary motor control, for example, are fulfilled, the infant still has to struggle to accomplish the upright posture (Kruger, 1988; Steyn, 1991). The initial attainment of the upright position in the infant, firstly when sitting unaided and secondly standing upright, is regarded by those around him as important first achievements (Kruger, 1988). With the approach of old age, however, maintaining this hard fought for uprightness may again become a problem (Barker, 1985; Hanna, 1988; Overstall *et al.*, 1977; Rolf, 1977).

In order to walk upright the infant must be able to support his mass, maintain his balance, and propel himself forward. Although the flexion and extension of the lower limbs at the hip- and knee-joints function at birth, the infant displays a decidedly helpless response to the force of gravity. The major task ahead of the infant, therefore, is to develop a system able to deal with and control the effects of gravity. This development is exceedingly gradual, and has a cephalo-caudal trend (McGraw, 1932).

From birth onwards the infant, later the child and adolescent, develops a mechanism which enables him to accomplish activities of daily living as well as activities which are highly complex. This mechanism, which functions automatically and largely unnoticed, is the postural reflex system (Bobath, 1980; Massion, 1992). According to Bobath (1980) this mechanism, which gives man the prerequisite for normal functional activity, is responsible for the evolution of three factors:

1) A normal postural tone; the activation of muscle synergies to control posture,

2) The great variety of interaction of opposing muscles, which may result in simultaneous contraction of opposing muscle groups, especially around the proximal parts (shoulders and hips), which allows the individual selective and skilled activity. In practice this means that skilled activity requires postural support and stability,

3) The great variety of patterns of posture and movement that are the common heritage of man. This is shown by the similarity in the fundamental sequences of the development of the motor mechanisms as the infant matures.

Thelen (1998) asserted that mainstream Western views of motor development, such as those of Bobath (1980) and McGraw (1932) discussed above, tend to look at things from inside out - waiting for the brain to mature in order to allow better body control. She (Thelen, 1998), is of the opinion that researchers today still use the assumption, that motor behaviour provides a good readout of the status of the central nervous system. She further added (p 268):

> *Rather, those pioneers failed to appreciate how much biomechanical challenges facing infants and their solutions to those challenges sculpt the brain. Bernstein, more than a half century before the recent discovery of brain plasticity, fully understood the bidirectionality of change. Researchers now must not ask not only how structural changes in the central nervous system allow and support body control but also how moving limbs and torso in a world of information and forces determine the connections in the brain.*

From a movement science perspective, the practical implication of Thelen's (1998) point of view is that the quality of postural- and movement development are not only dependent on the capabilities of the individual's central nervous system, but also on the quality of input from the environment and those responsible for the mental and physical development of the individual. In the sections below the importance of the latter will be highlighted.

4.2 PRENATAL AND POSTNATAL DEVELOPMENT

4.2.1 Prenatal development

The development of any embryo and the subsequent development of the newborn have one objective in mind, which is to become a fully integrated and functional adult as expeditiously as possible (Moody 1953). To accomplish this aim effectively the growing and developing individual has to go through a number of obligatory developmental phases, both structurally (Moody, 1953; Sinclair, 1991; Williams & Warwick, 1980) and functionally (Bobath, 1980; Gabbart, 1992; Payne & Isaacs, 1991; Thelen, 1998). These developmental phases will be reviewed on the following pages (section 4.2.2 to 4.6) with particular emphasis on the postural aspects.

Prior to birth the foetus lies comfortably in a position of flexion in his uterine bath. Growth takes place against the resistance of the elastic uterine wall. During foetal life the foetus is almost invariably in a position of **flexion.** The head is sharply flexed on the body, the arms and legs flexed on the torso. The convex curve of the spine lies in contact with the curve of the uterus (Asher, 1975; Phelps *et al.*, 1956). This is the posture which some individuals readily revert to later in life (Barlow, 1990; Goldthwait *et al.*, 1952; Hanna, 1988; Hellebrandt & Braun, 1939).

The foetus is surrounded by the uterus, partially suspended in amniotic fluid, of which the specific gravity is more or the less the same than that of the foetus. The gravitational effect of this is very similar to that exerted upon an individual submerged in sea water (Phelps *et al.*, 1956).

After birth the individual leaves his sea-like environment in order to move onto land. Now a very definitive change takes place in the newborn's environment, an environment which has an immense effect on the structure and posture of the newly born individual. After birth, gravity exerts its effects on the newborn in a medium with a much smaller specific gravity (air), and then the structure and mass of the child and its body segments become more important in relation to posture (Phelps *et al.*, 1956).

4.2.2 Postnatal development

During the first year, the infant spends a large amount of time in a horizontal position, either prone, supine or on its side. In this position, the child experiences the force of gravity on a horizontal plane, and tends to uncoil the *"coiling"* which it previously assumed in the uterus. In the prone position the flatness of the surface tends to fix the infant in a straighter position, while in the supine position the head and legs tend to lie flat, but are allowed greater freedom of movement (Phelps *et al.*, 1956). In those who have postural deviations or problems caused by poor posture, uncoiling of body structures is possible by the use of the mechanisms used by the infant (Barlow, 1990; Dart, 1947). These approaches will be discussed in Chapter 9.

When the supine infant tries out its muscles, this also serves as a way to straighten the back. Nevertheless, the C-shaped curve persists for several months after birth (Barker, 1985; Phelps *et al.*, 1956; Sinclair, 1991).

Since the newborn is flaccid it is simple for the parent to assist in the uncoiling of the infant's musculature by gently stretching it out in either the prone or supine position (Wenham, 1980). Due to this flaccidity the newborn is unable to maintain the sitting position, and falls into a "jack-knife" position when raised from a supine to a sitting position. A few days after birth, however, the infant will start showing a slight resistance to the forward fall, and will also be able to free his flexed limbs from beneath his body, thus getting him into a prone position (McGraw, 1932).

In the early months of postnatal life, when the baby extends his head, a small compensatory lordotic curve, convex forwards, appears in the cervical region. When he begins to sit up, a secondary lordotic curve, convex forwards, appears in the lumbar region (Asher, 1975). The vertebrae are then balanced squarely on top of each other and a minimum of effort is required to maintain the position (Wenham, 1980). The relatively heavy head gets pulled back into the upright position, its weight is brought over the centre of gravity, the eyes are pulled up and can look to the front. Initially the legs are spreadeagled to give a wide, triangular base for support as the balance is still poorly developed (Barker, 1985; Bril & Brenière, 1992). There is some persistent hip flexion during this stage which is associated with the upward rotation of the pelvis on the spine (Phelps *et al.*, 1956). It is noteworthy that at this stage the infant has to go through the same transformation than early man, when he progressed from quadrupedalism to the permanent erect position - a process which was discussed in Chapter 3, section 3.3.

The secondary spinal convex curves depend on differences in thickness of the intervertebral discs which become wedge-shaped to allow for necessary adaptation. The primary curves depend on differences in height between the anterior and posterior aspects of the vertebral bodies (Asher, 1975).

When the child is about to stand, the musculature of the extensors of the back and neck has become sufficiently well developed and the back is usually straight. The straightness results mainly from the slight tilting upwards of the front of the pelvis in full or nearly full extension of the legs (Phelps *et al.*, 1956). This is in agreement with the posture described in the previous chapter in section 3.4.

To reach the upright position the child develops a curve in the small of the back, the lumbar curve. This brings the head over the centre of gravity, the range of visibility is increased and the body weight can be supported by the bony frame. The only parts of the original spinal C-shaped curve (concave) which remain are in the chest and sacral regions (Barker, 1985).

There is a tendency towards full hip extension in the erect standing position as a means of easier and more perfect balance. At this moment the child is able to rotate his pelvis forward and upward by means of his *gluteus maximus* - a function which was discussed in great depth in the previous chapter (sections 3.3.2 & 3.4).

4.3 CHANGES IN BODY PROPORTIONS

At birth, sitting height accounts for 70% of total body length. By 3 years old, sitting height`s contribution to total body height has decreased to 57% (Gabbard, 1992; Payne & Isaacs, 1991). During this and subsequent growth periods the nervous system has to compensate for the change in body height, body mass and the size of different body structures in relation to each other by means of **learning** (Massion, 1992). This is possible if the growing individual is exposed to physical activities which will stimulate the adaptation and orientation of neural systems to the changes in body height, body mass, the centres of gravity of different body compartments and the relative sizes of body structures in relation to each other. In this regard, simple, yet effective physical activities sessions, will be those which alternate between actions such as walking, climbing, sliding, crawling, hanging and swinging (also refer to section 2.3).

During the first years of life the lumbar vertebrae grow rapidly in size, with consequent lengthening of the lumbar region and also of the loins. The lumbar development is probably associated with upright bipedalism; the longer muscles make walking easier and more efficient (Asher, 1975).

Until the age of 10 years for girls and 12 years for boys, both sexes exhibit almost the same increases in trunk length but usually boys have longer trunks. Boys are generally taller, thus prior to adolescence, boys have relatively shorter legs than girls regarding total body length. During adolescence and adulthood, females have shorter legs than males of equal stature (Asher, 1975; Payne & Isaacs, 1991).

One of the most noticeable characteristics in the newborn is the size of the head in relation to total body length. The head contributes about 25% to total body length, while the lower body limbs contribute only 15% (Gabbard, 1992; Payne & Isaacs, 1991).

Changes in body proportions are brought about by different growth rates of skeletal tissue. During infancy growth is most rapid, first in the head and later in the trunk. In the second year the legs begin to grow more quickly than the body, and this pattern continues until the onset of the growth spurt of puberty, when in both sexes the trunk grows faster than the limbs (Asher, 1975; Gabbard, 1992; Payne & Isaacs, 1991). Changes occur in lateral as well as in linear proportions. Although shoulder and hip width appear equal in the newborn, shoulder width is greater than hip width for all children. The adolescent boy experiences a more rapid rate of shoulder than hip growth, while girls have greater hip breadth gains relative to the shoulders (Gabbard, 1992).

4.4 CENTRE OF GRAVITY

The centre of gravity of the human body may be defined as a fixed point in the body through which the resultant of the gravity forces acting on all the molecules of the body may be said to act (Asher, 1975).

At birth the centre of gravity is located approximately 20 centimetres above the trochanters at the xiphoid process. During growth it descends slowly and at 6 years old has dropped through the diaphragm into the abdominal cavity and becomes located in the vicinity of the umbilicus. It rests at approximately 10 centimetres above the trochanters at maturity - on the level of the iliac crest at the second or third sacral vertebra. Although anatomical location of the centre of gravity changes with age, it remains a relatively constant proportion of total height. In the adult the ratio of the centre of gravity to the total height is 53% to 59% (Payne & Isaacs, 1991).

4.5 HEIGHT AND GROWTH RATE

The preferred measurement of body length is standing height (stature), which is the distance between the vertex and the floor.

The growth rates that occur during the 9 months preceding birth and the first year of life are the fastest that the body will experience. Typically the birth length increases by 50% in the first year and reaches approximately one - half of adult height by 2 years of age. Hereafter the growth rate slows to an average of 5 centrimetres per year until the onset of the pubescent growth spurt. A mid-growth spurt may occur between the ages of 5 ½ to 7 years. Females complete their peak growth period by 16 ½ years of age and males about 2 years later (Asher, 1975). According to Tanner (1978) maximum growth of the vertebral column may not be reached until about age 30, at which time an individual may add 2,5 to 5 millimetres to his or her height. Height remains relatively stable until sometime after the third decade of life when total height begins to regress (Gabbard, 1992).

Normal ageing causes bones to lose mass and the total height to decrease. Women begin to lose bone minerals at about age 30 and men at approximately 50 years. Stature decreases with age because of an increase in postural kyphosis, compression of intervertebral discs and deterioration of vertebrae (Brooks & Fahey, 1984). Estimates of height decreases from 35 to 75 years of age are about 2 ½ centimetres for males and 5 centimetres for females (Gabbard, 1992). In addition, the loss of trunk muscle strength approaches 1% per year, while passive tissue strength decreases by 30% in cartilage, 20% in bone and 18% in tendons and ligaments between the third and eighth decades (Ashton-Miller & Schultz, 1988).

4.6 POSTURAL PATTERNS IN CHILDHOOD

Postural patterns in childhood vary with age, sex, stage of development and body type. A constant pattern only emerges at the age of ten and older when a sufficient degree of development has been attained. Under 10 years old children are continually experimenting with different ways of reacting to gravity (Asher, 1975).

In the second and third years the characteristic picture of potbelly and lordosis is seen - the child`s method of distributing weight and ensuring balance. The pelvic tilt varies between 28 to 40 degrees but the child appears to vary the degree of lordosis by altering the curvature of the lumbar spine rather than altering the tilt of the pelvis. Balance is maintained by leaning forward and keeping the knees slightly bent (Asher, 1975).

At 4 years of age the child shows a comparatively constant average posture. The feet show a slight degree of pronation, a degree of dorsi-flexion well beyond a right angle is possible; the knees are straight when standing with a degree of incomplete extension when standing compared to the adult; the pelvis is tilted forward, abdomen prominent and lumbar lordosis fairly well marked; the dorsal spine is nearly straight and the neck shows a mild lordotic curve with no forward inclination. The increased size of the abdomen results frequently in a long lordosis extending to the upper dorsal region and producing prominent scapulae. This, and the less developed chest, are correlated with round shoulders (Phelps *et al.*, 1956).

The child who is 7 years old tends to tilt his pelvis and protrude his abdomen and hyper-extend his knees, thereby distributing his weight evenly (antero-posteriorly) on both sides of the line of gravity. The pelvic inclination varies between 30 and 40 degrees when measured with a Wiles inclinometer (Asher, 1975). Lumbar lordosis increases by about 10% between 7 and 17 years of age during which time the spine increases in length by about 26% (Ashton-Miller & Schultz, 1988).

During the time that posture is stabilizing, the pelvic tilt decreases and becomes more consistent. Pelvic inclination is an important mechanism in maintaining balance in the growing child - it enables him to distribute his weight about the line of gravity when body proportions alter. In tests using a Wiles inclinometer (Asher, 1975) pelvic inclination varied from 25 degrees to 40 degrees in the mid-school period, and settled down to less than 30 degrees during the growth spurt. It remained fairly constant at 20 degrees from the age of 18 onward (Asher, 1975).

4.7 NEUROPHYSIOLOGICAL ASPECTS

It would seem that the infant's inability to walk at birth is due more to an undeveloped equilibratory apparatus than to the absence of a walking mechanism. A primitive or vestigial mechanism exists, but it appears to be segmental and not integrated with related functions essential to upright ambulation (McGraw, 1932).

Cortically controlled voluntary movements develop in a fairly predictable sequence in infants. Gaining the walking mechanism follows the same pattern as gaining the act of standing erect. Voluntary movement follows a cephalo-caudal pattern of development. The head is the first body part to be voluntarily controlled - this allows the child to visually scan the environment more effectively (McGraw, 1932).

Body control is gained soon after control of the head. The upper body gains control first, with lower portions gradually acquiring voluntary movement. Control of the body enables appropriate positioning for the eventual acquisitioning of locomotion and allows the child to position the body in such a way as to free the hands for reaching and grasping (Payne & Isaacs, 1991).

Development of an erect posture and locomotion in infants adheres to the general laws of functional growth. Certain types of activities appear to function on a reflex level before they become a part of a controlled muscular pattern (see Bobath, 1980, for example). The reflexes tend to disappear before or about the time the controlled neuromuscular pattern emerges. For example, there is a diminution of the early reflex stepping movements before the controlled process of walking appears (Bobath, 1980). There is no evidence of a sudden emergence of a new totally integrated pattern when a new phase in the development starts. Rather, a new pattern unfolds slowly and takes over from the old pattern until it becomes dominant and finally is superimposed upon the old pattern.

Growth in the assumption of the erect posture and walking is an extraordinarily gradual procedure. It is dependent upon maturation of the nervous system, but also requires learning, which takes place during the various stages of the infant's development from the supine position to the eventual upright (Dart, 1947; McGraw, 1932; Thelen, 1998).

According to McGraw (1932) acquiring any new reaction pattern by the infant is associated with uncertainty or dyssynergia. Learning is unquestionably required to decrease the uncertainty and dyssynergia.

Infants come into the world seemingly ill designed for adaptive movement, especially as upright bipedal creatures (Thelen, 1998). They have large, heavy heads, narrow shoulders short legs and weak muscles, and come into the world from a supporting aquatic environment (see section. 4.2.1 & 4.3). From birth onwards nervous systems of infants have to contend with the effect of gravity, rapid changes in the infant's biomechanics, differences in a wide range of individual movement styles; problems which the nervous system could not have anticipated beforehand by hard-wiring all the solutions genetically. The only solution to this problem is that the system must be designed to learn by interaction with the environment (Thelen, 1998).

Added to this is that the weak-muscled infant has to achieve certain critical developmental phases before learning of specific skills become possible. Recent studies, for example, have emphasized the critical role of postural control in motor development, for example, visual pursuit of a target in two-month old infants depends on postural control of the torso. Children cannot begin to walk independently until they have sufficient extensor strength and postural control. It follows that whereas most of the components that appear to contribute to walking onset (for example, tonus control, articulatory differentiation, visual flow sensitivity, motivation) are functional, the lack of postural control and muscular strength prevents the development of independent walking (Bril & Brenière, 1992).

CHAPTER 5

MALPOSTURE

Remember that these relationships of one body part to another represent an ideal pattern
(Goss, 1986: 220).

You can tell a Najavo from a long way off by the straightness of his back
(Rees, 1995: 131).

5.1 INTRODUCTION

Many deformities develop during the growing years, mainly as the result of faulty body use. The normal growth and development of any bone are dependent upon the inherent tendency of the bone to grow in a certain manner as well as upon the stresses and strains that the bone endures during normal activities. Outside influences, however, can wholly change this inherent tendency to assume a certain shape (Roaf, 1960). Diseases of bone have the sole effect of softening of the bone and its ultimate shape depends entirely on mechanical factors. In the same way, permanent muscular weaknesses lead to failure in the normal support of a portion of the body, the position which it assumes depending on gravity, muscular imbalance and the general alignment of the entire body (Goldthwait, *et al.*, 1952). Muscles which become tight tend to pull at body segments to which they are attached, causing deviations in alignment. The antagonistic muscles may become weak and allow deviation of body parts due to their lack of support. The muscle tone will change via afferent impulses from the joint structures such as capsule, synovial membrane, ligaments and tendons. These impulses reflexively influence the tone of muscles (Ayub, 1987). In short, according to the Alexander principle: *Use affects functioning* (Barlow, 1990: 17).

5.2 MALPOSTURE SEEN FROM A TOTAL PERSPECTIVE

> *Faulty posture always expresses the emotional stress that has been responsible for its formation. The most frequent and observable one is the stress of insecurity in its different aspects, such as hesitation, fear, doubt, apprehension, servility, unquestioning compliance - and their exact counterparts* (Feldenkrais, 1985: 55).

> *It is alleged by teachers and physical culturists that bad posture is harmful. I venture to brave this opinion as ill-conceived. There is no general harm whatsoever in any awkward or ungainly configuration of the body in itself, except the minor local effect. A well-coordinated person can adopt any position for any length of time without the ill effects that accompany the same configuration (as they would put it) naturally. The ill effect that we do find is not due to an anatomical configuration that is harmful per se, but to the fact that it is compulsive and is the only one the ill-coordinated person uses for performing the act.*

> *.....The pattern of doing that has brought the person to this state is the harm producing agent, not the anatomical configuration* (Feldenkrais, 1985: 109).

> *I am not so much concerned with* ***attitudes*** *(that is to say, temporary postures and gestures), as with the basic* ***disposition*** *of the body, compounded as it is at any given time of the patterns which we have inherited and the patterns we have learned* (Barlow, 1955: 660).

Postural disorders of primary importance, according to Barlow (1955), are the head-neck relationship; joint surfaces which are pulled together and the pelvis being used as part of the leg. These postural disorders are, however, the result of behaviour rather than structure. This behaviour comprises all the habitual motor responses with which we react to the outside world and by means of which we adapt ourselves to its various stresses. Anxiety and muscle tension go together and a person's muscular tensions are a fundamental part of his defence against the world. Removing the tension state may cause a person to feel naked, defenceless and uncomfortable when going about his daily affairs and he may revert to his old tension state and the accompanying posture (Barlow, 1955).

Faulty integration of attitudinal and righting reflexes during the performance of a physical function, is the total problem of faulty posture and poise, according to Dart (1946). He pointed out that in the human disease of malposture, the bones, joints, muscles, nerves and coordinating brain are all complete in every detail. The malposture is purely functional - with a low neuromuscular coordination causing muscles to act in a less integrated manner; the smooth, balanced movements of body and limbs are lost (Dart, 1946).

Dart (1946, 1947) ascribed the lack of *poise* in human adults to inadequate exploiting, to short circuiting, or to actually eliminating the ancestral phases of posture - presented by the supine, ventrigrade and pronograde postures, to which the primate, anthropoid and humanoid stages may be added, during ontogeny (Chapter 4) in the infant's (or parent's) haste to become erect. He also reiterated the important role played by the position of the head in posture and movement:

> *But directly or indirectly every sort of bodily movement and skill illustrates the same principle: if the head containing the balancing organs is not the prime mover, if it is incorrectly placed and maintained for equilibrated execution of the movements planned, the movements will be unbalanced and in brief, caricatures of what those movements should be* (Dart, 1947: 11).

