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THE ANATOMICAL AND PHYSIOLOGICAL BASIS OF PHYSICAL TRAINING *

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In view of the recent interest shown by the State in problems of physical education it may be profitable to consider certain anatomical and physiological facts which so far have not been given the prominence and forethought they demand. I propose to consider certain anatomical features and growth changes in the spine, the upper limb girdle, and the lower limb girdle, together with certain physiological principles in relation to posture. Agility, strength, and dexterity are useful servants but dangerous masters. Any collection of skeletons in a museum shows a high percentage of aged females and a higher percentage of adventurous inquisitive young males.

The Spine

As Ward (1876) said: "The vertebral column is a remarkable piece of mechanism. Strong enough to support several hundredweight, yet pliant and elastic: furnished with levers and muscles, by which it is bent in every direction, yet lodging an organ susceptible to injury from the slightest pressure: formed, for lightness, of a loose and reticular tissue, yet capable of sustaining, without fracture, shocks, strains, and contortions of considerable violence: this column certainly combines the most opposite qualities, and performs functions apparently incompatible."

In the infant each vertebra consists of three bony parts, a centrum and two lateral masses, separated by the neurocentral articulation, which consists of a plate of cartilage faced on both sides by a thin layer of calcified cartilage (Harris, 1933). The presence of three tissues so different in physical properties as bone, cartilage, and the intervening calcified cartilage is in itself a source of mechanical weakness in each vertebra. Active growth in size of the vertebra takes place at the neurocentral articulation (Fig. 1). The cartilage plates grow in thickness, cartilage is calcified and replaced by bone: the three constituent parts of the vertebra are carried further apart. The cartilage plates are true epiphysal plates, and are therefore subject to all those injuries and diseases which take place in the fast-growing epiphysal plates of the long bones. Bony union of the centrum and lateral masses to form the definitive vertebra by calcification and

ossification of the neurocentral articulation is completed by 6 years of age.

In later childhood the spine consists of individual bony vertebrae, covered above and below by cartilage plates, and separated from one another by intervening fibro-

FIG. 1.—Radiograph of typical thoracic and lumbar vertebrae in the lamb to show the cartilaginous neurocentral articulation between the centrum and the right and left lateral masses. The spinal canal is larger than in the adult sheep.

cartilages. At puberty certain changes take place. Annular epiphyses of bone appear in the cartilage plates above and below each vertebra, so that the vertebra now consists of bone, epiphysal bone, epiphysal cartilage, and calcified cartilage (Figs. 2 and 3). This increase in the heterogeneity of the tissue elements in the spine accounts for its special susceptibility to deformity and disease in puberty and adolescence. Kyphosis, lordosis, and, in particular, scoliosis appear. The vertebra with its superior and inferior epiphysal bony annuli is not consolidated by cessation of growth, calcification, and ossification of the epiphysal cartilages and final union of the annular epiphyses until about 23 to 24 years, when all growth has ceased in the long bones.

The growth in length of the spine as a whole is most rapid in the first two years of life, when it increases from eight inches to sixteen and a half inches. Growth is then fairly regular and does not show the spurts which are registered so frequently in the lower limb. The adult spine in the male approximates closely to twenty-eight and a half inches and in the female to twenty-four and a half inches. Growth in the spine is not truly proportional, but takes place at varying rates in different parts,

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particularly during the first seven years of life. Roughly speaking, at birth the cervical, lumbar, and sacral parts of the spine each contribute one-fifth of the total length, the dorsal or thoracic region occupying two-fifths. From birth to adult life the spine increases in length by three and a half times, but whereas the cervical region

FIG. 2.—Model of the lumbar vertebrae in man and sheep in the position of extension to show the relative proportions of the fibrocartilaginous disks, the vertebrae, and the bony epiphysal annuli or plates which lie above and below each vertebra with an intervening plaque of growth cartilage.

