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The Biomechanics of Running

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It is our purpose to present certain aspects of body mechanics that affect running performance. The patterns and the types of running are so varied that it would be presumptuous to think that anything other than general principles could be discussed here. Basically, the objective of running is to gain increased speed and mobility. Speed is dependent on the length of the stride times the number of strides per minute. By definition, a running stride is a complete cycle of motion consisting of a period of weight-bearing or support on one foot followed by a period of non-weight-bearing or float, then a period of weight-bearing on the other foot and another period of float. This may be contrasted with walking, in which each period of support on one foot is followed by a period of double support when weight is borne on both feet. The distance covered by the runner in the phase of support is limited to the distance covered by the body as it pivots over the lower extremity. Of course, this is enhanced by the increased leg length provided by the extended foot and by the flexibility of the spine that permits the runner to reach farther backward at time of take-off. Naturally, it is greater in individuals who have long legs in relation to the other parts of the body. The distance spanned during the period of float is greater than that during the period of support and may be varied at the will of the runner by the force exerted at the time of take-off. Take-off starts at the time that the center of gravity passes forward of the metatarsal heads in the ball of the foot and ends when the foot leaves the ground. A more forceful thrust at the time of take-off with the subsequent increase in the distance covered in the period of float is what takes place when a runner is seen to increase his speed without changing the cadence of his stride. Mobility is dependent upon the ability to change the direction of the line of progression through lateral movement. It is not the purpose here to discuss the effect of age, strength, maturity, somatotype, reaction time, mechanical advantage of muscle insertion and bone structure, etc., but to apply some well-known postural principles to running gait.

The body posture in running is adapted to the purpose of the sport. For example, in track, speed and endurance alone are required, for the center of gravity is little affected by outside forces and movement consists essentially of straight, forward motion. Therefore, the trunk is carried in an upright position and the feet track directly under the body along the line of progression, and equilibrium is maintained through postural control. On the other hand, in such sports as football, the center of gravity is in constant danger of upset from the impact of body contact and the need for sudden change in direction of movement. Under these conditions the trunk is carried relatively low, and the feet are more widely spaced for sta-

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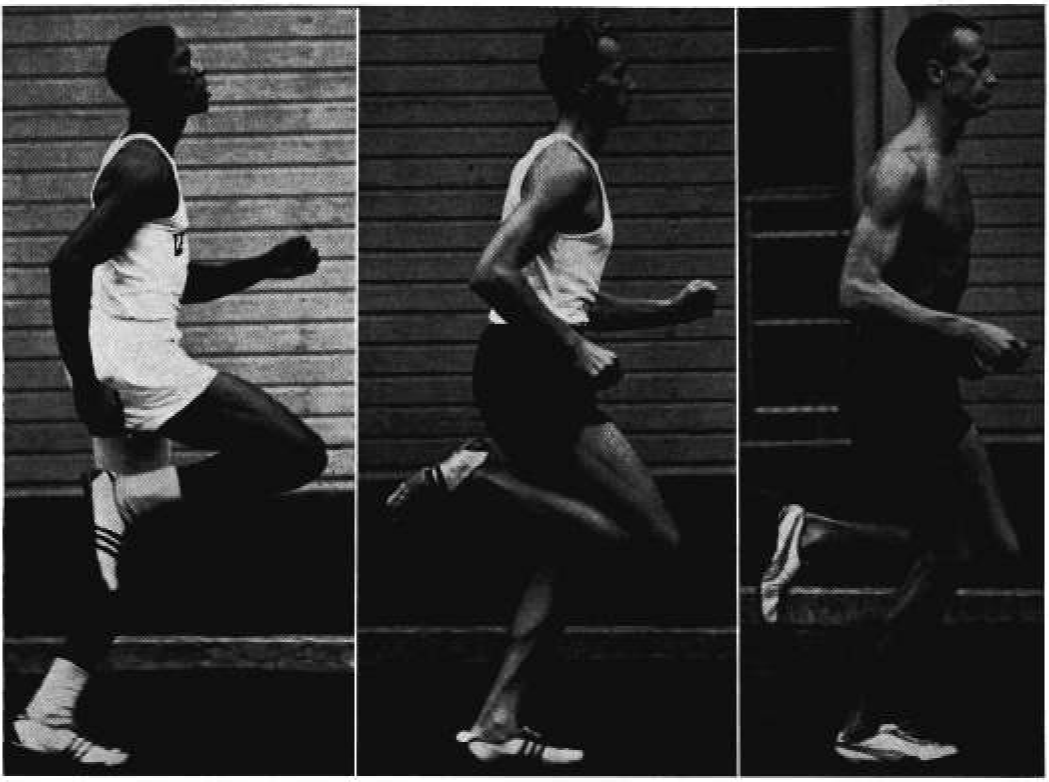