Stemming from incorrect use of the head, amongst other things, the vast majority of people tend to rely more on one torsional sheet than on the other, and then develop a right-handed or left-handed torque, an obliquity, twist or asymmetry of posture and movement (Dart, 1946; Chapter 9, sections 8.2 and 8.3). The neurophysiological background of this system is discussed in Chapter 6, section 6.4.6. In the sections that follow, malposture will be discussed in the various body segments.

5.3 THE UPPER QUARTER

5.3.1 The head and neck

Alexander (1932) emphasized the importance of the head and neck relationship, believing that misuse started there and then led to problems elsewhere. In the same vein, Sir Russell Brain (1959: 1491), physician of the London Hospital, noted:

> *At higher levels we need to consider the particular importance of the head, stressed by Sherrington, and the influence of the labyrinth and the neck upon bodily posture as a whole.*

5.3.1.1 Posture of the upper quarter

The large head is well-balanced on the flexible cervical spinal column with the *foramen magnum* opening towards the frontal plane and the heavy occipital portion offset by the large mandibula (Phelps *et al.*, 1956). The position of the head is significant in the determination of the overall body posture, as well as limb control. Abnormal positioning of the head on the cervical spine is increasingly significant when considering the importance of the upper cervical spine (the occiput on the atlas and the atlas on the axis) on the regulation of body posture. The essential afferent impulses for the static and dynamic regulation of body posture, as well as the ability to produce reflex changes in the motor unit activity of all four limb muscles, arise from the receptor systems located in the connective tissue structures and muscles within the upper vertebral synovial joints. The balancing of the head on the cervical column is like a lever system whose fulcrum lies at the level of the occipital condyles; the centre of gravity of the head is near the *sella turcica* and the apex of the cervical lordosis is located at the posterior-inferior border of the fourth cervical vertebra (C_4) (Ayub, 1987).

Flexion is achieved to a large extent by movements between the second and third and between the fifth and sixth cervical vertebrae. The first motion zone is the site of occasionally apparent forward displacement in children, while the latter region in adults shows the greatest osteoarthritic involvement (Barker, 1985; Barlow, 1990). The in-between vertebrae have some limited motion.

Rotation mainly takes place between the first and second vertebrae (Gorman, 1981; Phelps *et al.*, 1956). Neck muscles become activated during rotation, and in a balanced neck the longer muscles become activated, as well as the very short muscles (*rotatores, interspinales and transversales)* and short occipital muscles. Such a coordinated process produces stability and grace of movement (Rolf, 1977).

Normal movement of the neck depends on the superficial muscles attached to the shoulder structures (*trapezius, levator, sternocleidomastoid)* and on the deeper neck muscles (*semispinales, multifidus, longissimus capitis)* (Rolf, 1977). The intrinsic muscles of the atlanto-occipital and atlanto-axial joints all arise from the atlas or axis and have the function of moving the head on these joints and of holding the head securely. Movement at the atlanto-occipital joint is limited compared to the wide range of movement at the middle of the neck through the action of the large neck muscles. This points to a difference in function of the two groups of muscles: The first is a small movement within another large movement and the smaller movement is the all-important one of maintaining a proper balance of the cranium and a correct relationship between the cranium and the body. Poise and good posture come from the ability to control the function of these sub-occipital muscles (Alexander, 1941).

5.3.1.2 Developmental deformities of the upper quarter

Deformities about the head become apparent because of the symmetrical arrangement of the ears, eyes, nose, mouth and chin. One of the most common deformities is that of the tilted head position, either in the lateral or antero-posterior plane. With slumping of the head, there is not only a forward or lateral flexion, but usually also a twist. This latter may be the result of mild abnormalities in the cervical articular facets, the pedicles, or the transverse and the spinous processes which can be found on close inspection in almost every skeleton. Since this is the easiest position to assume, it becomes habitual if no effort is made to hold the head erect. The result is that soon contractures develop in those muscles which have had their origins and insertions brought closer together. This becomes a fixed position and the features of the face, the bones of the skull and the cervical spine adapt themselves to it (Goldthwait *et al.,* 1952). The extent to which each vertebra grows varies and in general cephalic vertebrae grow less than the caudal ones. In addition, the anterior elements grow faster than the posterior in the cervical regions (Roaf, 1960). This could have a transient effect on the posture of a young person.

5.3.1.3 Comments

Changes may occur in the skull in the shape of prominences in the regions of the occiput or temple. Occasionally these deformities may lead to obstruction in the upper air passages or in the accessory nasal sinuses and these are mainly the result of altered muscular pulls (Goldthwait *et al.,* 1952).

Vig, Showfety, and Phillips (1980) studied the effect of nasal obstruction on head posture and found that head extension was a result of closing the nasal airway. They stated that head posture was modifiable and that postural adaptations required altered muscular activity that might manifest itself in permanent changes to musculo-skeletal relations if it occurred during growth periods.

The importance of balanced mandibular posture to total systemic health has been expressed by many in the dental profession. Stenger, Lawson, Wright and Ricketts (1964) related mandibular over-closure to increased flexion of the cervical vertebrae in the area of C_2, C_3 and C_4, and Smith (1982) correlated muscular strength to jaw posture. Williams, Chaconas, and Bader (1983) concluded that mandibular position affects appendage muscle strength, and may be important to total body well-being. Kaufman and Kaufman (1983) linked headaches, neckaches, earaches and backaches to misaligned condyles in the temporomandibular joint. Repositioning the mandible to an anterior position and increasing the vertical dimension thus changing the head-posture relationship, alleviates stress and reduces pain. Repositioning the mandible with its condyles reduces stress placed on the spine by muscles and therefore, tension, stress and deformity on the body is also reduced. The result is a decrease in the curvature of the spine and, according to Kaufman (1980) an improvement in the scoliosis. Garbourg (1997) found that misalignment of the upper and lower front teeth was often reflected in some degree of crookedness of the spine. Aligning the teeth had a straightening effect on the spine, provided the curvature was not too pronounced.

Postural defects may be derived from deviations from the normal bite of the teeth. In a person with a prognathous bite, the jutting lower jaw could be the cause of slumped shoulders, a rounded back, and cervical and lumbar lordosis, as well as bowlegs and flat feet. In an individual with a retrognathous bite, the receding lower jaw is accompanied by cervical and lumbar lordosis, with the head tilted forward, the mouth open, nostrils dilated, narrow bridge of nose, fingers and toes straight, and the person standing almost on tiptoe. In a person where the biting surfaces of the upper and lower front teeth meet each other, the shoulders are pulled slightly back, the abdomen is thrust forward, the chest barrel shaped, cervical and lumbar lordosis is present, the heels are together, and the knees are locked; the head is raised and tilted tensely back. These observations were made by Garbourg (1997) during her fifty years of work with the body's sphincter muscles, a large part of it under the guidance of an orthopaedic surgeon. These specific observations will have to be verified by future research, the interesting point here though, is that Garbourg (1997) came to the same conclusion than Ayub, (1987) and Dart (1946), in that activity of the facial musculature has a profound effect on that of the muscles and structures in the rest of the body.

Chronically clenched or tightened jaw muscles are common and often distort the entire facial structure (Goss, 1986; Lowen, 1969). Strong emotions that are not expressed might be the cause. However, the universal distortion of a collapsed neck in which the chin moves forward out of alignment will often cause compensations in the jaw pattern (Goss, 1986).

Barker (1985) asserted that the double chin is largely a postural condition. It is often found in association with lordosis where the neck is usually held back excessively.

According to Barker (1985) the only part of the face affected directly by posture, is the area around the eyes. Sitting and looking down most of the day causes the lower eye lid to become creased and baggy.

Mobility of the head is largely dependent on the mobility of the mouth (the first survival tool) and the movements of the oral cavity are in turn dependent on those of the tempomandibular joint. Face pains, clenching jaws and teeth grinding are problems related to the tempomandibular syndrome (Gomez, 1988). This can affect the chewing motion. When chewing is done superficially and the oral cavity is not opened widely enough on the inside, the shoulders fall forward and the whole body droops (Garbourg, 1997).

Garbourg (1997) noticed that the shape of the lips had a decisive effect on the whole body. While a well-curved upper lip is usually associated with good posture, coordination, concentration, optimism and serenity, a flat upper lip indicates disturbed balance in the body such as the asymmetry of one shoulder being higher than the other. Contracted lips affect the back muscles and may lead to inner disquiet, restlessness and aggressiveness.

5.3.1.4 Movements of the head and neck

The spine provides an upthrust against the occipital condyles. The spine consists of a number of separate vertebrae linked firmly together by deformable intervertebral discs and this structural arrangement combines a very stiff resistance to longitudinal compression with a certain degree of flexibility in other directions (Roberts, 1995).

In man the cervical and upper thoracic vertebral joints are amongst the most flexible articulations of the spinal column. They allow the free movement of the head on the body, which in concert with the movement of the eyes forms the basis of much orientating, exploratory and reflex behaviour. However, the versatile mobility of the head-neck system places complex demands on the areas of the central nervous system concerned with postural stability and motor control (Dutia, 1991). The head is normally held pitched slightly forward, and maintained in this position by tonic activity in the muscles of the neck (Loeb, He & Levine, 1989).

The different cervical joints vary in their articulatory ability. The cervical vertebrae have at least 23 joints or points of contact at which motion occurs from the occiput down to the first thoracic vertebra (Kottke & Mundale, 1959) The articulation between the skull and the first cervical vertebra (the atlanto-occipital joint) allows a large amount of extension and flexion, but little or no axial rotation. The atlanto-axial joint, on the other hand, allows an axial rotation through a large angle of approximately 50 °, but little flexion and extension. The remaining cervical vertebrae (C_3-C_7) are less specialized, and have some freedom of movement in each direction. In man, horizontal turning movements of the head occur primarily around the C_1-C_2 joint, with the remainder of the cervical spine involved only in large head turns. The lateral flexibility (sideways bending) of the neck is limited by the geometry of the vertebral joints and ligaments, and involves mainly the lower cervical and upper thoracic vertebrae (Vidal, Waele, Graf & Berthoz, 1988).

Thus anatomical specialization of the vertebral column of the neck imposes mechanical restraints on the freedom of movement of the head-neck system in different planes. Movement of the head on the neck are not accommodated evenly over the serial linkages of the entire cervical vertebral column, but are accommodated instead by movements around particular vertebral joints or groups of joints, depending on the direction and amplitude of head displacement. Further specialization of vertebral motion of the neck, occurs as a consequence of the posture adopted by the head-neck system of the awake individual (Dutia, 1991).

Head movements may be made either in a distributed manner with small movements of many serially linked vertebrae, or in a more concentrated manner around a small number of appropriate joints, while the remainder are actively stabilized by compensatory neck muscle activity. In an individual at rest but awake, the major part of the cervical spine (C_2-C_5) is held in a characteristic near-vertical posture. This resting posture is attained by holding the lower cervical vertebral joints (C_5-C_7) nearly fully extended and the upper joints (Skull-C_1, C_1-C_2) nearly fully flexed. These are also the most mobile areas of the neck (Kottke & Mundale, 1959). Presumably this neck posture is the most energy-efficient for the support of the weight of the skull against gravity, reducing to a minimum the degree of tonic neck muscle activity required (Hellebrandt *et al.*, 1940; Joseph & McColl, 1961).

The location of both ends of the neck (being the vertical bridge between the head and shoulders) determines the stresses under which it functions. If the bridgeheads deviate, the structure is no longer vertical and is under strain; the flow of fluid to the head is constricted and the metabolic rate in head and brain lowered (Rolf, 1977).

The curved cervico-thoracic region of the spine with its associated muscles and ligaments, may also act as a damper or shock-absorbing system that isolates the head from perturbations affecting the body (Vidal, Graf & Berthoz, 1986). When the head is lowered, the cervico-thoracic joints presumably flex and come closer to their mid-range position, while the upper cervical joints remain more or less flexed as before. The lower cervical spine may then participate more significantly in head elevation than before: In effect, the patterns of neuromuscular activity required for head elevation may depend significantly on the original head-neck position, as does the posture taken up by the rest of the body (Abrahams, 1981; Dutia, 1991).

5.3.1.5 Muscles of the upper quarter

The cervical spine is invested with a rich assembly of muscles, reflecting the versatile mobility of its joints. In addition, the control of head position and movement is a complex task which depends upon the coordination of motor activity in multiple muscle groups, innervated by motoneurone pools in the entire length of the cervical- and upper thoracic spinal cord. This complexity is manifest not only in the control of voluntary head movements, but also in the dynamic stabilization of the head through coordinated reflex responses, to involuntary displacements. In addition, damage to neck muscles have resulted in disturbance of gait, dizziness and disorders of the occulomotor system (Abrahams, 1977, 1981; Jongkees, 1969).

A prominent feature of the anterior aspect of the neck, are the paired *sternocleido-mastoid* muscles. These muscles are attached to the mastoid process and to a considerable area of the occipital bone. At the lower end, some fibres run to the sternum and some to the clavicle. The mastoid portions of this muscle have the function of pulling the head and neck forward together without tipping and to control lateral movements of the head. The occipital fibres of this muscle form a crossed four-bar linkage with the skull, the vertebral column and the rib cage. The action of this linkage at any time is very dependent on what other muscles are doing at that time. If the cervical vertebral column is stiffened by the short-range muscles, the occipital fibres of the *sternocleido-mastoid* muscle will either pull the head and neck forward without tipping, or will tip the head backwards over the occipital condyles, according to whether or not the neck is permitted, by other muscles, to bend forward relative to the thorax. Unequal activity of these muscles on the two sides produces rotation of the skull around the long axis of the neck, as in shaking the head.

Under certain circumstances another set of muscles can influence the attitude of the head: The hyoid bone, lying in the neck just above the larynx, functions primarily as an anchorage for the tongue musculature. This bone is held in place by muscles running to the skull, to the lower jaw, to the sternum and to the clavicle. The sternum is thus linked to the skull through a chain of muscles, by way of the hyoid and the lower jaw. If the muscles stabilizing the hyoid are activated at the same time as the masticatory muscles that close the jaw, the combined effect can be to tip the head forward (Roberts, 1995). Appleton (1946) was of the opinion that the “poking” chin results from the fact certain muscles in the cervical spine are neglected.

The muscles of the neck possess a number of notable structural complexities: with the exception of the short intervertebral muscles, each of the neck muscles is innervated by branches of two to five spinal segmental nerves and the territory innervated by each spinal segment is clearly delineated. The dorsal neck extensor muscles are made up of compartments which are separated by tendinous bands that cross the entire width of the muscle (Roberts, 1978).

5.3.1.6 Innervation of the upper quarter

The spindles in the individual muscle compartments respond not only to the length of the compartment, but also to the contracting muscle, and to any differential length changes between compartments caused by unequal degrees of contraction.

The rich sensory innervation of the neck (which will be discussed in more detail in Chapter 6, section 6.3.2.3.1) is a reflection of its role in proprioception and its importance in the augmentation of reflexes controlling the posture of the legs and trunk. During natural movements of the head on the neck, simultaneous vestibular and neck afferent stimulation results in mutual cancellation of their reflex effects, allowing the head to move freely without disturbing the posture of the limbs and trunk (Roberts, 1978).

5.3.1.7 External appearance of the neck

The external appearance of the neck is affected by an individual's habits of using his body. In both types of postural abnormality (kyphotic and lordotic) the normal curvature of the cervical spine is altered. With both types there is an initial stretching of the neck. Later the skin becomes sagging, lifeless and parchment-like with creases at the back of the neck. The tall kyphotic type usually has an increased cervical curve to counterbalance an increased thoracic curve. The neck tends to become rigid and a nod backwards uses mainly the atlanto-occipital joint. The jaws tend to be thrust forward and jutting, stretching the skin of the front of the neck and creasing the skin at the back. A prominent Adam's Apple is common with age (Barker, 1985). These faulty body mechanics lead to antero-posterior flattening of the chest and result in the neck appearing longer (Goldthwait *et al.*, 1952).

Owing to the attachment of the deep cervical fascia, when the chin is thrust forward and there is cervical lordosis, the strands which pass down to the pericardium are relaxed, so that the heart sags down and with it the central tendon of the diaphragm, impairing both circulation and respiration (Forrester-Brown, 1930).

5.4 THE CERVICO-THORACIC REGION

5.4.1 General

Anatomists distinguish some 14 pairs of muscles attached to the skull and contributing to the task of supporting the head. The masses of the paired *sterno-cleido-mastoid* muscles, lying on each side of the larynx, are a prominent feature of the anterior aspect of the neck (Roberts, 1995).

In many necks the *m sternocleidomastoideus* is obvious and stands out like a rope (Rolf, 1977). This muscle is countered by the *m levator scapulae* and the *m splenius* and no "rope" is apparent when these three are in balance. The *m levator* scapulae arise from the transverse processes of the first four cervical vertebrae and inserts into the medial border of the scapula. It raises the shoulders in a shrug or gesture of protection. Habitual fear or - defence permanently shortens this muscle, which then deteriorates with patches of gristle (cartilage) at its insertion on the scapula bearing witness to its decreased mobility. Deterioration of the muscular function may glue one or both shoulder blades to the *trapezius* causing a new *trapezius-levator scapulae* complex which is unable to perform independent reciprocal movements, and forms the basis of the ineffectual rounded shoulders posture (Rolf, 1977).

5.4.2 Functional anatomy of the cervico-thoracic region

The cervic-thoracic region is a prominent area where the shape of the cervical vertebrae alters and the spinous processes become more prominent. This whole area at the base of the neck is a centre of muscular coordination which is affected by patterns of breathing and the use of the arms and shoulders. A good vertebral posture is required in this area for the mechanisms of speech and swallowing with the associated oesophagus, trachea and vocal structures to function well. The main nerve pathways pass through this area, including those nerves which control breathing, heart rate and blood pressure, and here the nerve roots become more liable to compression with increasing age. This is the area where 85% of the British population have arthritis by the time that they are 55 years old (Barlow, 1990).

5.4.2.1 Kyphosis in the upper back

Age increases the kyphotic curve (stoop), and fat may be deposited in the lower part of the back of the neck and over the shoulders. The extreme form of this is known as Dowager's Hump and cosmetic surgery has little to offer for this disfigurement which is caused by excessive and wrongly distributed muscle tension (Barker, 1985; Barlow, 1990). In a normal ribcage, the first rib approximates a straight line from front to back. The Dowager's Hump is the result of a major sagging of the ribcage, tilting the first dorsal and seventh cervical vertebrae. The strain here reflects also into the lumbar spine. In addition, the distortion at the cervicodorsal junction requires that the leg compensates by hyperextending (Rolf, 1977). Postural therapy will generally correct the problem painlessly and cheaply. If excessive curves are allowed to remain, osteoarthritis of the cervical and thoracic parts of the spine are likely to occur (Barker, 1985).

The cervic-thoracic area is where misuse of the body most frequently starts, according to proponents of the Alexander Technique. It is the area to start from to correct the multitudinous misuses that manifest in the rest of the body (Barlow, 1990; Macdonald, 1998).

5.4.2.2 Interrelationships between the cervico-thoracic structures

Waterland and Munson (1964) used a total of 1774 photographs to demonstrate the mutual interdependancy of the regions of the head, shoulder girdle and glenohumeral joint, that is activity in one area affects the behaviour of the others unless consciously inhibited. They found that the head affects the shoulder and then limb positions, and modification in limb positioning first affects shoulder girdle and then head posture.

5.4.2.3 Response of head and shoulder girdle to voluntary arm movements

Unilateral lateral rotation of the humerus evokes shoulder retraction, ipsilateral head rotation and atlanto-occipital ventral flexion. Medial rotation evokes the reversed position. Bilateral medial rotation results in protraction of the shoulders and ventral flexion of the cervical spine whereas retraction and cervical spine dorsal flexion result from bilateral lateral rotation (Waterland and Munson, 1964).

Glenohumeral flexion is associated with elevation and retraction of the shoulder girdle, dorsiflexion of the head and hyperextension of the vertebral column; extension at the glenohumeral joint shows the reverse of this pattern (Waterland and Munson, 1964).

Dorsal flexion of the head, occurring primarily at the atlanto-occipital joint, is linked with shoulder girdle elevation, ventral flexion with shoulder girdle depression (Waterland and Munson, 1964).

5.4.2.4 Responses of head and arms to shoulder movements

With shoulder girdle protraction-depression and retraction-elevation movements, the head and arms respond concurrently rather than in sequence. Retraction is associated with cervical spine dorsal flexion of the head; elevation with dorsal flexion occurring primarily at the atlanto-occipital joint. Protraction and depression is linked with cervical spine and atlanto-occipital ventral flexion, medial rotation and adduction of the arms (Waterland and Munson, 1964).

5.4.2.5 Response of shoulder girdle and arms to movement of the head

If the head is bent to the right side, it results in shoulder depression on the same side and elevation of the contralateral shoulder. Elevation of the arm on the chin side and depression on the skull side are thought to be a direct result of the changes evoked in shoulder positioning (Waterland and Munson, 1964).

Atlanto-occipital ventral flexion, linked with shoulder girdle depression generally evokes elbow flexion; dorsal flexion tied with shoulder elevation, evokes elbow extension. Cervical spine ventral flexion, which is involuntarily tied with shoulder protraction, is frequently associated with spinal flexion. Dorsal flexion of the head is associated with shoulder retraction and strong spinal extension (Waterland and Munson, 1964).