FIG. 3.—The same models in section to show the increased thickness of the fibrocartilaginous disk and the reduction of the plate-like epiphysis of the sheep to an annulus in man. The nucleus pulposus is nearer the posterior surface of the vertebra and may be dislocated posteriorly.

increases threefold the lumbar region increases fourfold, so that the greatest growth is in this region and is associated with the great growth in the lower limb—the skin, musculature, and joints of which are largely supplied by lumbar nerves.

The growth in transverse dimensions of the spine is determined essentially by the growth in the spinal cord. At 6 years of age the spinal canal is larger than in the adult and the spinal cord is almost adult in cross-section.

This precocity in growth of the spinal cord determines the time of onset of calcification and ossification in the neurocentral synchondrosis. Moreover, the epiphysal rings above and below each vertebra are an index of the attempt so to modify and control the growth of the spine that spine length shall be almost constantly twenty-eight and a half inches in the male and twenty-four and a half inches in the female, in accord with a spinal cord length of eighteen inches and sixteen and a half inches respectively. This relative lack of variation in spine length in the two sexes accounts for the trade in ready-made shirts, coats, and corsets, of given length but varying girths. Throughout puberty and adolescence the spine does its utmost to reach its normal length, irrespective of stature.

The Intervertebral Disks

The intervertebral disks are more complicated in structure than the vertebrae themselves. The nucleus pulposus at the centre is essentially a remnant of the primitive notochord. This is surrounded by the annulus lamellosus, which consists of concentric lamellae of fibrous tissue, some of the fibres circular, some spiral. Above and below this element are two cartilage plates bounding the adjacent vertebrae. Some fibres are inserted into the cartilage plate, some into bone, and some into the anterior and posterior common longitudinal ligament. George Murray Humphry (1858) described the nucleus pulposus as a "fluid ball girt by surrounding bands of fibrous tissue . . . which the adjoining vertebrae rotated in their movements on one another." This ball-bearing function of the nucleus pulposus is of the utmost importance, for the disks as a whole are more susceptible to age changes and to injuries than the bony vertebrae themselves.

The growth of the intervertebral disks is extremely interesting. At birth the nucleus pulposus is small and the disk is relatively narrow. The lamellae of fibrous tissue develop after birth and are distinct entities at 6 months, when the child is first able to hold up its head. With age the fibrous rings grow at the expense of the adjoining cartilage plates. At birth approximately one-third of the total length of the spine is due to the disks, which are practically half as deep as the individual vertebrae. At 7 years of age and on to adult life the disks account for one-fifth of the total length, so that they are roughly one-quarter the depth of the vertebrae. But the thickness varies considerably in different parts of the spine. Between the shoulders, in the upper thoracic region, the disks are thin, in accord with the reduced movements of flexion and extension in the vertebrae of a region subjected to the pull of the large muscles of the head and neck and upper limb. The disk between the second and third cervical vertebrae is thinnest of all. In the lower dorsal region the disks gradually increase in thickness, reaching their maximum in the lumbar region. This is due partly to the range of movement between the neighbouring vertebrae and partly to the large area of the contiguous surfaces which naturally tends to restrict the range of movement.

From birth to adolescence the total depth of the disks increases from 0.3 in. to 0.7 in. in the cervical region, from 0.65 in. to 1.45 in. in the dorsal region, and from 0.42 in. to 1.7 in. in the lumbar region. Thus the outstanding feature of the spine in man is the great size of the lumbar vertebrae and still more the thickness of the lumbar disks. In all quadrupeds the epiphyses of the vertebrae are relatively thick plates instead of rings, and the disks are relatively thin. Only in man and the great apes are the plates reduced to rings and the lumbar

disks increased so much in thickness. The range of movement and the large cross-sectional area in the lumbar and lower cervical spine are associated with the attempt to assume and maintain the erect attitude. Man alone has massive lumbar vertebrae, thick lumbar disks, annular epiphyses, huge buttocks, massive quadriceps, and long lower limbs. Even the gorilla, chimpanzee, and orang have failed to grow buttocks. It is only within recent years, as the result of the earlier isolated studies of Schmorl (1931) in Dresden, that the frequency of lesions in the intervertebral disks has been appreciated. More than 80 per cent. of these lesions are in the lumbar region, according to a recent report from the Mayo Clinic (Walsh and Love, 1939).