5.5 THE THORACIC REGION (CHEST)

It is easy to develop a sideways twist where the neck joins the back (at the base of the cervical spine). This is usually accompanied by the chest being twisted sideways in the opposite direction to the head. The clavicle on the side to which it is pushed over may be slightly higher than the other or both clavicles may be too high because of shoulder tension. The angle between the ribs will be sharper on one side and the chest may be more inflated on the other side with the cartilage of the lower ribs pushing more forward on that side. Such chest twists and rotations are often undetected and may be the cause of distressing pain in the chest (Barlow, 1990; Ayub, 1987).

Subsequent to the twist (torque force) at the base of the neck, there is a proportionate increase in thoracic kyphosis and a flat chest (Phelps, *et al.*, 1956). The increased thoracic convexity tends to abduct the scapulae and lengthen the rhomboid and lower *trapezius* muscles, while shortening the *serratus anterior*, *latissimus dorsi, subscapularis* and *teres major* muscles (Ayub, 1987).

5.5.1 Round shoulders

In addition, the increased scapular abduction shortens the pectoralis major and minor muscles, which, by their attachment to the coracoid processes of the scapulae, tend to pull the scapulae over the head of the humerus. The humerus then moves into internal rotation and the glenohumeral ligament is shortened. This may result in diminished shoulder abduction, lateral rotation and extension (Ayub, 1987) but not in increased tightness or lack of stretchability of the pectoral muscles (in women) according to Coppock (1958). Ayub (1987), however, accepted that a shortened muscle is a tight muscle which inhibits its antagonists, resulting in muscle imbalances. Thus, weakness of the lower *trapezius* muscle may result from shortening of the upper *trapezius, levator scapula* and *serratus anterior* muscles, whereas inhibition of the *rhomboid* muscles may occur in response to the shortening of the *teres major* muscle.

The movement of the scapula into abduction may result in increased acromioclavicular joint compression and shorten the conoid ligament, while lengthening the *trapezius* ligament. Due to the change in length of the rotator cuff muscles and the resulting dyskinesia, abnormal thickening of these tendons may occur, resulting in less space under the coracoacromial arch. The increased glenohumeral internal rotation stretches the rotator cuff and biceps tendon over the humeral head and may be a factor in their diminished blood supply. The vascularity of the rotator cuff is most impaired when the arm is adducted. Degenerative changes of the rotator cuff are frequent because of diminished blood supply at the watershed area, which translates to the distal portion of the *supraspinatus* tendon, proximal to its insertion into the humeral head. Therefore, small attritional tears have less capacity for repair (Ayub, 1987).

The shortening of the pectoral muscles pulling the scapulae anteriorly, as well as inferiorly, may approximate the acromion and humerus, decreasing the suprahumeral space. Activities such as abduction and shoulder elevation may impinge this already compromised region which may, over time, lead to the formation of osteophytes (Ayub, 1987).

5.5.2 The shape of the thorax

The shape of the thorax (chest cage) is of considerable importance in body mechanics. The antero-posterior diameter should be about two thirds of the lateral diameter and the circumference of the chest at the ninth rib should be greater than in the axillary region, while the sternum should be convex anteriorly (Phelps *et al.,* 1956). The shape of the chest in faulty body mechanics as well as in different body types varies greatly. Both Barker (1985) and Goldthwait *et al*. (1952) determined body type by measuring the subcostal angle at the join with the xiphisternal notch. The slender body type has a narrow angle, long thorax and smaller circumference whereas the stocky type has a wide angle, shorter thorax and greater circumference. Barker (1985) observed that the lower ribs of the slender type have a large range of movements and the wide angled have a small range of movements of the lower ribs. Goldthwait *et al*. (1952) noticed that the different body types were affected differently by the faulty body posture of kyphosis. In the slender type the costotransverse articulations are such that when the dorsal spine becomes more rounded, the head drops forward, causing an increased curve of the cervical spine, a downward and inward displacement of the sternum and the ribs may point downward instead of being at an angle of 30° to the spine. At the side of the chest the ribs are close together and the subcostal angle may become very narrow. In the stocky type, when the dorsal spine becomes more rounded, the head comes forward, the upper part of the chest and the sternum become more vertical and the lower ribs flare outward, both laterally and anteriorly. The ribs are close together but not as vertical as in the slender type.

The shape of the chest affects the muscles attached to the chest wall. When the chest droops downward the abdominal muscles (*recti*) are relaxed because their origins (the sternum and costal margin) and their insertions (Poupart's ligament and the pubis) have been brought closer together, thus making the function of these muscles less efficient (Goldthwait *et al*., 1952). On the other hand, if *recti* are shortened and thickened through repetitive flexing, complications arise with the most apparent distortion in the ribcage. Chronic shortening of these muscles drags down the rib structure as a whole, bringing the lower ribs too close to the pelvic brim. This chronic flexion strains the entire body, since neck and cervical spine are inevitably included in the compensation.

The myofascial structures of the cervical spine become anteriorly shortened and therefore the head comes forward (Rolf, 1977).

5.5.3 Thoracic kyphosis

Curvature of the spine is lordosis if the bend is backwards; kyphosis if it is forwards; scoliosis if it is lateral (Inglis, 1978; Jayson, 1981).

Not much has been published about the mean degree and range of thoracic kyphosis in either children or adults (Willner, 1981). One study, however, showed that the normal range of kyphosis is related to both age and gender of a person. The degree and rate of increase with age is higher in females than in males after the age of forty. The increase of the kyphotic curve is associated with changes in the soft tissues and mineral content of the bones with increasing age. Compression wedging of the vertebrae and its narrowing of the intervertebral discs take place. Poor posture and physical inactivity may lead to decreased tone on spinal ligaments and muscles resulting in an increase in kyphosis (Fon, Pitt & Thies, 1980). Posture, however, varies during the growth period with a tendency for a reduction in size in the thoracic kyphosis from the age of 8-14 years and reaching a minimum at the age of 12. This applies for both sexes and is thus independent of growth velocity (Dickson, Lawton, Archer, & Butt, 1984; Willner & Johnson, 1983). However, Ashton-Miller and Schultz (1988) found that although growth has little effect on the magnitude of thoracic kyphosis, a few degrees of increase occur from age 5 to 20. Childhood "drooping" which persists during the growing years, may lead to a lasting deformity (Goldthwait *et al.,* 1952).

5.5.4 The diaphragm

The effect of posture on the diaphragm is inconclusive (Barker, 1985; Goldthwait *et al.*, 1952; Kuhns, 1936; Laplace & Nicholson, 1936). The effect of the diaphragm on total well-being is indisputed, however (Barlow, 1990; Lowen, 1994; Wilson, 1982), and an increase in vital capacity with correction of faulty posture, has been a constant finding (Hellebrandt *et al.*, 1940; Kuhns, 1936; Laplace & Nicholson, 1936).

> *Immediate or extreme attempts at correction of posture will frequently put so great a task on the musculature of the thorax and abdomen that vital capacity will be diminished* (Kuhns, 1936: 1012).

5.5.5 Receptors in the chest

Godwin-Austen (1969) demonstrated the presence of receptors which are sensitive to rib movement and which are situated in the costo-vertebral joints, averaging about two in each rib joint. These receptors are capable of defining the position of these joints and the direction of velocity of the movement of the joint. These are not to be confused with respiratory receptors. Previously Cohen (1958) mentioned that it was reasonable to assume that position sense accuracy bears some relation to receptor density and he stated that joint proprioceptors contribute greatly to the sense of limb position. These joint proprioceptors are little affected by muscle tension. The interesting point of Cohen (1958)'s findings is that during passive movement, the first sensation experienced is a vague sensation of movement, followed by an awareness of the general direction of movement and finally replaced by an appreciation of the exact position of the limb. It is assumed that the same proprioceptors are responsible for each of the sensations. The thresholds for all three sensations are so low that separate sensations are indistinguishable during usual joint movements. This gives an inkling about why man is usually unaware of the positions of various parts of his body. However, Jakobs, Miller and Schultz (1985) demonstrated that healthy adult subjects have the ability to sense the lateral position of the top of their thoracic spine and can centre it over their pelvises. This finding was supported by Jepsen, Miller, Green and Schultz (1987) who added that positioning was less accurate from the anterior than from the posterior direction and suggested that the spine postural control system also used afferent information from joint receptors. One may argue that the sense may exist voluntarily but is probably often suppressed. Becoming aware of it may assist in regaining spinal alignment.

5.6 THE LUMBAR REGION

5.6.1 General

> *Because he has a greater number of free lumbar joints and a greater thickness of lumbar discs, man, of all primates, has the greatest degree of lumbar spine flexibility* (Farfan, 1978: 337).

One of the most important parts of the spine from the mechanical point of view, is the dorsolumbar region where the vertebrae change from thoracic to lumbar and extremes of motion takes place. The exact location of the maximum motion depends on the anatomical type and may be anywhere from the tenth thoracic in the stocky type to the third lumbar in the slender type (Goldthwait *et al.*, 1952).

The sharp backward bend between the lumbar column and sacrum is a particular human characteristic. This lumbo-sacral angle, which on average amounts to 142° with men and 144° with women, is the base for the attitude of all vertebral bodies. Seventy percent of all extensions and hyperextensions of the lumbar column take place at this point (Tittel, 1990).

5.6.2 Lumbar lordosis

Sagittal curves of the spine change during the different growth stages of the body. A slow increase of the lumbar lordosis was observed in children between 8-16 years of age. Ashton-Miller and Schultz (1988) estimated the increase to be 10% between the ages of 7 and 17 years. The normal range of lumbar lordosis has been assumed to be between 40°-60°. The range of thoracic kyphosis and lumbar lordosis is assumed to be interdependent (Willner &

Johnson, 1983). Postures such as sway back and hyperlordosis tend to rely on ligamentous support rather than muscle activity, eventuallly leading to disuse in the postural muscles (Norris, 1995).

The lordotic curve often diminishes after 64 years of age. This may result from increasing kyphosis pushing the centre of gravity of the body forwards with loss of lordosis from compensatory straightening of the lower spine (Ashton-Miller & Schultz, 1988; Milne & Lauder, 1974).

5.6.2.1 Low back pain and posture

Byl and Sinnott (1991) found that those suffering from low back pain had increased body sway, poor one footed balance with eyes closed, a posterior position of the centre of gravity and a tendency to fulcrum about the hip and back to maintain uprightness when exposed to challenging balance tasks. Healthy controls maintained their fulcrum for the centre of balance around the ankle. These findings suggest a defect in the tripartite mechanism in the control of the upright and even the sitting position.

Because of the mobility of the dorsolumbar area, habitual faulty mechanics tends to, at some stage, cause strain with accompanying inflammatory processes around the articular facets and the joints of the spine as well as irritation at the spinal nerve roots. Referred pain from this may be the cause of painful symptoms in the region of the appendix, the lower abdomen and the gallbladder (Goldthwait *et al.*, 1952).

The lumber spine may be the site of numerous orthopaedic ailments, but by far the most common one is the low back pain syndrome (Nachemson, 1976). Several psycho-social factors influencing low back incapacity have been suggested, for example: Disturbed personality (MMP), alcoholism, divorce, religiosity and job dissatisfaction. Radiologic abnormalities in the lumbar spine with significance for low back pain that have questionable values are, amongst others, severe lumbar scoliosis and severe lordosis, as found by Nachemson

(1976). A study by Christie, Kumar and Warren (1995), found an increased lordosis in a chronic low back pain group. They noticed a discrepancy in posture between acute and chronic low-back pain sufferers: acute low back pain sufferers tended to develop thoracic kyphosis. They postulated that it is an open question whether poor posture leads to pain, or precipitation of pain necessitates postural aberrations. According to Barlow (1990), lordosis plus scoliosis will usually be present when there is chronic back pain and it is only in the acutely painful back that the lumbar curve is flattened by spasm.

Considering the anatomy and mechanics of the lumbar spine, excessive curvature (lordosis) probably has some sort of affect on the functioning of the body as has excessive flattening of the lumbar curve. In a lordotic posture the stress on the facet surfaces is high and may be responsible for the high incidence of osteoarthritis in these joints. Also, the possible extra-articular impingement between the facet tip and the adjacent lamina or pedicle in a lordotic posture could be a source of low back pain, especially if the joint capsule is trapped between the bony surfaces. The extremely lordotic spine increases the load on the axial skeleton by 55-65% (Tittel, 1990). However, if flexion is excessive, so that the posterior intervertebral ligaments are overstretched, the anterior vertebral body may be crushed or there may be a sudden posterior prolapse of the intervertebral disc (Adams & Hutton, 1985).

Muscular deficiency has also been cited as the cause of low back pain with the following sequence offered as the etiology for the syndrome: 1) disuse results in atrophic changes; 2) the weakening musculature must then work at an increasing percentage of its maximum voluntary contraction capability; 3) whereas the normal musculature can work for prolonged periods without any electromyographic evidence of fatigue, in the weaker muscles such activity results in constantly rising levels of activity which ultimately result in tonic local muscle spasm; 4) the tonic local muscle spasm produces localized areas of ischemia; 5) the ischemia causes pain; 6) the pain causes increased muscular contraction and a vicious cycle is born which has as its end result the typical low back pain syndrome (DeVries, 1968).

5.6.2.2 Balance between lumbar structures

Reciprocal balance between lumbar spine and sacrum is of major importance and low back problems indicate a deterioration of the normal internal balance between lumbar spine and pelvis (Rolf, 1977). However, asymmetry of spinal lateral flexion and probably of human body mechanisms in general, should also be noted in back pain studies (Mellin, Härkäpää, & Hurri, 1995).

Poor postural control leads to postural disequilibrium and this may be the cause of idiopathic scoliosis. The researchers coming to this conclusion reasoned that a crooked spine would not cause a postural dysfunction and as a decrease in postural sway was measured in the patients with scoliosis, the disequilibrium probably preceded the scoliosis (Sahlstrand, Örtengren & Nachemson, 1978).

Tilting the pelvis posteriorly decreases the absolute depth of the lumbar curve, and tilting the pelvis anteriorly increases the absolute depth of the lumbar curve (Day, Smidt & Lehman, 1984). For upright standing the lumbar curve appears to be oriented more towards the maximal trunk flexed position than toward the maximal extended position (Day *et al.*, 1984).

Most habitual or preferred standing postures (such as resting on one leg) cause some degree of lumbar flexion, compared with erect standing, leading to the assumption that people want to reduce the lumbar lordosis whenever possible, even at the expense of increasing back muscle activity. Evidence suggests that such postures may be advantageous (Adams & Hutton, 1985; Dolan, Adams & Hutton, 1988). The compressive force on the apophyseal joints is reduced in flexed postures and the transport of metabolites is improved. Deficient metabolite transport has been linked to degenerative changes in the disc (Nachemson, 1976).

With increasing flexion there is an increase of tension in the intervertebral ligaments until the flexed trunk is supported by the ligaments, at which point the *erectores spinae* muscles relax (Floyd & Silver, 1955). During flexion of the trunk, the points of attachment of the *erectores spinae* muscles and the intervertebral ligaments are drawn apart. The consequences of this is that muscle fibres lengthen while exerting tension and hence do negative work, and the tension in the ligaments increases (Floyd & Silver, 1955). The myoelectric activity increases as flexion increases, until full flexion is reached. In this position the activity level decreases and frequently, activity ceases almost completely. Intradiscal pressure increases significantly more during flexion than during extension (Andersson, Örtengren & Nachemson, 1977; Portnoy & Morin, 1956).

5.6.2.3 Relationship of the lumbar area to others

Lordosis is a primary contributor to the subjective and objective weakness that accompanies cervical anteriority, according to Rolf (1977). Conversely, gross cervical displacement makes it impossible to reorganize a lower back. Any satisfactory remedy must deal with these circular interplays.

During lumbar flexion (posterior pelvic tilt), there is an inverse relationship with the lumbar curve length (T_{12}- S_2) and the thoracic curve length (C_7-T_{12}). As the pelvis rotates posteriorly, the thoracic area is rotated in the anterior direction by the abdominal muscles. Thus the length of the lumbar segment increases and the thoracic length decreases. Minimal thoracic spine movement in flexion and extension occurs during anterior and posterior pelvic tilt and the maximum change in thoracic curve depth is less than 0.3 centrimetres (Day *et al.,* 1984).

Pain in the lumbar spine and pelvis are correlated with forward head posture (Christie *et al.*, 1995).

5.6.2.4 Use of the pelvic region

When the body is used correctly, the mass is carried on the bodies of the vertebrae. When it is used incorrectly, the weight in the lumbar and the cervical regions is displaced backward, so that it increasingly presses on the articular facets, forcing the joints more and more to the extreme position of their range of motion. Whether this extreme position will be reached at the lumbo-sacral joint or higher up depends on the individual body type - be it stocky or slender (Goldthwait *et al.,* 1952).

5.7. THE PELVIC REGION AND THE LOWER EXTREMITY

> *Reciprocal balance between lumbar spine and sacrum is of major importance. Low back problems indicate a deterioration of the normal internal balance between lumbar spine and pelvis* (Rolf, 1977).

According to Rolf (1977) the pelvis is the key to the well-being of the individual. But it is a dynamic key, a process key. Technically and anatomically, the pelvis is a bony basin. Vitally and physiologically, it is a relation of energies. Optimal performance of such a system occurs only at the narrow peak of balance, which necessarily has to be very precise.

5.7.1 Flexion at the hip

Motion at the hip is under control of the hip musculature, while motion of the lumbar spine is under control of active spinal musculature requiring a complex ligamentous system as additional support. The sequence of forward flexion according to Farfan (1978) is as follows: in the first stage, the lumbar joints flex as the extensors lower the body weight above the lowest lumbar joint. The activity of these muscles increases with the increasing moment. The change in geometry causes the posterior ligamentous system to become tight and to develop tension. At a point near 45^0 of forward flexion and onward, the ligament tension increases rapidly, reducing the necessity for muscle activity. Further forward rotation then occurs with pelvic rotation under control of the hip extensors, allowing the trunk above the fully flexed hip joint to be brought to a horizontal position or beyond when the extensor muscles relax.

5.7.2 Functional variations

In the hip region a tight tensor *fascia lata* will produce an increased pelvic inclination and a hyperlordosis. A weak gluteus maximus will permit a flexion position of greater degree accompanied by a tight quadriceps and flexed knee (Phelps *et al.,* 1956).

The pelvis serves as a container for the abdominal viscera. In many people the pelvis is tipped forward causing the viscera to spill over and be restrained by the muscles and skin of the abdominal wall. This leads to a protruding stomach (Rolf, 1977).

Faulty body mechanics may cause the rami of the pubis and the ischium to project further forward resulting in a deformity called ischium varum or valgum (Rolf, 1977). The superior and the posterior margin of the acetabulum may be altered by the constant forward inclination of the pelvis, which also leads to a relative instability in the hip joint. The muscles about this joint are attached in such a manner that in normal function their contraction tends to pull the head of the femur into the acetabulum. When this pull is changed, as occurs when the pelvis tips forward, the action of the muscles in stabilizing the hip is lost, resulting in irritation and later arthritis at the hip joint (Goldthwait *et al.,* 1952).

Freedom in the hip joint is lost when the hamstring muscles shorten from any cause. The hamstrings traverse the back of the thigh, joining the ischial tuberosity of the pelvis to the leg below the knee. They shorten and thicken as a result of over-exercising. The three hamstring muscles may become "glued" together, losing independent movement by shortening and forming a bulge at the back of the leg (Rolf, 1977). (Myofascial sheaths surrounding individual muscles become glued together and cause restrictions).

Rotation in the hip joint is limited by various poor postural habits. Movement of the pelvis subsequently becomes restricted, forcing the substitution of bending the spine to achieve upright postures. Eventually the pelvis exerts a downward pull through the muscles of the back, causing the head to begin locking on the cervical spine. This may lead to compression of the spine and the emergence of painful conditions (Cohen-Nehemia, 1983).

Very little movement takes place at the sacroiliac joints (DonTigny, 1993). Lavignolle, Vital, Senegas, Bestandau, Toson, Bouyx, Morlier, Delorme and Calabet (1983) reported a rotation of 12^0 and translation of 0.6 millimetres on average in young adults. However, this is the locus of low back sprain known as the sacroiliac syndrome. In 1927 Lusskin and Sonnenschein, after thorough research, declared disability due to pain in the lower back as a definite syndrome. The four cardinal signs are: Flat back, scoliosis, tenderness over the involved joint and hamstring spasm. Correction of any postural defect or of a weak foot, will aid in the prevention of the occurrence.

Structurally the sacrum is suspended from the ilia. Significant mass-bearing is precluded by the verticality of the neutrally suspended sacroiliac joints (DonTigny, 1993). Mass bearing may be increased by a self-bracing mechanism which occurs during flexion of the pelvis (Vleeming, Volkers, Snijders & Stoekart, 1990). Pelvic flexion, caused by any mechanism which will rotate the innominates posteriorly (posterior tilt of the ilia to the rear) will result in the tightening of the posterior interosseus ligaments, and the sacrotuberous ligament which then markedly increases the friction and mass-bearing capacity of the sacroiliac joint. Anterior rotation of the innominates on the sacrum, on the other hand, decreases the tension on the sacrotuberous ligament, releasing the self-bracing mechanism, decreasing the mass-bearing and increasing shear (DonTigny, 1993). For the maintenance of the integrity of the sacroiliac joints good posture, associated with support by the abdominal muscles are essential (DonTigny, 1993).