Most of the exercises found in the handbooks of physical training, if employed without due care and supervision, may tend to abuse these recently acquired and peculiarly human features of the spine. Toe-touching and trunk-twisting are fraught with danger, particularly at such ages and in such types of build as are characterized by relatively long legs and short arms. Mobility of the spine, like the back view of the torso, is largely an individual characteristic. The rough-and-tumble of ball games is less dangerous than squad drill or organized "jerks."

The Upper Limb

The shoulder-blade in childhood consists of two bony elements—the scapula and coracoid—separated by a band of actively growing cartilage. Thus the shoulder-joint comprises on the one hand the head of the humerus and on the other the glenoid cavity, consisting of two elements separated by an intervening band of cartilage, the scapula occupying two-thirds and the coracoid one-third. This cartilage is a growth cartilage and allows the glenoid cavity to grow in accord with the head of the humerus. In all the main joints of the body Nature attempts to provide facilities for growth by arranging that a convex surface on one bone shall articulate with a concave surface on another two or three bones, these bones being separated by a growth cartilage. Like all growth cartilages, the intra-articular ones are separated from the adjoining bone by a narrow band of calcified cartilage. It follows that the shoulder-joint of the growing child is much more complicated than that of the adult, in that the glenoid contains two bones, coracoid and scapula, and the articular cartilage overlies growth cartilage, calcified cartilage, and bone.

During puberty the growth cartilage ceases to grow, calcifies, and ossifies. It is at this age, when the scapula and coracoid are becoming firmly knit, that the muscles of the neck and upper limb display active growth. The development of the neck and chest is rapid, as is that of the biceps and triceps. The boy begins to "throw his weight about" in more senses than one.

Union of the epiphyses takes place at the elbow earlier than at the wrist and shoulder. Thus fairly heavy muscular work involving the elbow-joint, such as bench work, is more easily faced by the adolescent than heavy muscular work involving the wrist and shoulder, such as coal-mining, quarrying, and heaving. Any undue load on the musculature of the upper limb, such as frequent and persistent throwing of the cricket ball, or carrying a heavy hod of bricks up a ladder, is to be deprecated; for not only is there danger to the upper limb itself, particularly the shoulder-joint, but there is danger to the upper thoracic and cervical spine, to which are attached the muscles involving violent movements, such as the

trapezius, and the muscles involving fixation, such as the rhomboids. Abuse of the upper limb muscles is a threat to the slender upper thoracic spinal column and the enclosed spinal cord.

Pelvis and Lower Limb

The sacro-iliac joint is formed by the auricular surface of the ilium and that of the sacrum. The sacral surface is complex, and consists of the bony costal elements of the first three sacral vertebrae, separated by fibrous tissue and cartilage. The ossification centre for the first and second sacral "ribs" is present before birth and that for the third "rib" appears soon after birth. At puberty a thin epiphysal bony plate appears in the cartilage on the auricular surface of the sacrum. This bony plate unites relatively late in adolescence and is associated with the late date of union of the first and second sacral vertebrae. Thus the sacro-iliac joint is definitely one in which the age changes and the number of separate elements involved are such as to call for the greatest care in its use. The common practice in secondary schools for girls to spend hours in jumping over a high rope is to be deprecated. Lastly, since the sacro-iliac joint is devoid of a cavity lined by synovial membrane it is, like almost all the vertebral joints, one which can be injured or diseased without pain becoming a cardinal symptom. The fact that pain may be absent in joints which are injured or diseased should be continually present in the minds of physical training instructors.