5.7.3 Pelvic tilt

Pelvic tilt is related directly to the position of the lumbar spine and the sacrum. A study by Levine and Whittle (1996) showed that pelvic tilt in the standing position significantly affects lordosis of the lumbar spine, the greater the forward tilt the greater the spinal lordosis and strain. In an unbalanced pelvis, the strain is reflected into the lumbo-sacral junction and movement is impeded. This is one of the most important joints in the body where a very slight mobility stimulates the autonomic plexi of the lumbar and sacral areas (Rolf, 1977).

Differences in leg lengths result in a lateral pelvic tilt (Phelps *et al.,* 1956). Lateral pelvic tilt produces apparent shortening of the leg which is usually the result of muscular imbalance in one ("shorter") leg where the adductors (inner leg muscles) are stronger than the abductors (Barker, 1985).

Pelvic tilt scoliosis is also caused by inequality of the length of the legs and has the secondary effect of minor, non-progressive, lumbar scoliosis. This accounts for 40% of spinal deformities (Dickson, 1983).

Deep muscles tend to cause the pelvic tilt, and the overlying and supporting muscles deteriorate. The tone of the muscles attached to the pelvis (*obliques, recti abdominis,* gluteal and rotator groups) reflect the general health and well-being of the pelvic and abdominal organs. A sagging potbelly and gluteals are not merely cosmetic offenses, but indicative of sagging reproductive and elimination organs. They also relate to the heavy, dragging gait of the individual (Rolf,1977).

An obvious lateral pelvic tilt is the relatively common postural fault when the person habitually stands with one knee bent and the opposite buttock pushed out. This results in stretching and weakness of the *gluteus medius.* Clinically, patients with this fault may present in one of three ways: backache; swollen hip, or pain referred to the abdomen (sometimes erroneously diagnosed as appendicitis) (Burt, 1950).

5.7.4 Sacrum and femur

The weight of the upper body tends to force the upper part of the sacrum forward and the upper coccyx may compensate by rotating backward. The strong ligaments binding the sacrum in place have the function of resisting these tendencies. An interosseous sacroiliac and sacrotuberous ligament form a joint of great strength that holds the sacrum fast against lateral rotation. The sacrospinous and sacrotuberous ligaments resist the tendency of the base of the sacrum to rotate forward. The piriformis (rotator muscle) lines the anterior surface of the sacrum and through this muscle deviation of the sacrum is transmitted as strain to the rotators of the thigh. A sacrum that is too deep causes as well as reflects inadequate support from the related rotators. Imbalanced rotators transmit disparate support; one or both femurs (together with the legs) will then be aberrant (Rolf, 1977).

Male and female femurs differ. In the male, the neck of the femur is not as horizontal as in the female and the head of the femur is inserted in the hip joint so that the neck of the femur is angled backward from the joint. The horizontal neck of the female femur causes wider hips and the appearance of knock-knees. With the female femur set forward, the lordotic curve is greater in order to bring the chest further back to counteract the forward weight of the thighs. Advancing years bring about increased lordosis and increased muscular imbalance. The buttocks project further and the little used gluteus muscles become enveloped in fat; the abdomen, breasts and chin sag and accumulate an excess of fat. The front thigh muscles never contract fully to straighten the knee and fat accumulates on them and behind the knee. Osteoarthritis may develop in the knees (Barker, 1985).

5.7.5 Lower extremities

Many workers in the field of posture and body-alignment, -mechanics and -treatment consider the feet as being of cardinal importance (Goldthwait *et al.*, 1952; Lowen, 1994; Rolf, 1977; Tobias 1982; Wikler, 1980). The body is balanced on the feet on the ground and the concepts of balance and grounding do have many interpretations.

Balance in the body begins with feet, for the basic work of foot and ankle is to offer a reliable base by which the upper body can relate to the horizontal plane of the earth. Competent feet and ankles must offer a mechanism for continual shifting and adjustment by the overlying body (Rolf, 1977: 45).

The foot is one of the most common sites of deformity in faulty body mechanics (Goldthwait *et al.*, 1952: 89).

Wikler (1951; 1980), a podiatrist, who worked for more than half a century on the mechanics and treatment of feet, attributed many prevalent diseases to wrong use of the feet. These range from breast cancer, cardiac diseases and diabetes to nervousness and emotional imbalances. He also showed that people with disordered feet tended to have round shoulders and with one foot worse than the other, one shoulder would droop more than the other.

5.7.5.1 Foot deformities

Abnormal supination is the inability of the foot to pronate effectively during stance and is commonly referred to as the high-arched foot. This is hypomobility of the joints of the foot and ankle that may result from muscle imbalances and soft tissue contractures. Abnormal supination is usually associated with a rigid structure which is unable to function as an efficient shock absorber or as an adapter to changing terrain. The abnormal supinators usually do not demonstrate a progressive breakdown in tissue (producing a hypermobile foot), such as occurs in the flexible, pronated foot. Rather it is an inflexible foot that causes tissue inflammation and possible joint destruction.

Congenital or acquired abnormal pronation (flat foot) changes the alignment of the calcaneus, talus, cuboid and navicular bones. The change in alignment produces poor articular congruity and alters the arthrokinematics of the ankle, subtalar and midtarsal joints. The excessive movements produce excessive forces within the foot and ankle and throughout the lower kinetic chain. The tibia, talus and calcaneus move simultaneously as the foot pronates. The talus and tibia are rotated medially and the calcaneus rolls laterally into eversion. In abnormal pronation the calcaneus subluxates under the talus. Such arthrokinematics are abnormal because they are excessive and persistent throughout the stance phase. Normal pronation is a temporary condition of the subtalar joint which might occur in response to a change in the terrain (Donatelli, 1990).

Changes in the mechanics of the rear foot and mid foot produce certain anatomic changes including everted position of the calcaneus, medial bulging of the navicular tuberosity, abduction of the forefoot on the rear foot and a reduction in the height of the medial arch. As a result of the excessive pronation, the soft tissue structures are traumatized over a long period of time, resulting in breakdown and pathology. Abnormal pronation (flat foot) can be a deformity present at birth or an acquired deformity due to extrinsic factors such as rotational deformities of the lower extremity and leg length discrepancies (Donatelli, 1990).

Lumbar lordosis and forward tilting of the pelvis moves the body's centre of gravity slightly forward, in front of the acetabula, and stabilisation is obtained by internally rotating the femora. This in turn causes toeing in which may be corrected either by external rotation at the knee or by eversion and abduction of the feet. As the former is not a comfortable permanent posture, the flatfoot position is assumed (Donatelli, 1990).

Another common factor in the production of flatfoot, is contraction of the posterior calf muscles, and referred to as a short Achilles tendon. The condition is characterised by the inability to fully dorsiflex the foot at the ankle joint (Goldthwait *et al.*, 1952; Wiles, 1937).

Foot problems also have a psychological aspect. Rolf (1977) noticed a deep, unconscious feeling of insecurity in people with any kind of foot problem, while

Lowen (1994) developed his famous grounding exercise to place the feet firmly in contact with the ground and in so doing establishing an emotional balance where it had been lacking, and bringing them in touch with reality.

5.7.5.2 The ankle joint

Much of the posture, weight and movement of the body are handled by the ankle joint. While standing, gravity constantly tends to carry the body forward around the axis of rotation of the ankle joint. This dorsi-flexing force is resisted, and the upright posture is maintained by active and passive forces tending to cause plantar flexion at the ankle. The active force is the result of a postural contraction which is located mainly in the triceps surae and the passive force is the result of tension in passive extra-articular tissues in the posterior crural region (Smith, 1957).

An ankle is a hinge joint (Donatelli, 1990; Rolf, 1977) - thus it operates most effectively if primary movement takes place in one directional line - fore and aft. Length and elasticity of individual tendons and ligaments determine the position of the bones and chronic shortening of any tendon will aberrate movement. In the normal ankle joint, tendons adjust to permit the sole of the foot to make contact with and to adapt to the ground surface (Rolf, 1977).

The ankles are formed by the lower prominences (malleoli) of the lateral fibula and medial tibia (Donatelli, 1990; Rolf, 1977). The muscles, tendons and ligaments holding these bones together may be affected by a persistent postural pattern causing a change in the contour of the ankle (Rolf, 1977).

5.7.5.3 The knees

The knees are also hinge joints and move forward and backward. Ideally, movement of knee- and ankle joints should be parallel and the joints themselves should be centred one above the other. Movement will then be graceful in a straight forward direction due to the fact that the muscles are in balance. Footprints should show a straight forward directional tracking (no deviation of the toes outward or inward) and a light weight transmission over the total area of the footprint. People walking with everted feet (one or both) have chronically shortened (hypertoned) peroneal muscles on the lateral side of the leg which over balance the tibialis group. Ankle movement then becomes limited and the ankle, knee and hip rotate (Rolf, 1977).

Postural aberrations of the knees are: hyper-flexion, hyper-extension, bandy-knees and knock-knees. These are not primary causes but symptoms of imbalance or of faulty body mechanics. In the child, changes take place in the neck of the growing femur. With the forward inclination of the pelvis and the subsequent internal rotation of the femur in order to bring support under the changed centre of gravity, a torsional stress is placed on the femoral neck which may produce a coxa vara and an anteversion. A twist or outward bowing may appear in the shaft of the femur. These changes develop more rapidly and to a greater extent if any conditions which weaken the bones are present. At the knee, with faulty carriage of the body, the weight is thrust more to the medial side of the joint, leading to a knock-knee deformity. The torsion of the femur may be carried into the tibia, leading to a twist or bending in this region. The forward inclination of the pelvis leads to a change of origin of the hamstring muscles and contraction of the iliopsoas group of muscles, causing a flexed or hyperextended knee when standing. Shortening of the heel cords is the most common cause of hyperextension at the knee. The mass is borne on the inner side of the foot and the big toe. The foot is inverted and turned inwards (pigeon toed). The angulation at the knee is difficult to realign, but if it continues for long the condition leads to deformity in the articular surfaces of the knee joint and in middle age is a common cause of arthritis of the knee joint (Barker, 1985; Goldthwait *et al.,* 1952; Phelps *et al.,* 1956).

All the mass is supported on the outer edges of the feet when a person has bandy-knees. To keep balance on one foot, the bandy person flattens the foot to bring more of it in contact with the ground, points the foot outwards and bends the knee forward and inwards. Using the inner leg muscles (adductors) constantly to frequently bring the leg across the mid-line, as is done during some sport activities, is often a cause of bandiness (Barker, 1985).

5.8 EFFECTS OF FAULTY POSTURE

5.8.1 Faulty posture

It is arguably easier to describe a faulty body posture than it is to describe the normal body posture. However, in order to determine an aberration, a norm has to be defined. There is a need for a wide definition because of the large variation in physique or body type (Forrester-Brown, 1930; Heptinstall, 1995). This can be classified according to Goff (1951) into the fat type, the muscular type, the thin elongated type and the balanced type. Sheldon's classification into ectomorph, mesomorph and endomorph was used by Burt (1950) and the stocky and slender type was favoured by Barker (1985) and Goldthwait *et al.* (1952).

The commonest test to determine posture, is to suspend a plumb line from the tip of the mastoid process. This line should pass through the greater tuberosity of the humerus (shoulder), the great trochanters of the femur (hip) and through a point approximately 45 millimetres in front of the lateral malleolus. This line will not pass through all these points if the chin is poked forward, the shoulders are rounded, or if there is a forward or backward carriage of the pelvis (Burt, 1950; Minton, 1990; Turner, 1965; Wiles, 1937).

Sweet (1939), a paediatrician, listed obstacles to be overcome before the complete upright posture can be obtained, obstacles which strongly resembles those listed in muscle imbalance (see section 5.9.3):

❑ 1) Short calf muscles or, occasionally, too long calf muscles,

- 2) Short hamstring muscles (*biceps, semimembranosus, semitendinous*),
- 3) Weak, underdeveloped external rotators of the thigh,
- 4) Weak, underdeveloped *glutei,*
- 5) Weak, underdeveloped muscles of the abdominal wall,
- 6) Strong, overdeveloped *erector spinae* muscles in the lumbar region and correspondingly weakened members in the dorsal region,
- 7) Strong, short, overdeveloped anterior shoulder girdle muscles and
- 8) Forward thrust of the head, with shortening of the upper *trapezius* and splenic muscles.

In addition to the fact that faulty posture moves the body out of the vertical line, it may also cause diminished length. Accentuation of the normal spinal curves, often coupled with bent knees, causes a reduction of stature. The increase in cervical lordosis forces the person to carry his head bent forward, the degree depending on the lordosis. To maintain the head positions puts extra work on the extensor muscles of the back of the neck, so a position of comfort unconsciously results in the bowing of the head. This necessitates a strain on the extra-ocular muscles (*superior recti*), it being easier to lift the eyes than to lift the head (De Puky, 1935; Kerr & Lagen, 1936).

Between the ages of 20 and 80 there is an increasing tendency for the stature to shorten, the waist to thicken, the chest to flatten and the head to thrust forward and down (Jones, Hanson, & Gray, 1964; Tanner, 1990).

Effects of faulty posture are: Inability to relax muscles, diminished agility and limitation of movement of the spine. Inability to relax muscles produces or increases fatigue and muscle pain. Ultimately it leads to muscle wasting for a muscle which never fully relaxes, never fully contracts and a period of incomplete muscular contraction is followed by wasting. Lack of agility and movement are also effects of incomplete muscular relaxation as well as myofascial adhesions between muscle fibres or muscle groups which interfere with muscular contraction (Burt, 1950; Rolf, 1977).

In view of the above, it is thus not surprising that a higher incidence of sports injuries are found in sportsmen with habitual malposture. Knee injuries were associated with lumbar lordosis and sway back; muscle strains with lumbar lordosis and abnormal knee interspace; back injuries with poor shoulder symmetry, scapulae abduction, back asymmetry, kyphosis, lordosis and scoliosis (Watson, 1995).

It is often not realised that although posture affects respiration, the reverse is also true. The whole position and shape of the rib cage is affected by patterns of respiration and this in turn has a profound effect on resting habitual upright posture (Painter, 1986; Plummer, 1982).

It has been suggested that the commonly used standing position for work tasks is a potentially harmful one, and it is one that has been reinforced in many schools and work situations. This deleterious position is one in which the feet are together, the lower limbs are stiffened and the upper body is in a flexed position. This posture produces sustained tension that may lead to loss of normal elasticity of the tissue, reduced circulatory efficiency, progressive reduction in the range of movement and chronic general fatigue (Turner, 1965).

People working with their hands while in a standing position tend to hyperextend the legs and to create excessive tension in the cervical and thoracic areas. Feet should be separated into a forward and backward position for balance and reduced tension while the legs are flexed and the neck and chest muscles are relaxed (Cooper, Adrian & Glassow, 1982).

Faulty posture does not only affect the physical aspects of a person. Educators have found that improving the total alignment and posture of a student, improves his learning ability and academic performance (de Quiros, 1976; Doane, 1959; Kohen-Raz, 1981; Kohen-Raz & Hiriartborde, 1979; Rosborough & Wilder, 1969; Sents & Marks, 1989). Cervical malposture could involve dysfunction of the hypothalamus and result in emotional imbalance (Rosborough & Wilder, 1969).

Studies have shown that correcting a student's slouching posture can bring about a total improvement, including social and intellectual, as well as increased attention span and improved attitude (Bell, McLauchlin & Hunsaker, 1979). Thorough research done by Riskind and Gotay (1982) on the slumped posture, indicated that even periodic slumping has a detrimental effect due to residual after-effects. In the slumped (depressed and submissive) physical posture subjects showed significantly lower persistence in the execution of certain problem-solving tasks and later, with an improved posture, had a strong feeling of helplessness when faced with a problem. The result of the studies suggest that the self-perception of being in a more slumped-over physical posture predisposes a person to more speedily develop self-perceptions of helplessness. Physical postures of the body frequently change with emotional experience (dejection, elation) but postures may constitute more than just passive indicators of emotions, because posture may have the capability of partially affecting the susceptibility of a person to such emotions (Riskind & Gotay, 1982).

5.8.2 Clinical manifestations of faulty posture

> *No disease is known to be caused by poor posture alone, but serious disturbances in function can occur in poor posture* (Kuhns, 1962: 64).

5.8.2.1 Back pain

Dull, aching pain in any region of the back which develops during the day, is made worse by standing and is relieved by a night's rest, is probably due to faulty posture. Muscular imbalance (see section 5.9.7) may lead to fatigue due to the fact that some muscles, being under-utilized, become too weak for prolonged use while others play too great a part in the maintenance of the erect posture (Barlow, 1990; Burt, 1950, Jull & Janda, 1987; Richardson, 1992; Turner, 1965).

Dysfunction of the sacroiliac joint as an impairment of the self bracing mechanism (section 5.7.2) is a common source of low back pain. It is a condition which is far more common than is suspected, and may mimic disc disease or give the impression of a multifactorial etiology of back pain (DonTigny, 1993).

5.8.2.2 Acroparaesthesia

The symptoms of acroparaesthesia are: pain down the arm, numbness and tingling of the hands of both sides, being worse at night and first thing in the morning. The condition may result due to an altered relation of the shoulder girdle and thoracic outlet secondary to poor tone of the shoulder girdle muscles. Traction and compression of the lower cord of the brachial plexus and subclavian artery are the essential mechanical factors underlying most cases of acroparaesthesia. The condition may be treated by correcting the sagging shoulders by improving the tone and strength of the elevator muscles (Burt, 1950; Dart, 1947).

5.8.2.3 Back strain

Back strain is a tear of a muscle, joint capsule or ligament causing acute back pain. The strain (tear) most likely occurs at the junction between elastic and less elastic tissues such as the attachment of tendon or ligament to bone. The reason why strains are particularly common in individuals with faulty posture, is because of their lack of agility and limitation of movement. The shortened muscles and ligaments are likely to be torn due to a sudden or relatively large movement (Burt, 1950; Turner, 1965).

5.8.2.4 Cervical spondylosis

Head and neck arthritis, fibrocytis or cervical disk pressure. The symptoms are numbness or tingling in the fingers of one hand due to pressure on nerve roots from the compressed and fore-shortened neck vertebrae. Sometimes the first symptom is severe pain in the neck, shoulder or arm, worse in the early morning. Rectifying the faulty posture or use which caused the condition usually brings relief to the symptoms (Barlow, 1990; Burt, 1950; Goldthwait *et al.,* 1952).

5.8.2.5 Fibrositic headache

Faulty posture of a long duration may cause a persistent, burning pain with a poor response to rest. The source of the pain of a fibrositis headache is at the insertion of the cervical muscles into the occiput. On palpation there is marked occipital tenderness. The pathology is the condition is similar to "tennis elbow" - it is due to trauma at the insertion of muscle into bone which is often caused and perpetuated by prolonged muscle tension (Turner, 1965).

5.8.2.6 Osteoarthritis

Osteoarthritis occurs in joints where the mechanism has been disturbed by disease, accident or faulty posture. This is a late effect where faulty posture has become chronic (Barker, 1985; Burt, 1950; Turner, 1965).

5.8.2.7 Vertigo

Postural imbalance may cause vertigo due to a head-neck disturbance, in association with nuchal myalgia, which may interfere with the neck reflexes. These patients are often relieved by postural correction (Turner, 1965).

5.9 POSTURAL IMBALANCES

Good dynamic posture frees one from tension and gives the body a feeling of lightness, of moving through space, rather than being earth bound. The body then becomes the instrument of the individual rather than the anchor dragging at the day's activities. The tendency to fatigue is reduced, and there is more energy left for other things. Accidents are far less common and usually less serious with good dynamic posture. The principles of good dynamic posture, precision, smoothness, power, balance, good timing, rhythm and coordination may be used not only for the physical body in action but as an approach to life (Howorth, 1946: 1404).

Postural imbalances are such a common, and an accepted part of most people's appearances, habits and characteristics that they are quite unnoticed by their fellow man. Exceptional cases may be commented upon as being a recognizable feature, seldom as a defect.

Pilbeam's (1990) contention was that conservation is frequently found in evolution and new structures are rare; new configurations are produced by tinkering with old structures. Barker (1985), Dart (1946), Keith (1923), Lovejoy (1988), Phelps *et al.* (1956), Tobias (1982) and Wolpoff (1996) are some of the authors who explained at length the ingenious development of posture by the modification and adaption of existing anatomical structures, and its outcomes during the evolution of man (see Chapter 3), therefore it is an integral part of our being, an inborn knowledge (Roberts, 1995). Dart (1946) traced the evolution and development of human poise for whose endowment nature consumed millions of years. He (Dart, 1946: 12) referred to the:

.....well balanced but gyratory bodies nature aimed at for mankind, bodies which every person should possess. Secondly,

> *we should realise that failure to develop a perfectly-poised body represents, like any other teratomous conditions, a developmental arrest.*

In a similar vein Feldenkrais (1985) came to the conclusion that good use of the body is a sign of maturity. Yet there is a lack of understanding and above all a lack of trust in this power of the body. In an overview of modern man`s postural habits Dart (1946: 13) had the following to say about lack of poise:

> *This lack is the more regrettable in that the underlying neuro-muscular knowledge is not a novel acquisition restricted to mankind but is something extremely ancient, his despised or neglected or overlooked heritage from the very remote past of phylogeny.*

Although the reasons given for the endemic poor postural habits are legion (Barker, 1985; Dart, 1946; 1947; Hanna, 1988; Jull & Janda, 1987; Lowen; 1969; Mandal, 1984; Richardson, 1992), all researchers ultimately agree - directly or indirectly - that what is affected in the end is that man's inherent tripartite mechanisms are not allowed to function in an integrated manner.

The human disease of malposture is purely functional, with low neuromuscular coordination and low muscular integration causing a lack of smooth, balanced movements of bodies and limbs (Dart, 1947). Feldenkrais (1985: 54) was in full accord with this when he said:

> *To have a good posture, therefore, it is necessary to be skilled in the use of the mechanism for projecting action patterns, to have a good configuration of the body segments and a coordinated smooth control of the muscles - not simply to stand in one particular way or to sit nicely.*

5.9.1 Postural imbalances due to the fear of falling and other fears

Due to the fact that man is precariously poised posturally, he is in a state of alarm as soon as he senses a potential loss of balance and responds by contracting his muscles (spastic rigidity). This leads to a habit of muscular fixation which overrides the basic righting reflexes (Dart, 1946, 1970), and also dampens muscle and joint sensations and leads to a restricted range of variation in movement - the range within which the individual feels secure.

> *So the primary fear to overcome is his fear of falling* (Dart, 1970: 32).

According to Feldenkrais (1985), a person who stands wider than necessary is doing so in order to prevent himself from falling. The infant balances himself on a wide base, and if there is a fear of falling, the habit becomes established. The reactions to falling in all onsets of fear, is that the flexor muscles are tensed and the extensors inhibited. The lowering of the head and sinking of the chest are actions to protect the body from injury and give a sense of relative security in the face of danger. According to Feldenkrais (1985) insufficient tone in the antigravity extensors is the resultant rule in bad posture.

Lowen (1994) also paid much attention to this basic fear of falling and since he considered this problem to be serious he devised an exercise to overcome this in order to overcome emotional fears at the same time. This exercise is discussed below because this procedure invariably highlights modern man`s lack of mastery over his reflex machinery and consequent intermeddling with "reflex details" (Dart, 1947), or man`s inability to allow things to happen of their own accord (Gallwey, 1974; 1976; Gallwey & Kriegel, 1977; Koizumi, 1986).
The exercise is done as follows:

- ❑ Place a rubber mat or heavy-folded blanket on the floor in order to prevent injury. The subject stands in front of this, so that when he falls, he will land on the mat/blanket. He then is requested to put all his mass on one leg, bending that knee fully. The other foot touches the floor lightly, only for balance. The person stands in that position until he is unable to maintain this position, and then falls, **but he is not allowed to *let* himself fall**. The subject should not allow to let himself self down consciously, since the subject then controls the descent. To be effective, the fall should have an involuntary quality. This is achieved by setting the mind on holding the position, then the fall will represent the release of the body from conscious control. Since most people are afraid to lose control of their bodies, this in itself is anxiety-provoking (Lowen, 1994).

Although the principle of "non action" is ascribed to Zen Buddism by many (Herrigel, 1985; Gallwey, 1974, 1976; Gallwey & Kriegel, 1977; Koizumi, 1986), studies on the control of posture and movement also emphasise the principle, which is to allow certain neurophysiological circuits to function without interference of the will (Dart, 1946, 1947; Magnus, 1926a; Roberts; 1995). "Central pattern generators" (Latash, 1998) (see Chapter 6) in the nervous system, which individually and collectively are responsible for the control of functions, such as posture, and which developed over a period of millions of years, are structures and systems imminently suitable for the control of human skeleto-muscular functions. Whether this system has adapted to modern ways of using the body (Alexander, 1996) such as sitting for long periods of time is debatable. In this respect a number of authors have noticed that poor posture and poor postural habits are pandemic in modern man, and refer to these problems as diseases of civilization (Dart, 1947; Zeller; 1982).

5.9.2 Psychological aspects

5.9.2.1 Malposture and the experience of physical and psychological pain

Plummer (1982) traced the cause of malposture to the experience of pain. The reaction to pain is muscle contraction - the body's attempt to form an armour to protect itself from pain. When pain is experienced biomechanically significant points come under stress and the receptors at these sites send off signals which are carried to the thalamus and limbic system, where endorphins and other neurotransmitters are liberated, resulting in a blockage of nociceptive impulses at the synapses and lack of pain perception. The effectiveness of this mechanism depends on the amount of available neurotransmitters and the extent of muscular armouring. If, during the healing phase, the full range of movement of all the tissues and structures involved is not carried out, then new lines of biomechanical force resulting from an abnormal resting position, cause reorganization and laying down of connective tissue. The tissue is laid down according to the direction of lines of stress to which it is being subjected. This results in fascial adhesions at the biomechanically significant points and are known as neural points or trigger points. The trigger points thus developed in the affected muscles perpetuate the armour and may exhibit a localized stretch reflex initiated by the biomechanically incorrect resting position of the muscle. Signs of unresolved physical trauma develop in this way and muscle imbalance results. Former painful sites continue being protected to the detriment of the person (Plummer, 1982).

Psychological trauma evokes certain patterns of muscular contraction (Hanna, 1988; Lowen, 1994; Painter, 1986; Plummer, 1982). The particular pattern depends upon the particular causal factor, sometimes it may be fear, sometimes aggression. The new resting positions of the muscle groups involved result in the development of new lines of biomechanical force with increased stress at biomechanically significant points. The result is the same as that of physical trauma described in the previous paragraph.

Plummer (1982) concluded that muscle imbalance or malposture is due to the accumulative effects of unresolved trauma whether it be physical or psychological. This is in total accordance with the theories of Lowen (1994) and Reich (Wilson, 1982). The physical characteristics of muscle imbalance will be discussed in section 5.9.7.

Another way of explaining malposture and unresolved traumas, is via the withdrawal reflex or startle pattern/response (Hanna, 1988; Jones, 1979). This is a total reflex involving the relation between the head and the trunk and is a primitive reflex of survival which is present in all mammals. (Even very simple organisms rapidly withdraw from threatening stimuli). This reflex action is elicited by a sudden loud noise and the sequence of events is as follows: Within 14 milliseconds the muscles of the jaw begin to contract; 20 milliseconds later the eyes and brow contract and at 25 milliseconds the *trapezius* and *levator scapulae* contract, raising the shoulders and bringing the head forward; at 60 milliseconds the elbows bend and then the hand turn palms downward. The descending neural impulses continue by contracting the abdominal muscle, bringing the trunk forward, pulling down the rib cage and stopping the breathing. This is followed by bending the knees, rolling the feet inward and lifting the toes up. This flexed, crouched position is the body's withdrawal from danger. Jones (1979) found that the startle pattern contained elements of extension as well as flexion and that the response begins with extension.

The impulse originates in the brain stem and reaches the muscles of the head region first before cascading down the nerve pathways to the lower parts of the body. The withdrawal reflex is more primitive than voluntary actions and is much faster. It happens before it can be consciously perceived or inhibited and is a basic neuromuscular response to stress. This is a protective response to negative stressors (Hanna, 1988). The startle response serves also as a model for other slower response patterns such as fatigue, anxiety, fear or pain which show postural changes similar to those of startle (Macdonald, 1998).

5.9.2.2 Psychological problems

> *There is a compelling propensity for most individuals to seek some sort of kinaesthetic satisfaction from frequent and unnecessary bodily movements, all of which bring about a measure of flexibility in the conformation of the body-image. In part at least this may be regarded as a sort of play - ie, the*

> *execution of movements for their own sake* (Critchley, 1950: 336).

> *Under the influence of tonic posture exercises the required level of vigilance and attention is sustained, operative memory is optimized; at monotonous kinds of work the development of the state of monotony is eliminated or slowed down; during the work with nervous tension unnecessary, excessive, unproductive nervous tension is reduced* (Briedis, Jurévics & Kaskina, 1978: 58).

Postures of sadness, aggression and fear are familiar to all, and are of a transient nature. Deep seated psychological problems such as depression and schizophrenia may also be detected in the person's posture (Barker, 1985; Lawson-Wood & Lawson-Wood, 1977; Lowen, 1971, 1994).

Self-image probably translates into posture. Positive and negative beliefs about the self form the basis of self-image and are the result of past experiences including thoughts and performances. Just as subliminal motor movement takes place during visualization of a physical performance, muscular contraction may result from a mental state. Mental practice to improve a specific skill imprints the mind, nervous- and muscular system with a blueprint of how to do the skill (Curtis, 1991). A blueprint for faulty posture may also develop if a habitual muscular contraction accompanies a certain emotion/mental state.

Kiernander (1956: 668) emphasised the relationship between posture and mood, and the necessity of recognising its importance:

> *An individual's mood is shown in his posture: The erect carriage and speedy movements of the happy person is shown at one end of the scale while the depressed or melancholy patient, with his drooping posture and retarded movements, is an example at the other end.* ***Before going into the other factors in***

> ***postural defects, this side must always be explored fully, inasmuch as even a temporary psychological upset will very frequently produce a deterioration in posture.*** *The child who has an unhappy home or is unhappy at school, or even one who has had a conflict with his family, friends or colleagues at work, will show this in a variety of postural defects, and unless the psychological difficulties are corrected he will not improve* (emphasis that of the present author).

Briedis *et al.* (1978) suggested the use of postural exercises in order to optimize the neurodynamics of the central nervous system, and by doing so reduce unproductive nervous tension.

5.9.3 Habituation

Constant repetition of a response leads to habituation. When someone exhibits any or all of the postural distortions of the withdrawal response, the posture has been imprinted in the neuromuscular system by habituation and the person has become maladapted in his neuromuscular habits. This can happen at any age, even in childhood (Kiernander, 1956), but the dowager's hump, round shoulders and bent knees always have the appearance of old age (Hanna, 1988).

In humans the startle reflex has a graded amplitude of response and the response can be low to very high. Initial fear or anxiety can cause a higher startle reaction or trigger the startle response more easily. In addition, the human neuromuscular system has the ability to adapt to a higher level of muscular tension, triggered by the withdrawal response. The chronic tension in the muscles lead to what Hanna (1988) calls sensory-motor amnesia and he designed his "Somatic Exercises", based on the work of Feldenkrais (1972; 1985), to reduce the effects thereof.

Dart (1947, 1950), similarly, developed a series of posture improving exercises. These, and other exercises will be discussed in Chapter 7 (Table 7.1 and sections 7.2.1-7.2.9).

5.9.4 Posture and fatigue

Feldenkrais (1985) was a great advocate of mono-motivational movement, declaring that parasitic movements cause unnecessary fatigue. Fatigue causes uncoordination, excessive movements and thus more fatigue. According to Cohen-Nehemia (1983) frequent body movement involving the pelvis release a defence mechanism in the body which prevents excessive muscle contraction by a timely release of the contracted muscle. Keeping the head in the balanced position and practising muscular inhibition, and inhibition of parasitic movements, reduces the occurrence of fatigue (Jones, 1965; Jones & O'Connell, 1958, Jones, Gray & Hanson & O'Connell, 1959).

Kubíček and Kubíčkova (1965) advised against the habit of keeping a group of muscles in the same position for a great length of time, since they tire easily, and the spinal column is deformed by the mass of its own body. Muscular exhaustion may lead to a more convex shape in the lumbar region of the spine, and this could cause a permanent deformity of the spine.

5.9.5 Affectation

There are fashions in posture as in any other cultural event. Prominent or admired public figures with a high profile often have their postures and mannerisms imitated. This is usually done unconsciously and is of a passing nature. It follows the same pattern as people in empathy with each other during a conversation mirroring each others gestures. Young people do sometimes voluntarily imitate a hero figure in order to be like the person if they look like the person. Any affectation, if performed long enough, may become a permanent habit (Barlow, 1990; Lawson-Wood & Lawson-Wood, 1977; Pease, 1981).

5.9.6 Habit

Physical habits may have many origins, both physically and psychologically. They are usually the result of occupational strains and stresses brought about by performing a certain task excessively. Examples are the dentist's rounded shoulders and the soccer player's bandy legs (Barlow, 1990; Cailliet, 1995; Lawson-Wood & Lawson-Wood, 1977; Phelps *et al.*, 1956).

5.9.7 Muscle imbalance

5.9.7.1 The concept of muscle imbalance

> *As far as body mechanics and joint protection are concerned, muscle imbalance probably presents a much greater danger for the joint system than muscle weakness alone* (Janda, 1993: 87).

> *.....we consider one of the main causes of the development of dysfunction and later degenerative joint lesions, in particular the vertebrogenic type, to be the impairment of central motor regulation resulting in defective or at least uneconomical movement patterns. As a consequence, imbalance between certain muscle groups develops. This imbalance is developing systematically and regularly and can even be predicted. In our opinion the discovery of this systematic reaction is the basis of a really solid, thorough and rational approach to preventive as well as therapeutic methods* (Janda & Schmidt, 1980: 3).

Barker (1985) and Lowman (1958) are of the opinion that muscle imbalance is the cause of poor posture. The strength-balance ratio between the trunk-flexor and trunk-extensor muscles, for example, was found to be an especially important variable in the alignment of the trunk and of the contribution of the trunk to anterior-posterior posture (Hutchings, 1965). The issue of muscle imbalance was recently reviewed by Janda (1993), Jull and Janda (1987) and Richardson (1992).

In 1964 Janda (cited by Janda, 1993) defined muscle imbalance as an impaired relationship between those muscles which are prone to develop tightness and shortness, and those muscles which are prone to inhibition. Under the term muscle imbalance, therefore, Janda (1993) was of the opinion that at least three factors should be considered, namely: Muscle length, the irritability threshold of specific muscles and altered recruitment of these muscles. An example of how factors such as these can influence posture is seen in the common collapse of the front of the body, and its concomitant tightening of the pectoral muscles, the pulling down of the head, and its associated tightened neck and upper *trapezius* muscles (Macdonald, 1998).

Sahrman (1987) considered muscle imbalance to be a failure of the agonist-antagonist relationship, and is present when one of a synergistic pair of muscles predominates during movement, or in the maintenance of posture. Richardson (1992: 127) agreed with this when he stated that:

> *The term 'muscle imbalance' represents a specific problem of movement dysfunction. One concerned with inadequate control and co-ordination of muscles for the protection of joints and surrounding structures.*

A typical example of muscle imbalance would be the common phenomenon of rounded shoulders, in which muscles such as the pectorals will be shortened and their antagonists lengthened and weakened.

Muscle imbalance has its root in the fact that many different muscles are capable of producing similar movements due to their anatomical location. A division between functional work exists between synergists, with some designed primarily for a stability role, while others, due to their anatomical and biomechanical features, are more suitable for the execution of so-called "goal directed" movements (Richardson, 1992).

Muscles tend to react by overactivation and tightening or by inhibition. The way in which muscles tend to react appears to be fairly consistent for the particular muscle concerned. Therefore tightness or weakness may vary in degree between subjects, but rarely in distribution (Jull & Janda, 1987). So, for example, do muscles which span more than one joint, show a tendency to become tight. In general, muscles which are prone to tightness are approximately one third stronger than those prone to inhibition (Jull & Janda, 1987). The underlying mechanisms of these muscle reactions are not known, but it is interesting to note that the typical muscle responses seen in malposture and joint pathologies are identical or very similar to those seen in lesions of the central nervous system (Janda, 1977 - cited by Jull & Janda, 1987). A typical hemiplegic posture may be an extreme expression of the imbalance between the muscular chains that exist to some extent under normal physiologic conditions (Jull & Janda, 1987).

One of the underlying causes of muscle imbalance is an impairment in control of the motor system (Jull & Janda, 1987; Richardson, 1992). The lifestyle activities of modern man tend to favour the use of multi-articular muscles. In the upright posture, for example, there is a tendency to rely more heavily on ligamentous support than on active muscle contraction. This leads to a rearrangement of the working muscles in response to the gravitational effect. An illustration of this is seen in anterior pelvic tilt where the supporting role is taken over by a two jointed muscle - the *tensor fascia latae* rather than the *gluteus medius* (Richardson, 1992). In working situations or sports increasing the speed of repetitions may also favour the movement synergist with less activation of the stabilization synergist (Richardson, 1992). Several other factors, such as lack of adequate sensory input, unreliable sensory appreciation, lack of variety in movement, arthrogenic inhibition, stress, emotional states and fatigue and poor postural habits, contribute to demonstrable changes in muscle tone, which is accompanied by poor quality of posture and movement and its control (Alexander, 1932, 1996; Cailliet, 1995; Janda, 1993; Jull & Janda, 1987; Lowen, 1969, 1971, 1975, 1994; Rolf, 1977). A question that arises from the above argumentation, is whether muscle imbalance and muscle armouring (discussed in Chapter 7, sections 7.2.1 & 7.2.2 and Figure 7.1) are not intimately related entities.

The significance of muscle imbalance, as far as posture is concerned, lies in its influence on the motor patterning process. A tightened muscle, for example, can influence posture and movement in several ways. The irritability threshold of tight muscles is lowered, which can lead to the situation where the tight muscle is activated more than is necessary (Jull & Janda, 1987).

With continued disuse the slow twitch muscle fibres in muscles with a prime antigravity/stability function undergo change to eventually resemble fast twitch fibres. In man exposing antigravity stability muscles to inactivity leads to decreased slow twitch (tonic) function, which is illustrated by either a decrease in the number of slow twitch fibres, a relative increase in IIB muscle fibres or faster contraction speeds (Richardson, 1992). This could possibly explain the weakness seen in postural muscles of those with poor postures (see Table 5.1 for example).

5.9.7.2 Syndromes involving the muscles

Jull and Janda (1987) identified three syndromes involving the musculature - syndromes which may affect posture locally and in general. These are:

- ❑ Common syndromes

The tendency of muscles to respond by overactivity and tightness or by inhibition is not random, but follows a set pattern according to Jull and Janda (1987). Also, muscle reactions do not remain in one region, but may facilitate a chain reaction, which eventually can affect the whole tripartite system, thus affecting total posture and movement.

- ❑ The pelvic crossed syndrome

Muscle imbalance tends to be more evident or starts to develop in two regions, namely the pelvic-hip complex and the upper quarter (shoulder-neck region). The former is characterised by the imbalance between shortened and tightened hip flexors and tight lumbar *erector spinae*, with weakened gluteal and abdominal muscles. Frequently the hamstrings are found to be tight, probably in an effort to lessen forward pelvic tilt. The muscle imbalance found in pelvic crossed syndrome promotes a forward pelvic tilt, increased lumbar lordosis, and a slightly flexed position of the hip. If the lordosis is deep and short the imbalance is principally located in the pelvic musculature. On the other hand, if it is shallow, but longer, as well as extending into the thoracic area, the muscle imbalance is more marked in the muscles of the trunk.

In the upper quarter this syndrome will be associated with shortened and tightened upper *trapezius, levator scapulae, sternocleidomastoid* and pectoral muscles, with weakened *rhomboid,* short cervical and lower *trapezius* muscles.

The pattern of muscle imbalance should be viewed not only from its ventro-dorsal crossed antagonist pattern, but also from the relationship between adjacent muscles. So, for example, will overtightness in the *erector spinae* associated with weakened *glutei,* alter the pattern of a fundamental gait pattern, such as hip extension.

Postures resulting from these imbalances can change the force distribution in both the lumbar motion segments, the hip joint and the upper quarter. In the erect posture, an increase in the forward pelvic tilt and associated lumbar lordosis results in a change in the posture of other areas in order to maintain postural equilibrium. An increased thoracic kyphosis leads to a compensatory cervical lordosis in an effort to balance the upper structure against gravity and to keep the head and eyes in an upright position. The way in which postural equilibrium is maintained in different individuals with muscular imbalance will be discussed in Chapter 8 (sections 8.2 & 8.3). Approaches and methods designed to deal with this problem is discussed in Chapter 7 (section 7.3.8.4).

- The layer syndrome

Marked impairment of motor control is associated with this form of muscle imbalance; an imbalance which is accompanied by poor movement patterns. This syndrome is characterized by alternating "layers" of hypertrophic and hypotrophic muscles, in which a layer of hypotrophied muscles in a body segment is alternated with a layer of hypertrophied muscles in an adjacent body segment. These "layers" are best observed from the dorsal aspect of the subject (Janda & Schmidt, 1980). These are listed in Table 5.1.

Table 5.1 Alternating layers of hypertrophied and hypotrophied muscles in subjects with layer syndrome (Jull & Janda, 1987)

Body segment	Muscle hypertrophy	Muscle hypotrophy
Cervical	Cervical *erector spinae*, upper *trapezius, levator scapulae*	
Shoulder girdle, upper thoracic		Lower stabilizers of the scapula
Thoracolumbar	Thoracolumbar *erector spinae*	
Lumbosacral		Lumbosacral *erector spinae*, *gluteus maximus*
Lower limbs	Hamstrings	

Inherent to the layer syndrome is poor muscular stability in the lumbosacral region, which could predispose to the development or perpetuation of low back pain (Jull & Janda, 1987).

Apart from the muscle hypertrophy and hypotrophy in the dorsal musculature listed in Table 5.1, there is also weakness of the abdominal muscles, particularly of the rectus abdominis and the *tranversus abdominus.* Contrary to this, the oblique abdominals appear to be overactive.