The hip-joint in the child displays the general rule that a joint will be formed if possible between more than two skeletal elements. The convex spherical head of the femur articulates with four other elements consisting of ilium, ischium, pubis, and the triradiate cartilage which separates the three constituent bones. In all animal forms the triradiate cartilage is a true growth cartilage and is separated from the neighbouring bones by thin strips of calcified cartilage. About puberty the growth cartilage ceases to proliferate, calcifies, and ossifies. The ossification is often patchy, and so accounts for the irregular features displayed radiologically in the cartilage by the so-called os acetabuli. Thus, from puberty to adolescence the hip-joint is even more complicated than the shoulder-joint. The bearing surface in the acetabulum, by reason of the growth at the triradiate cartilage, gives rise to many of the deformities and diseases of the pelvis. The hip-joint is often considered only in terms of the head of the femur. The hip-bone is forgotten.

Mention should be made of the cartilage at the conjoined ischio-pubic ramus, over which is attached the crura of the penis. Union of the two rami by calcification and ossification of the cartilage usually takes place at about 8 to 10 years of age. This area of union is liable to disease, and is particularly liable to injury by falls on the edge of a chair, rail, fence, gymnastic apparatus, or by jumping on to a bicycle. Such injury or disease is difficult to diagnose, and may eventually appear as an abscess in the adductor muscles or an osteomyelitis following an osteochondritis. Injury of any part of the pelvis may lead to bony union of the sacro-iliac joint on one or both sides.

The first thoracic nerve and ulnar nerve in association with cervical rib, and the fourth and fifth lumbar nerves in association with sacralization of the fifth lumbar vertebra, and several other anatomical anomalies, call for special care. Space does not permit a detailed account, but one may say that the ulnar nerve and the lower two lumbar nerves are always living dangerously.

Need for Caution in Physical Training

I do not wish to be regarded as an opponent of all forms of physical training, but the anatomical and physiological basis of such training is a subject which calls for cautious research on the part of all concerned. As Cathcart *et al.* (1935) state, no certain index of physical fitness, industrial or other, has yet been discovered. It is essential that we should ask if the boys and girls of this country are to be submitted to as expensive and unproductive a course in physical training as that to which they have been subjected in Latin and French. Many children in Wales have learnt to speak Welsh and English at home by 3 years of age without tears and without specialist teachers. Countless children have learnt to play, to work, and eventually to support themselves and a family without being subjected to lifting, throwing, hitting, gripping, swinging, bending, and twisting by numbers in regimental formation. To be born in a comfortable nest, den, or house, to have adequate food and unorganized free play—these are Nature's own essentials for physical training.

The ideal of *mens sana in corpore sano* is essentially a demand for two distinct attributes of mind and body that are not necessarily closely related. Between intelligence and common physical measurements such as height and weight there is but a low correlation, which decreases still further during adolescence. There is practically no correlation between mental intelligence tests and the physical measurements most commonly studied in children. There is a positive correlation between the mental test scores and the precocity of puberty in school children. On the other hand, slow rate of development is a peculiarly valuable human feature: apples which ripen most slowly last longest.

No two children progress towards maturity at the same pace, yet natural forces have a way of reducing the differences to some extent as maturity is approached. It is an impossible and unnecessary task to make all children conform to a standard rate of growth, to attain a standard developmental pattern or a standard physical performance test in terms of age.

Chronological age in itself is a snare, for the most developed of a group of 9-year-old children will often be more mature than the most immature of a group of 12-year-olds. Attempts at substituting skeletal age in terms of ossification of the carpus and hand, or mental age in terms of intelligence tests, are equally dangerous. Children are parts of the group in which they live, but they are also individuals who have a right to develop at their own pace.

Posture and Attitude

"Posture" is not a question of physical exercises, physical jerks, or training of the muscles. Posture is essentially the *nervous* (not *muscular*) mechanism which "keeps the world right side up for the organism by keeping the organism right side up to the external world" (Sherrington, 1906), as a result of the co-ordination of visual and labyrinthine stimuli with stimuli from the proprioceptive nerve endings in muscles, tendons, and joints. The midbrain contains the important group of centres concerned in the acquirement and maintenance of equilibrium and posture.