5.9.8 Clothing

Shoes are notorious for having a bad effect on posture. So, for instance are high heels responsible for an increase in lumbar lordosis (Twomey & Taylor, 1987; Wikler, 1980). Wearing of tight clothes prohibits proper rotation in the hip joint when seated (Barker, 1985; Cohen-Nehemia, 1983).

5.9.9 Sedentary lifestyle

Certain hollow-backed car seats force destructive slouching if a person sits sitting for long periods of time in a car. Passive entertainment (television), training (lectures) and sedentary employment bring about long hours of physical inactivity and sitting on poorly designed furniture (Cohen-Nehemia, 1983; Mandal, 1984), both leading to muscle imbalance and muscle weakness (Richardson, 1992) (see section 5.9.7.1).

5.9.10 Standing for prolonged periods

Standing for a long time tends to produce an increase in the lordosis of the lumbar spine as postural muscles begin to tire and as the slow "creep" of the soft tissues often emphasises the natural tendency towards extension of this region. Since most individuals tend to lean forward (Woodhull *et al.*, 1985), this is a problem in most individuals, because their line of gravity is put in front of the sacral promontory. The effect of gravity pulling through this centre tends to pull the lumbar spine into a more lordotic posture in those individuals (Twomey & Taylor, 1987).

5.9.11 Congenital deformity

Deformities acquired during foetal development are present at birth and usually need surgical intervention (Goldthwait *et al.*, 1952; Lawson-Wood & Lawson-Wood, 1977; Phelps *et al.*, 1956).

5.9.12 Injury

This covers a wide spectrum from an insignificant bruise to an amputation. Any injury leaves scar tissue which causes a degree of immobility in the area. Psychological injury has much the same effect (Lawson-Wood & Lawson-Wood, 1977; Lowen, 1994).

5.9.13 Illness

Chronic or acute diseases, for example, of the chest or bones usually have an effect on posture (Barker, 1985; Goldthwait *et al.*, 1952; Lawson-Wood & Lawson-Wood, 1977).

5.9.14 Accumulation

Postural defects are sometimes due to a succession of trivial and insignificant minor causes. The totality becomes important (Lawson-Wood & Lawson-Wood, 1977).

5.10 CONCLUSION

Posture is the appearance and use of the body. The ideal posture would be perfect vertical alignment, and a balance between all synergic muscle groups (Alexander, 1996; Barker, 1985; Rolf, 1977). This would lead to a perfect carriage as well as optimal functioning of all body organs and systems. Unfortunately body misuse is a common phenomenon and an inhibiting factor in smooth functioning of the body. Overcoming postural defects might lead to releasing the human potential and providing a more comfortable body which functions efficiently (Barlow, 1990; Dart, 1946, 1947).

A large number of factors are singly or jointly responsible for the common malaise of malposture (see sections 5.9.1-5.9.14). So, for example, is it possible that some psychological problem be responsible for the phenomenon of muscle imbalance? The resultant malposture may, in turn, lead to injury, which as a consequence compounds the malposture. For the practitioner involved in the creation of total well-being this presents an interesting problem. Recognising postural defects and being aware of their origins and causes might go a long way in preventing and treating postural imbalances. Knowing the short and long term effects of such misuses of the body may also strengthen the resolve to overcome the problem (Rolf, 1977).

CHAPTER 6

THE NEURAL CONTROL OF POSTURE AND EQUILIBRIUM

6.1 POSTURAL CONTROL

The fact that human beings are able to maintain ***vertical posture*** *is in itself a miracle. One would have hard time imagining a mechanical system that is less stable in the field of gravity* (Latash, 1998a: 163).

Human beings should be able to discharge all their vital activities without their suffering from impediment of any kind whatsoever, in a state of ***poise****: with their heads pivoted on their spinal columns, and their bodies pivoted upon their feet; while their convergent eyes are so pivoted upon their objective that the entire apparatus of movement is the reflexly operating instrument of their concentrated purpose* (Dart, 1947: 90).

The mind, the emotional substratum, is reflected in posture, but many vital factors which bring about posture, work below the threshold of consciousness. Posture is one of the expressions of neuromuscular habits and any improvement in posture must be due to re-education or reconditioning of the neuromuscular pathways (Denniston, 1938).

During analysis of vertical posture, the human body can be modelled as an inverted pendulum, which is inherently very unstable, and therefore not easy to equilibrate, especially in the presence of external perturbations and changes in orientation with respect to the field of gravity. The situation, however, is made more complicated by the presence of joints along the axis of the pendulum (Latash, 1998a). The best way to deal with a situation where the area of support for a human being is small (more or less 0,09 square metre), is to stack the body segments between these joints exactly on top of each other, and to fine-tune the position between body segments (Rolf, 1977), as well as the interaction of the movement between the different joints (Latash, 1998a).

The maintenance of the vertical posture is probably the most frequent motor task that the nervous system has to deal with (Latash, 1993), aiming to keep the centre of gravity of the body directly over the centre of the basis of support (Hellebrandt & Franseen, 1943). Frequent control of posture even applies to sedentary man, where the upright sitting position in chairs has to be maintained for extended periods of time, a lifestyle which may be unnatural (Gorman, 1983). According to Latash (1993) it is reasonable to presume that the mechanism of vertical postural control is well "defended" against external perturbations. The dynamic forces during natural limb movements are more than sufficient to destroy the fragile postural equilibrium. Amazing from an engineering point of view, is the fact that this unstable multi-link (multi-joint) inverted pendulum can walk and run, on even, uneven or undulating surfaces (Latash, 1998a). The implications of this are that in upright multi-link man, multiple goals have to be controlled simultaneously by the nervous system to maintain the selected static and dynamic posture.

A central issue in postural research at present is the coordinated nervous control of posture and movement (Latash, 1998a; Massion, 1992; Massion, Alexandrov & Vernassa, 1998). For postural control Nashner and McCollum (1985) proposed the existence of a repertoire of **postural synergies**[1], which are based mainly on the biomechanical characteristics of the multi-link chain. Specific postural synergies exist for the control and maintenance of the upright posture,

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[1] Nikolai Bernstein, the first scientist to work in the area now known as motor control (Latash, 1998b), was the first to initiate the concept of **synergies**, which are built-in **coordinated** combinations of motor commands to a number of joints or body segments leading to a desired goal. Synergies were viewed by Bernstein as building blocks for movements that could be scaled and **combined** according to a particular motor task. Nashner and McCollum (1985) defined muscle synergies **as the contraction of muscles in stereotyped patterns.** The presence of synergies is assumed to simplify the control of, and to diminish the computational burden associated with the control of vertical posture (Latash, 1998a) and voluntary movements in multisegmented limbs (Rymer, Dewald, Given & Beer, 1998). This is achieved by constraining a group of muscles, often spanning several joints, to **act as a single functional unit** or coordinative structure.(Tuller Turvey & Fitch,. 1982).

or its correction in the event of external or internal perturbations. Once a perturbation is felt, a specific postural synergy will be triggered in order to restore the initial posture, or to preserve the antero-posterior position of the centre of mass (Nashner & McCollum, 1985). Some of the postural synergies are discussed in section 6.3.

The execution of a motor task requires a combination of information from the senses regarding the movement. When standing upright, for example, knowledge of eye and head movements is essential to interpret visual motion information correctly. Additionally, the scheme for combining information from different sensory modalities has to take into account that each of the sensory modalities, senses body orientation to a different reference point, and that individual orientation points of reference can move in relation to one another. Postural control and orientation of the body in relation to the outside environment, and its segments in relation to each other, require integration and correct interpretation of information from various sensory sources (Latash, 1998a; Massion *et al.,* 1998; Nashner & McCollum, 1985). Malposture, induced either by sensory dysfunction (Alexander, 1987; Sherrington, 1946), or by inadequate stimulation, arises from an intersensory mismatch, with information from one system at variance with the others. The intensity of malposture is a function of the magnitude of the mismatch and is further increased if appropriate afferent information is eliminated, such as eye closure with an acute unilateral labyrinthine lesion (Lestienne & Gurfinkel, 1988). In a society characterized by malposture, the quality of the sensory awareness, and that of the integration of sensory input are questionable (Alexander, 1932, 1996; Feldenkrais, 1972, 1985; Sherrington, 1946). This may contribute to intersensory mismatch.

Postural control and maintenance can be accomplished through a complex anti-gravitational neuromuscular system based on integrated information from the proprioceptive, vestibular and visual systems (Lestienne & Gurfinkel, 1988). These systems overlap, which enables them to compensate partially for mutual deficiencies. Nashner, Black and Wall, (1982) assumed a dominant hierarchical influence of the vestibular system, this serving as a fixed orientation reference while vision, in normal subjects, subserves fine tuning of posture on the basis of the vestibular reference value within this multiloop-control (Paulus, Straube & Brandt, 1984).

Man will lose balance only if none of the three systems works correctly, or if the information given by the three systems is in disagreement. If one system functions at a lower level, the other systems usually take over the function of that system (Kapteyn, 1973).

6.2 NEUROMUSCULAR-SKELETAL CONTROL OF THE UPRIGHT POSTURE FROM A PALEO-ANTHROPOLOGICAL PERSPECTIVE

> *From the phylogenetic point of view, one would say that only movements able to take advantage of the enormously elaborate analysis of tactile messages provided by the development of the somatosensory cortex ascended during evolution to the motor cortex, while movements that work just as well without sophisticated tactile regulation (such as eye movements) maintained their centres at the older, lower levels of the central nervous system: i.e. the vestibular nuclei, reticular formation, and red nucleus; all three receive afferents from the cerebellum and the last two from the basal ganglia* (Kornhuber, 1974: 611).

In order to understand the gradual evolvement of the vertebrate nervous system to what it is today, a brief explanation of some terms used in neurophysiology is necessary.

6.2.1 Muscle synergies and Central Pattern Generators

Muscle synergies have already been discussed in the footnote on page 163. These muscle synergies are controlled, as far as stereotyped muscle acts are concerned, by Central Pattern Generators (CPG's) in the spine (Grillner & Wallén, 1985; Latash, 1998a). The neurons responsible for creating a particular motor pattern are referred to as a CPG. The term CPG rather refers to function and not to a circumscribed anatomical entity (Grillner & Wallén, 1985). Separate CPG's exist for each limb (for example the positive supporting reaction, section 6.3.2.1.1), and for the separate parts for the trunk. CPG's may be combined in different ways in order to create required musculoskeletal responses. In this respect they are under the control of higher control systems (Grillner & Wallén, 1985; Kornhuber, 1974). CPG's and CPG control systems are found both in lower and higher centres of the central nervous system (CNS) (Grillner & Wallén, 1985; Kornhuber, 1974). An example of such control is the regulation of the different limbs and trunk in the asymmetric tonic neck reflexes, discussed in section 6.3.2.3.2 - the action of each individual limb being controlled by a CPG, while integration of these GPG's are dealt with by control systems in the brain stem (Fukuda, 1961; Kornhuber, 1974; Magnus, 1926a,b).

The upright human body is made up of various segments, each controlled by its own CPG (Grillner & Wallén, 1985). The actions of the CPG's involved in the control of upright posture, can be envisaged being integrated (connected), or alternatively fractionated (disconnected), by means of higher control or interference by the will (Alexander, 1932). Upright posture in man is phylogenetically a new development (Chapter 3). Does the control of man's posture need a large sensory input and sensory cortex? Alexander (1932, 1941, 1987, 1996) and Feldenkrais (1985), by way of their practical experience, thought so, which is why they so strongly emphasized the importance of sensory awareness. Whether their opinions can be validated by research is a question that needs to be answered.

6.2.2 Evolvement of movement control

As vertebrates evolved from fish, with their simple undulating body movements, (described in Chapter 3, section 3.3.2.8), to the human, with the ability to perform delicate and intricate movements, such as those with individual digits, the more integrated the function of the nervous system had to become. Lower vertebrates tend to use their limbs in "whole limb" synergies involving mainly flexion and extension muscle synergies. The more evolved the animal, in the phylogenetic sense, the more versatile the tripartite motor system tends to be. This increased versatility eventually led to an adeptness in the fractionation of the motor pattern of the whole limb synergy. This development gradually took place in phylogeny from an independent control of the large joints to a precise control of the individual segments as is found in primates (Grillner & Wallén, 1985). (During ontogeny the reverse happens in the human infant, however). Development of precise motor control probably occurred in conjunction with the development of the somatosensory cortex, which in turn was associated with the elaboration of the analysis of tactile messages (Kornhuber, 1974).

The descending control over the segmental apparatus in lower tetrapods is relatively stereotyped, but a more refined motor control developed gradually during evolution. Descending motor systems gradually acquired a more specific control over parts of the spinal circuitry. In the primate, for example, the corticospinal tract, which is responsible for muscle synergies controlling independent finger movements, is well developed, while another descending tract, the rubrospinal, is associated with independent wrist movements (Grillner & Wallén, 1985; Lawrence & Kuypers, 1968a,b). Phylogenetically older descending tracts, such as the reticulospinal, which originate in the brain stem, are responsible for the control of muscle synergies in proximal parts of the limbs and that of the trunk (Lawrence & Kuypers, 1968a,b); the latter structures in primates also receive some corticospinal input (Williams & Warwick, 1980). The refined precision movements would thus use part of the old segmental motor apparatus (lower level CPG controllers), which in turn provide ready-made modules for activation of appropriate motor nuclei in the spinal cord and suppression of others.

The single limb, segmental and general control of the upright posture is discussed in section 6.3.2. In quadrupeds standing is dependant on CPG's and their integrative control from centres in the brain stem (Magnus, 1926a,b). Because of this, standing can be maintained for extended periods in animals with only the brain stem and spinal column intact (Magnus, 1926a,b). Humans, on the other hand, require an intact neocortex in order to stand upright (Latash, 1998a), despite the fact that human CPG's have access to control centres in the brain stem (Bobath, 1980; Fukuda, 1961; Gowitzke & Milner, 1988).

In the quadruped the trunk is supported between the four supporting limbs, and therefore does not fulfil a postural role. In upright man, however, the head and trunk are balanced upon only two limbs (Gorman, 1981). The spine is made up of a number of relatively freely moving segments (vertebrae) (Gorman, 1981). Each of these segments' position is probably controlled by its own CPG. In the more primitive CPG control systems of the brain stem, provision has not been made for integration of the function of these structures, and this function therefore had to be assigned to newly evolved neural systems - systems solely associated with upright man. Systems like these can only be accommodated by the newly developed neocortex with its extensive sensory input, and its extended ability to integrate functions of CPG-controlling centres in the brain stem, as well as CPG's in the spinal cord [see Kornhuber (1974), for example].

6.3 THE REACTIONS (REFLEXES) RESPONSIBLE FOR MAINTENANCE OF POSTURE

6.3.1 Introduction

For the maintenance of posture, appropriate forces must be exerted at every single joint which compromises the articulations of the skeleton. At the same time, the mass of the soft parts has to be appropriately suspended from the bony framework. Often the necessary forces are developed reflexly in response to the deformations that arise from the interaction between the effect of gravity and the nature of the available support (Roberts, 1978; Rolf, 1977).

Changes in posture are due to differences between the relative sensitivities of the stretch reflexes in the various groups of muscles. Thus a change in the angle at a particular joint may be produced by altering the reflex sensitivity in one of the muscles acting at that joint, or by increasing reflex sensitivity in one muscle, or decreasing it in the antagonist, or by making the two changes simultaneously (Roberts, 1982).

To maintain a stable posture during movement and the presence of perturbations the orientation information provided by the senses must be sufficient to accurately detect the position of the body, body part, environmental conditions and how the body relates to them, or the occurrence of a perturbation in posture (Alexander, 1996; Nashner & McCollum, 1985). This will determine the magnitude and direction of the postural reaction/correction. The orientation information is contributed by a combination of the three independent sensory modalities, proprioception (somesthesis), the vestibular system and vision. Since each of these modalities senses the orientation of the body or its parts in relation to a different internal or external reference, there is a potential continuum of different sensory input combinations that may contribute to the required orientation information (Nashner & McCollum, 1985), and a great possibility for conflicting and confusing interpretation of sensory input by the brain, which may arise from a defective kinaesthetic system (Alexander, 1996).

6.3.2 Somaesthetic (proprioceptive) reactions

These can, according to Magnus (1926a), be classified into local, segmental and general postural reactions. This arrangement fits in well with the recent concepts of how postural and other reactions are organized in the nervous system (Grillner & Wallén, 1985; Massion *et al.*, 1998; Nashner & McCollum, 1985). These reactions will be discussed briefly in sections 6.3.2.1-6.3.2.3.

6.3.2.1 Local postural reactions

Local reactions are those in which only one part of the body, for example the limb, is used (Magnus, 1926a,b).

6.3.2.1.1 The positive supporting reaction

To support the body in an upright standing position requires each of the limbs to act as quite a rigid pillar, a feat which is accomplished when all the joints in the limbs are fixed to a small extent by ligamentous support, but mainly by means of coactivated muscular action at each of the joints in the lower limb (Magnus, 1926a). The latter action is brought about by muscle synergies which cooperate in order to fix the joints in the supporting limb. The muscle synergies responsible for this are elicited by a specific complex stimulus situation. When the foot is placed on the ground, the distribution of forces in the inter-phalangeal joints of the digits alters in a characteristic way and the small *interosseus* muscles between the digits are stretched by the splaying of the foot. Certain combinations of these stimuli appear to be recognized by the spinal cord as signalling that the foot is in contact with a suitable support, and the appropriate stretch reflexes are facilitated so that the limb is converted to a fairly rigid pillar capable of supporting the mass of the body (Magnus, 1926a; Roberts, 1982, 1995). This phenomenon is known as the positive supporting reaction. Receptors in the skin are not essential for eliciting the reaction, nor is consciousness involved, and the supporting surface need not be uniform or smooth (Roberts, 1969, 1982). In the spine the positive supporting reaction is probably controlled by means of a CPG.

For the pressure on the foot to be classified as indicating the presence of an acceptable support, it is necessary that the information from other parts of the limb should conform to a particular pattern of change during the onset of the reflex contraction of the extensor muscles. If the pattern deviates in one direction, a stepping response is elicited instead of a supporting reaction (Roberts, 1978).

In the standing quadruped, for example, the positive supporting reaction elicited in all four limbs serves to support the trunk. The upright human, on the other hand, has to deal with the control of structures in the trunk which have to be supported one on top of the other (Chapter 3, section 3.4) in a similar way to that seen in the lower limbs. How and from which centres in the CNS this is controlled is an open question.

6.3.2.1.2 The negative supporting reaction

This reaction is the opposite of the positive supporting reaction, and is elicited by simply removing the stimuli responsible for evoking the positive reaction or the plantar flexion of the foot. The reaction is seen as a reflex relaxation of the extensor muscles in the leg - in this way the whole limb is loosened and becomes free for movement (Magnus, 1926a).

6.3.2.2 Segmental postural reactions

Here the stimulus and effect are not confined to one limb, but to the opposite limb in the same body segment. Segmental postural reactions require the use of two CPG's in the same spinal segment, CPG's which are interconnected from the one side of the spinal cord to the other (Magnus, 1926a).

Hanna (1988) developed an exercise to train pupils in the correct way of walking by making use of CPG's and their segmental interconnections. Walking is divided into a vertical and a horizontal component. The former is made up of the positive supporting reaction in one leg, while in the other leg the negative supporting reaction is elicited. Support on the one leg is accompanied by an upward movement in that side of the hip, with the bending and loosening of the other leg being augmented by the lowering of the other side of the pelvis. The loosened leg is now free to execute the horizontal aspect of walking which is the forward swing of the leg.

In the author's experience this exercise has proved to be an invaluable aid in the retraining of those with postural problems, and those who cannot walk correctly, as well as retraining the head injured in how to attain balance while standing and how to start walking again.

6.3.2.3 General postural reactions

In the general postural reactions more than one segment of the body, even the whole body, is involved (Magnus, 1926a). Here different CPG's interact to produce the different types of interlimb coordination (Grillner & Wallén, 1985) used in postures assumed in response to different sensory inputs. The system is probably organized in the same way as depicted in Figure 6.1.

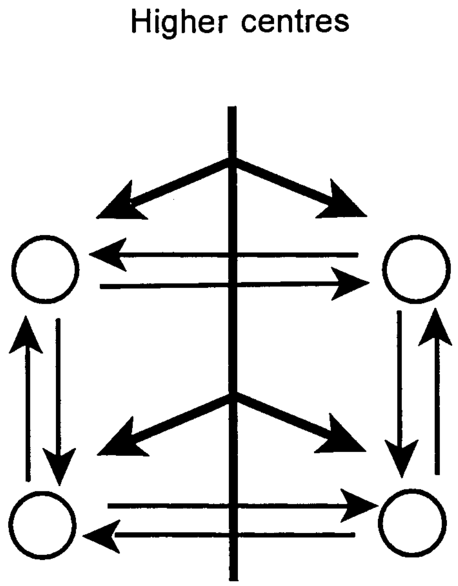

Fig. 6.1 Interaction between CPG's of the four limbs (Grillner, 1975; Grillner & Wallén, 1985).

6.3.2.3.1 The neck as a receptor

> *The importance of the motor system controlling head movements is obvious. Survival itself is often dependent on brisk orientation reflexes in which the head and eyes can be brought to bear on*

any new or unexpected stimulus. This action permits rapid analysis which initiates the appropriate behavioural response. The provision of a stable platform for the eyes is equally dependant upon the functioning of the head motor system. The motor physiologist who is concerned with the operation of the head motor system finds that these obvious functional roles are subserved by a system full of interesting specializations. Some parts of the system also play a much wider role in the regulation of posture. This wider role is clearly expressed in the function of the sensory apparatus of the neck (Abrahams, 1981: 24).

The neck as a receptor has long been an important concept in neurophysiology (Abrahams, 1977). Early work by Magnus (1926a,b) has shown that certain reactions (tonic neck reaction or reflexes) are due to the activation of receptors in the neck. The rich sensory innervation of the neck is a reflection of its role in proprioception (Taylor & McCloskey, 1988), and its importance in the elaboration of reflexes controlling the posture of the limbs and the trunk (Roberts, 1978). Aberrations in neck sensation can cause vertigo and disorientation (Cohen, 1961).

The major part of the sensory input from the neck is concerned with sensory receptors in the small intervertebral muscles and in the long muscles of the neck. These muscles contain relatively high densities of muscle spindles, Golgi tendon organs and Pacinian corpuscles (Abrahams, 1977, 1981; Richmond & Abrahams, 1975), with the intervertebral muscles extremely densely populated with muscle spindles (500 spindles/g muscle tissue) (Abrahams, 1981).

Information from these receptors goes to the first and second segments of the cervical spine (Magnus, 1926a). Powerful descending spinospinal tracts then interact with other areas in the spine (Abrahams, 1977). Little is known about the pathways which link sensory input to the neck and motorneurones in the spinal cord (Wilson, 1984). Integration of sensory input from the neck muscles probably occurs at medullary level in the brainstem, with the descending reticulo-spinal tracts responsible for regulation of spinal cord CPG's (see Fig. 6.1) (Wilson, 1984). According to Fredrickson, Schwarz and Kornhuber (1966) the vestibular nuclei also receive sensory input from the neck muscles.

6.3.2.3.2 The neck reactions (reflexes)

Magnus (1926a) referred to these reactions as the tonic neck reflexes. Despite its name the reflex is not purely tonic, but has phasic components as well (Fukuda, 1961; Wilson, 1984). These reflexes are present in the human at birth in a stereotyped form, and persist postnatally in compulsive form for a short period (Gowitzke & Milner, 1988). The following are typical neck reactions:

- ❑ Rotation of the head to one side causes extension of the upper and lower limbs, towards which the jaw is rotated, and relaxation of the limbs towards which the occiput is rotated - the asymmetric neck reflex. Inclination of the head towards one shoulder elicits a similar response (Magnus, 1926a).

- ❑ Dorsiflexion of the head causes extension of the upper limbs and relaxation of the lower limbs, while ventriflexion causes the opposite response - the symmetrical neck reaction (Magnus, 1926a).

In the human these reflexes become less apparent as motor development in the infant proceeds, and are no longer compulsive by the sixth to eighth week after birth (Gowitzke & Milner, 1988; Mysak, 1968). Their circuits remain intact throughout life, however, and interact with others. They have a prominent role in maintaining equilibrium in adults, as seen from the fact that surgical interference with the neck or the upper cervical nerve roots may lead to body disequilibrium similar to those seen in bilateral removal of the labyrinths (Kornhuber, 1974; Longet, 1845, quoted by Abrahams, 1981). The role of these and other primitive reactions in normal human posture will be discussed in section 6.4.6.

6.4 THE VESTIBULAR SYSTEM

Phylogenetically the primary function of the vestibular apparatus is to regulate body position, a function particularly important in organisms in which the head and body form a single unit, such as in the fish (Fredrickson *et al.,* 1966; Roberts, 1978). In higher vertebrates the regulation of body position becomes more complicated as the neck allows for a greater degree of independent head movement. Consequently, in higher vertebrates, the vestibular apparatus informs the central nervous system only with respect to head position and not that of the body (Fredrickson *et al.,* 1966).

Parts of the inner ear are associated with equilibrium. These parts are very similar in all surviving members of the vertebrates. The organ apparently evolved from the system of tubes which forms the lateral line organ still found in fishes and amphibia and has retained its original tube shape with patches of sensory epithelium in various places. The sacculus, utriculus and three semi-circular canals which make up the labyrinth are recognizable, although variable, in all species (Roberts, 1978; Romer, 1964). In the human these form the labyrinth which is imbedded in extremely hard temporal bone (Gorman, 1981).

Contained in the labyrinth of the ear, is the primary organ for equilibrium, namely the vestibular apparatus/complex. This sense organ is specialized to register the position and movements of the head in space. The information is used in the regulation of motor activity at subcortical level (Meyer, Meij & Meyer, 1994).
The combination of vestibule and semicircular canals make up the vestibular complex. The vestibule includes a pair of membranous sacs, the sacculus and the utriculus. Receptors in the sacculus and utriculus provide sensations of the effective direction in which gravity acts, as well as linear acceleration (Carpenter, 1984). Those in the semicircular canals are stimulated by rotation of the head (rotational acceleration). Together, the perceptions of the effective direction in which gravity act, linear and rotational acceleration, combine to provide the sense of equilibrium or balance (Martini, 1992).

The major contribution of the vestibular apparatus to posture is the reflex maintenance of the head and neck in the vertical position. Reflexes from neck muscles then affect other supporting muscles of the body and their reaction to change of position of the head in space. The vestibular contribution, therefore, may be measured by noting movement of the neck in relation to tilt of the body. In the normal person the neck maintains the vertical position - or may overreact away from the angle of tilt. In the case of any vestibular impairment, the neck falls with the angle of tilt (Brocklehurst, Robertson & James-Groom, 1982).

6.4.1 The semicircular canals and the orientation of the body

The orientation of a body is defined by the direction in space of any two non-parallel lines through fixed points on the body. Normally the head is in a vertical position and one of the lines of reference can be the horizontal line running through the centre of the external auditory meatus on each side of the head (Roberts, 1978).

The second reference line poses a problem because in man there are no obvious straight lines in the profile or on the skull, to serve as guides. Many points of reference have been proposed including the lower margin of the orbit, together with the upper margin of the external auditory meatus, to provide a standard plane for purpose of anthropometry. To decide on what the “normal” position of the head of man is, it is feasible to use the anatomical position of the horizontal semicircular canals, as suggested by Roberts (1978). He pointed out that when the horizontal semicircular canal is parallel to the horizon, the head is in the position characteristic for a boxer on the alert to defend his equilibrium. It corresponds to the attitude commonly used for reading or examining something held in the hand. In contrast, bringing the anthropometric reference plane into the horizontal position gives the head the unnaturally elevated attitude of a military parade (Roberts, 1978).

6.4.2 The neural pathways for equilibrium

Natural activation of canal or otolith receptors leads to a variety of responses of the head and body musculature, all tending to prevent falling and to maintain normal head position (Allum, Honegger & Pfaltz, 1989; Wilson & Peterson, 1978).

Hair cells of the vestibule and semicircular canals are monitored by sensory neurons located in adjacent vestibular ganglia. Sensory fibres from each ganglion form the vestibular branch of the vestibulocochlear nerve (N VIII). These fibres synapse on neurons within the vestibular nuclei at the boundary between the pons and medulla. The two vestibular nuclei: 1) Integrate the sensory information arriving from each side of the head, 2) Relay information to the cerebellum, 3) Relay information to the cerebral cortex, providing a conscious sense of position and movement and 4) Send commands to motor nuclei in the brain stem and spinal cord. These reflexive motor commands are distributed to the motor nuclei for cranial nerves involved with eye, head and neck movements (N III, IV, VI and XI). Descending instructions along the vestibulospinal tracts of the spinal cord adjust peripheral muscle tone to complement the reflexive movements of the head or neck (Martini, 1992).

Since the vestibular system informs the nervous system about head, and not body position, a close somato-vestibular integration exists in order to carry out the necessary coordination between head and body movement. Vestibular nuclei receive, apart from vestibular information, information pertaining to vertebral- and extremity joint movement, as well as some about the movements of the extremities *per se* (Fredrickson *et al.,* 1966).

6.4.3 Reflexes of balance

The central nervous system formulates the reflexes of balance response from information arriving from the labyrinth in conjunction with information from any other receptors. These responses include 1) acceleratory reflexes from the semicircular canals and 2) positional reflexes initiated from a variety of other reflexes, including the otolith organs in the labyrinth.

The purpose of the reflexes of balance are 1) to stabilize the direction of gaze of the eyeballs when the head moves and 2) to adjust the attitudes of the limbs and neck in order to compensate for asymmetries of the surface underfoot, as well as to stabilize the head (Roberts, 1978; Wilson & Peterson, 1978).

If the combination of stabilization and compensation fails to preserve balance, another set of responses, the "rescue reactions" are initiated at the point of overbalancing. The "righting reflexes" (see labyrinthine and righting reactions, sections 6.4.3.1 & 6.4.4) come into play after displacement, to restore the head and body toward a standard "normal" attitude (Roberts, 1978).

Higher vertebrates have a freely moving head, with the labyrinths indicating body position in conjunction with information from the neck. Therefore body position can only be stabilized if the position of the head relative to the body is taken into account. There is a conflict between the requirement for stability (mainly a specific position in defiance of external forces) and the requirement for mobility (executing movements that constitute natural behaviour). If the stabilizing mechanisms were absolute, no change in attitude would be possible - any attempt to move would be countered by reflex adjustments tending to restore the normal attitudes. If stabilizing mechanisms need to be disabled to permit voluntary movements, all benefits of stabilization are lost and loss of balance may occur (Roberts, 1978).

6.4.3.1 The labyrinthine reactions

These reactions were originally referred to as tonic labyrinthine reflexes by Magnus (1926a). These reactions are not evoked by movement *per se*, but rather by body position or inclination of the head (Gowitzke & Milner, 1988), and arise from the otolithic organs of the utriculus (Magnus, 1926a).

The supine position or corresponding orientation of the head with gravity facilitates extension in all limbs and inhibits flexion, while the prone position or head orientation result in the opposite response. Lying on the side or an equivalent position of the head induces extensor facilitation of the top limbs with reciprocal inhibition of the antagonists (Gowitzke & Milner, 1988).

6.4.4 Interactions between the neck and labyrinthine reactions

In many respects the neck and labyrinthine reactions are exact opposites (Kornhuber, 1974; Roberts, 1978, 1995) (Figure 6.2). Conflict between these reactions is resolved in the CNS so that the individual can move his head freely in any direction without altering the disposition of the trunk and limbs (Roberts, 1995). In Figure 6.3 these interactions are shown in a scheme of stick figures.

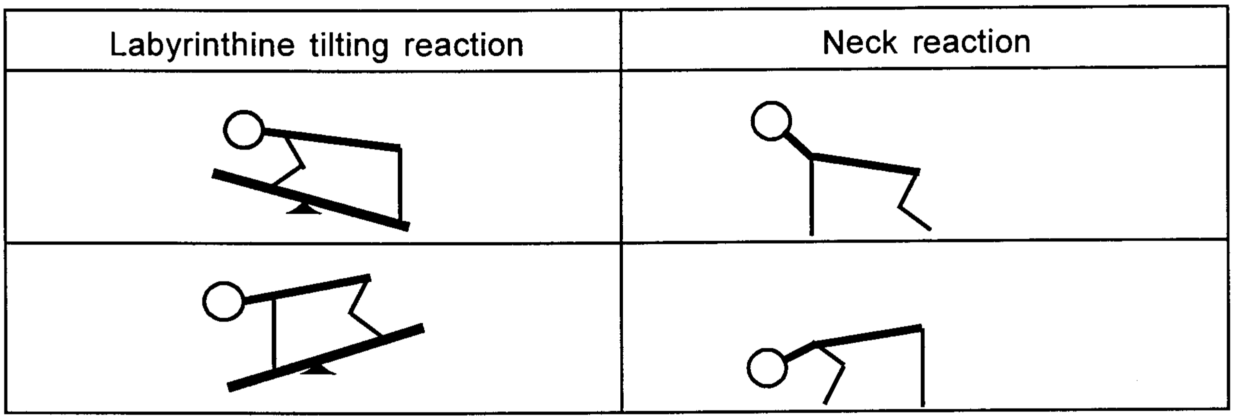

Fig. 6.2 **The symmetrical neck reflexes (responses to tilting of the head and neck) as antagonistic to the labyrinthine tilting reflexes (reactions of body in response to tilting of a platform for example) [Adapted from Kornhuber (1974)].**

When an infant's head is turned with the nose to the left, the asymmetric neck reaction will induce extension of the left arm and flexion of the right. Rapid lateral tilt with the nose turned to the left, however, causes extension of the right arm and flexion of the left. Labyrinthine reactions prevent falling during rapid tilt, while the neck reactions prevent falling due to labyrinthine reflexes, when only the head is moved (Kornhuber, 1974).

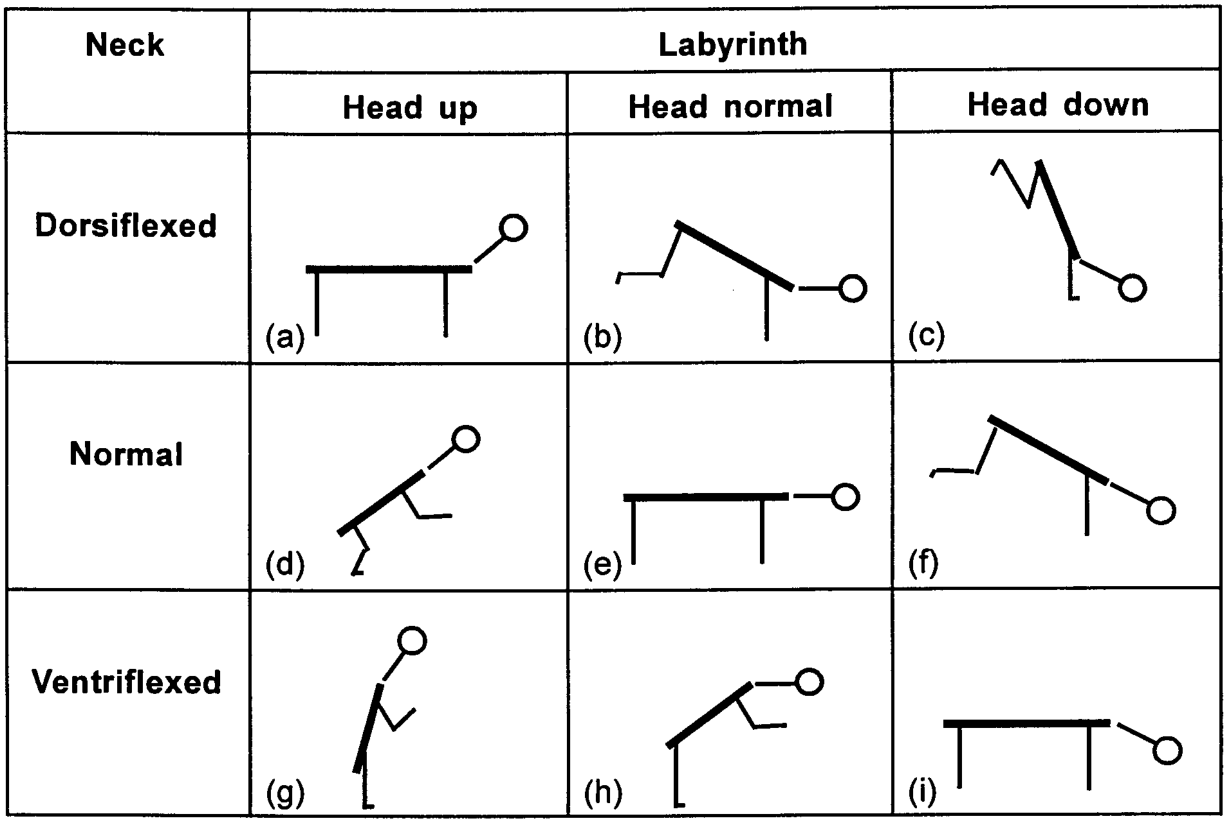

Fig. 6.3 **Scheme of stick figures illustrating the interaction between positional reactions from the neck and the labyrinths. In (g) upright man is shown, in (d) the human orthograde posture and in (e) a crawling infant. Further extension in (c) will result in a handstand (Adapted from Roberts, 1995).**

Magnus (1926a) was of the opinion that if both the neck and labyrinthine reactions are present (which in normal individuals is always the case), they cooperate so that the tone of every single muscle depends upon the algebraic sum of influences derived from the proprioceptive receptors in the neck and those from the utriculus. Kornhuber (1974) felt that Magnus (1926a) failed to appreciate the concept that the neck reactions were the exact opposite of the labyrinthine tilting reflexes (Figures 6.2 & 6.3). Von Holst and Mittelstaedt (1950) [quoted by Kornhuber (1974)] concluded that neck input must be subtracted from the labyrinthine to yield the correct signal to the motor systems in the brain stem. Integration of these two apparently conflicting inputs is probably done at brainstem level in the vestibular nuclei and reticular formation (see Figure 6.1). This interaction is shown in Figure 6.3.

6.4.5 The righting reactions

6.4.5.1 The five reactions

As growth and development proceed the labyrinthine reactions are supplanted by more complex responses - the righting reactions (Gowitzke & Milner, 1988).

In relation to gravity each vertebrate normally has a certain head and body position. When the position of the head or body changes in relation to the environment or horizon, reactions occur to enable the individual to recover the normal head and/or body position (Fukuda, 1961). This is accomplished by contraction of neck-, trunk- and limb muscles in order to raise the head and to attain the vertical posture. Five righting reactions were identified by Magnus (1926b), each serving a specific purpose. They are (Gowitzke & Milner, 1988; Magnus, 1926b):

- ❑ The labyrinthine righting reactions

These reactions provide for orientation of the head in relation to space, gravity being the controlling influence. Stimulation of the labyrinthine receptors evokes contractions of the neck muscles from a horizontal to a vertical position. These reactions may be divided into two groups: Symmetrical and asymmetrical. The former is elicited by stimulation of the receptors in the utriculus, while the latter is evoked from the sacculus.

- ❑ Body-on-head reactions

Asymmetrical stimulation of the skin receptors on one side of the body results in the activity of trunk and limb muscles, which raises the head in an upright position. Similar reactions may also be evoked, not only by stimulation of the trunk, but also from the soles and palms.

Abnormal positions of the head are corrected by these reactions, and are an indication of the importance of tactile stimulation for orientation of the head.

- Neck righting reactions

These reactions orientate the body in relation to the head. Impulses arising from the receptors in the neck produce contractions of body and limb muscles, aligning the body with the head. These reactions make it possible, by simple movements of the head, to bring the body of a large animal such as a bull to its side.

- Body righting reactions acting upon the body

The body righting reactions right the body in relation to the ground or any surface with which the body comes into contact. An example is climbing. These reactions make it possible to right the body even if the head is not in the normal position.

- Optical righting reactions

Visual feedback is used to orientate the head and body correctly to the environment.

In the attainment of the desired posture the integrity of every single factor is doubly ensured. The head is righted by labyrinthine, optical and tactile stimuli. The tactile stimuli act separately upon the body and upon the head. The orientation of the head and the body takes place in relation to the effect of gravity, the sustaining surface and to parts of the body - a very complex combination of reactions according to Magnus (1926b).

6.4.5.2 Centres for the righting reactions in the central nervous system

Centres in the CNS for the righting reflexes are found in different areas of the midbrain, with the *nucleus ruber* and its descending rubrospinal tract mainly involved in the labyrinthine and body reflexes acting upon the body. Body righting reflexes upon the head righting reactions have their centres at the same level in the midbrain, while the centres for the neck righting reflexes are found in the pons. Visual righting reactions are cortical (Magnus, 1926b).

6.4.6 The general reactions in man

In the adult the circuits of the neck and labyrinthine reactions are still intact, but they are influenced and even dominated by patterns developing later and, according to Gowitzke and Milner (1988) more useful patterns. The presence of the neck and labyrinthine reactions was demonstrated by Hellebrandt and Waterland (1962). Magnus, according to Fukuda (1961), failed to demonstrate these reflexes in normal monkeys, as well as in normal healthy adult humans as basic patterns for their daily movements. Magnus felt that in the human, these reactions were obscured by actions of higher centres, and also due to the fact that human posture differs radically from that of quadrupeds (Fukuda, 1961). With the aid of numerous examples Fukuda (1961) demonstrated the presence of these reactions in normal healthy adults. He came to the conclusion that the neck reactions form an important basic pattern which participates in the composition of momentary dynamic postures, and the righting reflexes (labyrinthine and visual) also play an important role in maintaining human postures. Alexander (1932, 1941, 1987, 1996) was well aware of this, and probably based his concept of the "primary control" (section 7.2.4.1.1.4) on the existence of these reflexes. Researchers, such as Dart (1946; 1947; 1970), Jones (1965; 1979), Jones & O'Connell (1958), Jones *et al.,* (1959), Jones *et al.,* (1964) and Sherrington (1946) also took cognisance of the importance of primitive reactions in human motor behaviour.