"Posture is the solid foundation upon which perception is built, and it is of such pre-eminently vital importance to the animal that it is subserved almost entirely, even in Man, by a dyscritic (protopathic) mechanism. Posture is a relatively

static condition, maintained indefinitely so long as circumstances remain relatively unaltered: so far it demands a plastic pose, subserved by tonic impulses and muscular contractions. Posture on the verge of change assumes a dynamic aspect and becomes an *attitude*, in which the distribution of tone in various muscles is in a sense precurrent—prepared for active movement" (Parsons, 1927).

Even attitude, posture on the verge of change, is subserved almost entirely by a protopathic mechanism.

Much of the physical drill is directed towards the acquirement of an attitude rather than the maintenance of a pose. The soldier on parade too often exhibits attitude—not posture. The maintenance of attitude involves continuous conscious endeavour. The maintenance of a natural posture is automatic and involves the minimum of mental and physical fatigue. A natural "posture" does not lead to fainting; a forced "attitude" may, as is so well known on parade or at morning prayers. If one watches a group of children playing "blind man's buff" one may see and analyse the various elements concerned in the maintenance of posture. The "righting reflexes" can be classified as:

1. Labyrinthine reflexes tending to restore the position of the head to the normal.
2. Reflexes arising in the muscles of the body wall so that, if the trunk be bent to the right, muscle tonus is increased on the left as a preparation for restoration of the trunk and head to the erect position.
3. Reflexes arising in the muscles of the neck as a result of the reflexes initiated in the labyrinth with a view to rapid restoration of the position of the head on the neck, irrespective of the position of the trunk and limbs.
4. Reflexes arising in the muscles of the trunk and limbs as a preparation for the necessary movement to maintain balance and equilibration.
5. Reflexes arising in the retinae with a view to acting on the muscles of the neck, trunk, and limbs in such a way as to retain the visual field so far as possible in its normal orientation.
6. Reflexes arising in the skin of the soles of the feet.

The extent to which the visual mechanism is concerned is clearly seen in the different movements, particularly of the upper limbs, in the blindfolded and the normal child. The effect is still more exaggerated if the ground surface becomes more rough and irregular, or if the blindfolded one is spun a few times, and even more so if the child is blind in one eye, deaf in one ear, crippled in trunk or limb, wry-necked, or suffering from cold feet. The maintenance of posture is controlled in most mammals by the midbrain. In fact, it is entirely so in the guinea-pig and rabbit. The visual cortex of the cerebrum is concerned with the ocular "righting" reflex to an increased degree as one passes from cat, dog, and monkey to man. One may regard the maintenance of posture as fundamentally a protopathic mechanism which in man has become augmented by an epicritic mechanism dependent upon the ocular reflexes and the power of binocular vision localized in the visual cortex.

In assessing alike the stance and the poise of children it is important to remember that the widely accepted appreciation of military "smartness" has no anatomical or physiological basis. Military drill is designed to make a group of different individuals look alike and act alike synchronously. It is the worship of uniform and of uniformity. Physical training should involve something distinct from regimentation. It should aim at the cultivation of the maximum efficiency consonant with the neuromuscular equipment of the individual.

The feats of daring, of physical and mental endurance, the lonely watches and the forced marches, whether at the Equator or the Poles, on the Himalayas or in the Arabian Desert, have been a product of the spirit of the British race, not of the gymnasium or the barrack square. Drake, Cook, Scott, Lawrence, and Somerville are not the product of any system of physical education or sport. Among the golden words of the English language are those in Captain Scott's farewell letter to his wife:

"Make the boy interested in natural history if you can; it is better than games: they encourage it at some schools. I know you will keep him in the open air.

"Above all, he must guard and you must guard him against indolence. Make him a strenuous man."