The role of these reactions in posture is best summed up by Magnus (1926a: 536) when he stated that they form a group of actions:

> *.....by which the body musculature can be integrated for a contained and a highly adaptive function. The entire body follows the direction assumed by the head, this being very often moved in a certain direction under the influence of the teleceptive higher sense-organs. This provides one of the ways in which the relation of the body to its environment is regulated.*

Dart (1946), agreed with this view in the human, and preceded those of Fukuda (1961) when he portrayed the practical aspects of the righting and the neck reflexes thus:

> *The tutelage that results in skill is devoted, whether recognised or not by the participants, to the process of coordinating the existing attitudinal and righting reflexes of the body (well-, badly- or indifferently-integrated as they already may be), with new movements now being personally designed for the first time. But if the new sets of movements have an asymmetrical attitudinal effect on the body, and the body as a result of its previous neuro-muscular experience has already attained an oblique postural state (i.e. with a bias or slope in one direction whether rightward or leftward) or asymmetry the new movements can have no other effect, however seemingly accurate their performance, than further emphasising and consolidating the postural asymmetry resulting ontogenetically from previous faulty integration. Faulty attitudinal integration or imperfections in the use of both spiral sheets and in the ability to secure the balance or body poise essential for this truly skilled execution of movements is the general characteristic of all human beings at the outset. Unfortunately, we understand so little of the reflex*

> *nature of the body poise we should be aiming at when as infants, we are becoming erect, that we prevent the emergence of the underlying attitudinal and body-righting reflexes essential to acquiring postural poise. We acquire despite our asymmetrical rigidity a passable degree of skill for one that succeeds in satisfying us, without ever knowing or experiencing the postural poise for whose endowment nature consumed millions of years* (Dart, 1946: 11).

6.4.7 The inner ear and the upright posture

Alfred Tomatis, the renowned musicologist, viewed the ear as the key organ in humanity's development of a vertical posture (Campbell, 1997). From the very first vertebrate life, the ear has been used not only for auditory purposes but also to regulate movement. The evolvement of the ear from the fish to the human, brought about progressive development of the organs in the inner ear that aid in establishing motion, laterality and verticality. This process has been critical in the evolution of the human into a being able to move forward, backward, up and down, and side to side at will (Campbell, 1997). He described the ear as choreographing the body's dance of balance, rhythm and movement:

> *The ear choreographs the body's dance of balance, rhythm, and movement. From the simple motions of jellyfish through the complex activities of homo sapiens, the ear is the gyroscope, the CPU, the orchestra conductor of the entire nervous system. The ear integrates the information conveyed by sound, organizes language, and gives us our ability to sense the horizontal and the vertical* (Campbell, 1997: 53).

Through the *medulla* the auditory nerve connects with all the muscles of the body. Thus muscle tone, equilibrium and flexibility are also directly influenced by sound. Sitting or standing upright allows maximum control over the listening process and stimulates the brain to full consciousness (Tomatis, quoted by Campbell, 1997). The ear's vestibular function influences the eye muscles, affecting vision and facial movements. Disorders or weakness in the vestibular function may result in speech impediments, poor motor coordination, and difficulties in standing, sitting, crawling or walking (Campbell, 1997).

Tomatis, according to Campbell (1997), asserted that following the labyrinthine thread of sound through the ear and central nervous system, and comprehending the way in which the inner ear affects jaw movement and the ability to turn, to bend and situate ourselves in space, is central to an understanding of human development. One wonders whether speech followed erectness.

6.5 VISION

6.5.1 The role of vision in postural stabilization

Vision plays a major role in the multisensory process of postural stabilization. Physiologically it attenuates self-generated body sway by 50%. Unlike vestibular stimuli, which invariably lead to the sensation of body motion (and therefore require a postural reaction in order to maintain balance), visual stimuli provide for two perceptual interpretations: either self-motion or object-motion. The decisive visual signal that starts active postural correction of body tilt may be dependent, either upon relative image shift on the retina of the stationary visual surroundings, or on 'efferent motion perception' when fixating stationary targets (Paulus *et al.,* 1984).

Vision becomes of greatest importance when the ankle - foot proprioception is missing, for example standing on a soft, compliant surface or narrow beam. In addition, the view that vision is also more important than the vestibular function, is held by Brocklehurst *et al.* (1982) and Fernie and Holliday (1979).

The eyes endeavour to keep the visual axis stationary in spite of movement of the head. This is accomplished by the three pairs of voluntary eye muscles. Tilting the head but keeping the angles of the neck-joints constant, elicits the labyrinthine effect. The eyes tilt in their sockets and these movements are compensatory, like those in the acceleratory reflexes. The positional reflexes maintain the compensatory pose in the new position. Roberts (1978) concluded that the compensatory pose of the eyes during maintained inclination of the head, is due to the activity of the otolith organs.

Taguchi (1980) claimed that maintaining the eyes in the normal position is so important that the body's centre of gravity moves in order to keep the head steady. The head moves slower than the centre of gravity, and the head's movement is controlled by the body's centre of gravity. The head containing the brain, eyes and vestibular organs, must maintain its balance so as to fix the gaze upon an object. In this way one orientates one's position in space. In order to attain these functions, the centre of gravity seems to move appropriately. The head's movement in relation to the centre of gravity constitutes the mechanism of the righting reflex. This point of view puts vision and vestibular function on equal footing (also see Roberts (1978).

The dominant eye for verticality in healthy subjects is the left one and this causes oscillations of the body axis predominantly to the right, thus deviation of the body axis is predominantly to the right. This is not influenced by handedness as both left- and right-handed subjects share this trait (as do blind subjects). Cernacek and Jagr (1972) explained these findings based on the observations of the functional prevalence of the right hemisphere for non-verbal, optic, auditory and somatosensory stimuli, contrasting with the better performance of the left hemisphere in the verbal sphere. This could also be extended to the vestibular system and seems to be the most probable explanation of the greater frequency of the deviation of the body axis to the right. This again indicates a close connection between eye and ear.

Visual stabilization of posture is obviously dependent on the performance of the visual system. Paulus *et al.* (1984) found that decreased visual acuity causes increased postural instability, indicated by body sway, twice as prominent for fore-aft than for lateral sway. Any measurable visual contribution for fore-aft sway ceases with a visual acuity lower than 0.03 and for lateral sway with an acuity lower than 0.01. The central area of the visual field dominates postural control with the foveal region exhibiting a powerful contribution, particularly for lateral sway.

Visual input has an additional effect on postural stabilization. A partial but significant visual stabilization is preserved with a visual input rate between 1 to 4 Hertz flicker frequency. As soon as continuous motion perception becomes involved with frequencies higher than 4 Hertz, visual stabilization gradually improves with a saturation at frequencies higher than 16 Hertz.

Amblard, Crémieux, Marchand and Carblanc (1985) suggested the existence of two modes of visual control of lateral balance in man, which are well separated in terms of the frequency range of body sway: the first mechanism operates below 2 Hertz and seems to control the orientation of the upper part of the body; the second mechanism operates above 4 Hertz, centres on 7 Hertz and seems to immobilize the body working upwards from the feet. Thus static visual cues may slowly control re-orientation or displacement, whereas dynamic visual cues may contribute to fast stabilization of the body. Interesting enough in this respect is the observation by Begbie (1969) that peripheral vision is more useful than central vision in aiding balancing.

Eye-object distance and lateral body sway are linearly related - body sway decreases with increasing distance (Amblard *et al.,* 1985).

Visual surroundings play a definite part in the maintenance of posture control. Soechting and Berthoz (1979) claimed that vision had a powerful influence on postural control but stressed that other sensory cues in the control of posture should not be precluded. Their work indicated that vision plays an important, direction-specific role in the control of postural reactions during sudden perturbation of stance. When the linear acceleration is of short duration (less than 10 seconds), visual influences become apparent only when the visual information conflicts with other sensory inputs. Motion of the visual environment produces a greater effect when tested in the dynamic condition of postural change than when tested in isolation in a static posture maintenance condition. A moving visual scene produces an illusion of translation to a stationary observer (Berthoz, Pavad & Young, 1975) and such moving visual environments result in postural readjustments of the observer. A visual surround moving in the antero-posterior direction produces an inclination (pitch) of an erect person in the direction of surround motion (Lestienne, Soechting & Berthoz, 1977) (the pitch amplitude can be up to 3 degrees which is approximately 50% of maximal tolerable body pitch compatible with postural stability). Brain stem structures, particularly the vestibular nuclei, are involved in the mediation of these effects in primates (Waespe & Henn, 1977).

6.5.2 Vision and vestibular function in the maintenance of posture

The importance of vision in the maintenance of posture has been well documented as has been shown in the previous section. It is also generally accepted that the role of the vestibular system during quiet stance is primarily to solve problems of conflicting sensory information (Amblard *et al.,* 1985), and that chronic vestibular deficits, in the absence of conflicting sensory information, are relatively well compensated for in quiet stance by vision, vestibular information and proprioception (Diener, Dichgans, Guschlbauer & Bacher, 1986; Dichgans & Diener, 1989). In contrast the exact consequences of somatosensory loss on the control of posture remain largely undetermined (Paulus *et al.*, 1984). The latter reflects on the many forms of somatosensory input which originate from sensory receptors in the joints, muscles, tendons and skin (Simoneau, Ulbrecht, Derr & Cavanagh, 1995).

6.6 ORGANIZATIONAL HYPOTHESIS FOR THE SENSES

Interpreting sensory information and coordinating muscle reactions are, according to Nashner and McCollum (1985), analogous organizational problems; in both processes potentially endless computational problems must be simplified. This is to avoid too much neural organization and neural computation. Such a mechanism would be to break down functions for posture and movement control into functional elements which then are executed by specialized subsystems (Nashner, Shumway-Cook & Marin, 1983).

If one assumes that posture is organized into distinct strategies related to separate regions within the body position space, then there is a simple scheme for organizing sensory inputs to posture, based upon the information requirements of the muscle synergies. Specifically, it is possible to reduce complex multidimensional orientation information to a series of simple scalar quantities which map directly onto specific parameters of the muscle strategies (Nashner & McCollum, 1985). The positive supporting reaction in which a single CPG is involved and the neck reactions in which a number of CPG's are involved, (sections 6.3.2.1.1 & 6.3.2.3.2) are examples of such an arrangement. In the first example proprioceptive information from the foot is linked to the posture of the lower limb. In the second example the position of the head and neck is linked to body posture and position of the limbs. In the latter example the sensory input is probably not only linked to the individual CPG's controlling the functions of the various body parts, but also to a system which integrates the function of the various CPG's (See Figure 6.1). Effective functioning of CPG's is only possible, however, if sensory input is sufficient and appropriate. For the equilibrium control centres, information on the position of the head relative to the shoulders (see neck reactions, section 6.3.2.3.2) is of no value if information on the position of the shoulders relative to the actual supporting surface is not available (Lund & Broberg, 1983).

6.7 A CONCEPTUAL MODEL FOR THE CONTROL OF POSTURE

A conceptual model for the control of posture was compiled by Hayes (1982). The model assumes two function generators or GPG's. The first provides the antigravity torque commands (suspension CPG), while the other is responsible for postural sway (sway CPG). These CPG's influence the musculature of the lower legs according to fixed muscle synergies. The output of the two CPG's are controlled by input from higher centres (Denny-Brown, 1964). Feedback about ankle rotation, including input from muscle proprioceptors, pressure receptors (within joints and the vertebral column) and joint afferent, regulates the activity of the sway generator (Hayes, 1982; Horstmann & Dietz, 1990). Likewise is the activity of the suspension generator regulated by input from afferent about the knee joint (Hayes, 1982).

Visual, vestibular and somatosensory inputs, together with inputs from brain areas associated with aspects such as emotion (see chapter 7) all converge to influence the overall output level of the CPG's, and contribute to the plasticity demanded of the system. This is accomplished by changing the "gain" of the inputs from the various proprioceptors (Hayes, 1982). The then pre-established pattern reflects a central "model" of the movement task, including the anticipation of external loads and disturbances. When the task is well learned and conditions predictable, the nervous system will adapt its "model" to the task (Nashner, 1976).

6.8 THE ANTICIPATORY TRAITS OF POSTURAL CONTROL

6.8.1 Cortical representation of the body surface (neural maps)

One of the obstacles in improving posture, lies in the fact that each person has difficulty in perceiving his own stature. People do not know what they look like. Alexander (1987) solved this problem by using the mirror as his most powerful tool in his own postural re-education. However, the dimensions and shape of the body have long been thought to be coded in the activity patterns of topographic somatosensory maps in the thalamus and cortex of the brain. Within this neural framework, limb length and trunk contours are represented by the discharge patterns of neurons in particular areas of the neural maps (Martini, 1992; Meyer *et al.,* 1994). Research indicated that more than the activity of somatotropic neural maps is involved in the perceptual specification of body configuration. Indeed, it became apparent that spatial information about other parts of the body is also implicated, and that position sense and the body schema represent a collaborative interaction of multiple afferent and efferent domains. These can result in a multitude of apparent positions and orientations, real or illusory, being generated (Lackner, 1988). This seems to be corroborated by the work of Lestiene and Gurfinkel (1988) who found that the implementation of different postural tasks requires the knowledge of the state of many variables which cannot be directly signalled by specific receptors, for example, body segment length and the sequence of the segment linkage. They postulated a hypothetical central organization of postural regulation based on an internal model of the body. This "body scheme" is characterised by: 1) an inborn structural organization of the body, such as the upper and lower end of the body, left and right side, dorsal and ventral surface; 2) a system of references connected to both the vestibular system (absolute vertical) and visual and proprioceptive systems (proprioceptive vertical) and 3) a higher form of sensory organization akin to a "sensory envelope" formed from active movements and everyday experiences. The main function of the "body scheme" is to predict the state of the complex multicomponent mobile system of balanced elements. This prediction is conceived as a dialogue between the external world, the state of the body segments and the body scheme (Lestienne & Gurfinkel, 1988).

6.8.2 Modification of neural maps

Some investigators have shown that there is considerable plasticity in the neuronal representation of the body surface in the somatosensory cortex; in fact, the cortical maps of somatosensation are modifiable (Kaas, 1983). Although the receptive fields of particular neurons may remain fixed, this stable organization appears to be the result of balancing dynamic influences. When this balance is disrupted by inactivating part of the peripheral sensory input, the organizations of the cortical maps are immediately altered and continue to change over time. Thus, even in the adult, the maps of somatosensation are dynamically organized and potentially modifiable. Lackner (1988) found that perceptual representations of the body surface in the adult human could be greatly modified and perceptual remappings could be generated within seconds. The limbs, which are the more mobile parts of the body, seem to have representational priority in affecting the body schema and this may have considerable functional significance in the body schema during the course of development and probably also in learning.

In the course of development, the dimensions of the body change greatly. These changes continue to a lesser extent in adulthood with variations in body mass being a relatively common occurrence and other changes, such as a gradual diminution in height, being less frequent. The "maps" underlying position sense and somatosensation have to be recalibrated to take into account changes in body dimensions. Position sense could possibly be updated on the basis of sensory motor transactions such as the reach of the arm to bring it in contact with an object. Thus, position sense of the independently mobile parts of the body can be maintained through transactions with the environment. The rest of the body is not subject to the same degree of interaction with the external environment and it may be that its somatosensory representation is updated by contact with the motile appendages of the body (limbs and eyes) and the position of the hands and other parts of the body can be accurately determined in relation to the head (Lackner, 1988).

6.8.3 Oculomotor control

Lackner (1988) suggested that the above notions of position sense could also be applied to oculomotor control and that limb position information could be used in calibrating the direction of the gaze of the eyes, because it is known that the apparent position of the eyes can be influenced by information about limb position (Levine & Lackner, 1979).

Posture and occulomotion may be linked in an additional way. Kohen-Raz (1981) explored the relationship between posture and academic achievements. He proposed a theory why posture and reading should be correlated: It is assumed that certain cerebral and cerebellar mechanisms control, via the gamma efferent system, the scanning of minute temporal and spatial sequences. This takes place both in the domain of postural functions, as well as in basic oculomotor perceptual and cognitive processes involved in the decoding, interpretation and transmodel transfer of visual and acoustic patterns of signals and symbols.

6.8.4 Centre of gravity control

Posture, which is the position and orientation of the body segments, and balance, the control of the centre of gravity of the body, are coupled. Most postural adjustments change the location of the centre of gravity. During stance and movement, the central nervous system presumably controls body segment alignment in order to control the location of the centre of gravity. Thus the brain controls posture to maintain balance (Riley *et al.,*1990). Postural control is then the ability to maintain equilibrium and orientation in a gravitational environment (Crosbie, Durward & Rowe, 1996).

The human body may attain equilibrium in an almost infinite number of postures, though postural adjustments are invariably associated with purposeful movements. Coordination between posture and movement is a task where multiple goals have to be controlled simultaneously during the same motor act.

6.8.5 Anticipatory postural adjustments

Gurfinkel and Shik (1973) noted that changes in postural activity have not only a compensating, but also an anticipatory character. The latter is essential since movement of the limbs, for example, can displace the body's centre of gravity, and anticipatory postural adjustments are known to occur to reduce instability (Forget & Lamarre, 1990).

On the basis of behavioural data and reaction time, a theory was formulated by Woollacott, Bonnet, and Yabe (1984), that changes in the activity of supraspinal structures activating postural muscles are triggered by preparatory advance information. Massion *et al.,* (1998) referred to this as anticipatory postural adjustments. Both peripheral and central mechanisms are used to guide responses to anticipated postural perturbations (Horak, Diener & Nashner, 1989) These responses usually precede the macro-movements and take into account the expected result of the movement. More recently it was stated that a prerequisite for understanding what is controlled by the anticipatory postural adjustments is to define which goals are achieved by these anticipations (Massion *et al.*, 1998).

When a voluntary movement is performed while standing, the muscle activation and the kinematic changes are not restricted to the segments which are the targets of the voluntary command, but also concern other segments involved in the control of the posture and equilibrium of the whole body. Voluntary bending movements of the trunk, for example, are accompanied by associated movements of hip and knee (Pedotti, Crenna, Deat, Frigo & Massion, 1989). It was found that during fast forward and backward bending, the onset of EMG activation or inhibition of not only the prime mover (trunk flexors or extensors), but also of the lower limb muscles involved in the associated movements (ankle, knee and hip flexors and extensors), clearly precedes the onset of the kinematic changes in any segment, indicating that they are all centrally programmed. Pedotti *et al.* (1989) concluded that the performance of movements which greatly disturb the maintenance of equilibrium is associated with the control of multijoint segments through synergies involving a given set of muscles. Prewired postural synergies responsible for the performance of fixed postural tasks probably exist, but a flexibility exists among the synergies regarding the timing of the onset of muscle activation and the combination of muscles involved. It has been suggested by Nashner and McCollum (1985) that only six muscle synergies are required for the control of balance in any direction: forward and backward ankle and hip synergies and upward and downward suspensory synergies. Anticipatory postural adjustments are achieved by a very limited set of muscle synergies and these postural synergies are organized at a lower level of the motor system hierarchy (Gahery & Massion, 1981). Cordo and Nashner (1982) proposed a separate central command for postural and focal muscle activation (executing a push or pull task). This is because time is needed for focal muscle activation and not for postural muscles. The timing is controlled by the central nervous system (Brown & Frank, 1987).

Most anticipatory postural adjustment goals are aimed at minimizing the postural or equilibrium disturbance provoked by a voluntary movement, for example during a load-lifting task the goal of the anticipatory postural adjustment is to provide a stable postural reference frame during the task. Two parallel controls exist, one for the postural anticipation and the other for the load-lifting movement. The main role of the voluntary movement is to provide a timing signal for the disturbance to occur. The highest control level is related to the selection of the postural reference position for the task to be performed by the moving hand. A lower level of control is in charge of executing the movement as well as the anticipatory postural adjustments. The motor field under control during the anticipatory postural adjustments is compatible with a change in the point of equilibrium. The anticipatory postural adjustments are based on a motor memory built during the acquisition of the task. The memorized motor skill is lateralized and not transferable (Massion *et al.*, 1998).

In the upper trunk bending paradigm, a single coordinated control exists, achieving simultaneously the movement and the postural adjustment. The central control would be simultaneously addressed to the various joints involved in the task, whether they contribute mainly to the movement or to the associated postural adjustment. Thus, there is an integration between postural and movement control.

This single, coordinated control would result from experience and practise. At the end of the acquisition process, a motor skill would have emerged from the interaction between the learned central command, the assisting feedback loops and the dynamic interaction between segments (Massion *et al.,* 1998).

Woollacott *et al.* (1984) proposed a model representing possible psychological processes and neurophysiological mechanisms underlying preparation and initiation of postural adjustments associated with voluntary movements. The preparation is the selection of the appropriate primary (movement of the arm, for example), and postural response synergies from a predetermined alternative (for example push or pull). The central circuits involved in the activation of these response synergies are progressively organised during the preparatory period after the selection process has taken place, and direction-specific changes occur only in the central circuits. It is suggested that the postural synergy output initially inhibits the primary synergy output (Cordo & Nashner, 1982). The reasons for this conclusion are that subjects sometimes responded with a postural output without subsequent activation of the primary synergy, and ageing subjects may activate a primary synergy without previous activation of the postural synergy and subsequently lose balance. Woollacott *et al.* (1984) thus proposed the existence of a possible inhibitory mechanism operating in the normal young adult, which delays the voluntary output until after the beginning of the activation of the postural synergy. Also, the postural system is modulated by preparatory processes.