Bodily Habitus, Constitution, and Health

In the Report on the Primary School (Harris, 1931), when discussing the four physical types—hypersthenic, sthenic, hyposthenic, and asthenic—it was emphasized that any one type of bodily habitus and visceral topography cannot be radically altered. Concentration should be directed towards making each child efficient within his group. In view of recent attempts to classify children in terms of psychological characters in relation to bodily habitus a word of warning is necessary. There is much nonsense talked about "constitutionalism." Prejudices, beliefs, sentiments, and that authoritarianism which is the pitfall of the educationist play a large part in the prevailing fashionable beliefs. The canons of statistical sampling are rarely satisfied, and it is essential that much of the fashionable talk about the pyknic child or the asthenic child, particularly in relation to his mental and emotional qualities, should be recognized as the result of amateurism and unwarranted speculation. In a recent survey of 500 asthmatic and 500 rheumatic children in one of the large hospitals (Young, 1933) no distinct difference in anthropometric measurements or body build was found.

Mankind has always been dominated by a belief in the mental significance of particular physical features. Chaucer, Shakespeare, and Dickens have impressed upon us an association of this type. Modern playwrights, novelists, and, above all, the cinema, exaggerate it. At present there is no scientific evidence that any of the accepted criteria of the relation of mental qualities to physical traits are sound. Goring (1913) effectively destroyed the belief that the possessor of the "high brow" was more intelligent than he of the "low brow." Pearson (1906) has proved that "it is impossible to use head size as a basis for judgment as to intelligence." He proved that eye colour and hair colour are as closely related to intelligence as are head diameters.

The intelligence tests of Binet, the study of skeletal development by x rays, the measurement of height and weight of the body, and of the head in particular, have yielded nothing more definite than that little correlation exists between mental and physical status. On the other hand, the various attempts to correlate the type of body build with temperament have been somewhat more successful. Draper (1930) in America is of the opinion that certain types of body build are associated with a predisposition to certain diseases. Kretschmer (1925) in Germany connects body build with temperamental disposition. It is probable that Alfred Adler's (1938) theory of "organ inferiority," based upon a demonstrable physical deficiency, is the only field in which definite correlation has been proved between physique and temperament.

In short, apart from disease of the central nervous system and grave physical defects, the prevailing notions as to the relation of *mens sana* and *corpus sanum* have been grossly exaggerated. Malnutrition, poverty, dirt, and even a succession of acute or chronic diseases do not seem able, of themselves, to subdue the master organ of the body, the brain, to any considerable extent. On the other hand it is obvious that malnutrition, poverty, dirt, disease, and war do wipe out individuals, families, and races. The effect on the race or the breed should not be confused with the effect on the brain of the individual.

The psychological effects of class gymnastics have not been considered any more than the psychological effects of grooming, dress, and personal adornment. The present problem is anatomical and physiological. Growth, development, posture, like health, depend to a large extent on the freedom for the individual to join in any play, game, or sport, to exert himself according to his powers, and to know when he has had enough. Food, fun, and frolic are of more importance than drill and discipline.

Summary

The pattern of growth in the spine, upper limb, and lower limb is described.

The difference in the structure of the spine in man from that of quadrupeds is discussed in its relation to the assumption of the erect attitude in man.

Posture is considered as a nervous mechanism, and emphasis is laid on the importance of the "righting reflexes."

The fixity of bodily build or habitus in an individual is emphasized.

Food, play, and free unorganized games in early childhood are discussed in their connexion with healthy growth and physical training.

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Asthma.—In thirty-seven of fifty unselected cases of bronchial asthma from a clinic for allergic cases an emotional component could be seen in the aetiology of their attacks. The thirteen others were predominantly young males. Of those with a large emotional component only 20 per cent. were benefited by somatic therapy, as against 54 per cent. of the "non-emotional group." Thirty of the patients showed long-standing neurotic traits, usually of an obsessional character.—Psychiatric Survey of Fifty Cases of Bronchial Asthma. T. N. McDermott and S. Cobb.—*Psychosomatic Med.*, April, 1939, 1, 203.