FIG. 1. The erect posture with the flexed, flat-back position of the lumbar spine preparatory to the synchronous extension of foot, ankle, knee, hip and lumbar spine favors maximal backward thrust by the trailing leg. Three running styles are demonstrated by (*left*) the world 400-meter champion, (*center*) the Canadian 800-meter champion and (*right*) the United States mile and 1,500-meter champion. (Slocum & Bowerman: AMA, Proceedings of the 2nd Annual Conference on the Medical Aspects of Sports, p. 53, Washington, D.C., 1960)

bility and meeting the demands of lateral movement. This need for lateral movement requires a variation in gait also, for only when the foot is in contact with the ground can the direction of movement be changed; therefore, the stride is shortened and the cadence accelerated, so that the periods of support are more frequent and of longer duration in relation to the length of the stride. It is only when the danger of body contact is over that the player assumes the upright position and more extended stride consistent with greater running efficiency and speed.

The position of the pelvis is the key to postural control in running. This has long been recognized in standing and walking gait, but it has not been applied generally to running. The position of forward or backward rotation of the pelvis controls the motion of the lumbar spine, the degree of flexion of the hip relative to the ground, and the degree of outward rotation of the hip. It is a well-known principle of postural correction that forward rotation of the pelvis results in extension of the spine in the sway-backed, lordotic position, increased internal rotation of the thighs, secondary lowering of the longitudinal arch, a relative lessening of the ability to flex the hip in relation to the ground, and a forward shift of the center of gravity so that weight falls more heavily on the ball of the foot. In contradistinction, backward rotation of the pelvis results in flexion of the spine into the flat-backed position, increased ability to rotate the thigh externally, increased hip flexion, and a backward shift of the center of gravity so that weight falls more toward the heels.

Hildebrand, in his analysis of the running of animals, has stressed the prime importance of spinal movement. It plays an equally important role in the running of the human species. It is commonly assumed that the leg from the hip joint distalward provides the length, the motive power and the range of motion necessary for running. Setting aside this assumption, consider the concept that it is the leg plus the pelvis and the low back from the lumbar joint complex distalward that provides these elements. It takes little imagination to appreciate the increase in extensor thrust given the weight-bearing leg in take-off. The lower-extremity lever system is lengthened to all intents and purposes, for a more proximally placed joint complex becomes the pivotal point; the motive power now is augmented by the strong musculature of the trunk; and, last but far from least, the range of motion is increased, for, where the extension of the hip is limited normally to 20° to 30° by the strong anterior capsular ligaments, the working range of extension of the lumbar spine is normally some 40° to 45° from the flexed position (although the total range of motion is somewhat greater.) If it is granted that some added motion of the lumbar spine is desirable, and that it acts through the pelvis by providing additional extension, it becomes evident that the starting position for this motion must be the flat-backed, flexed position of the lumbar spine. It also becomes evident that this starting position must coincide with the time of mid-support, i.e., when the supporting leg is almost directly under the body, if the lumbar spine is to participate effectively in the co-ordinated extension of hip, knee, ankle and foot, which provides the thrust during takeoff. In addition to allowing a wider range of lumbar flexion and extension, this flat-backed position facilitates spinal rotation as well. When an individual runs, the spine undergoes a twisting motion: the lower spine rotates backward with extension of the trailing leg, while, at the same time, the upper spine rotates forward synchronously with the arm on the same side to maintain equilibrium. Actually, this twisting motion is two counterhorizontal rotations about the same axis at different levels and may be likened to the countertwisting of both extremes of a flexible rod. Simple experiment shows that such an action is carried out more easily and more efficiently about a relatively straight rod than on a curved one. The flat-backed, erect position of the trunk effects a straighter axis and at the same time affords a slightly greater degree of rotation in the lumbar spine, which in the extended lordotic position is restricted by the vertebral articular facets that act as anatomic doorstops to motion.

The value of increased external rotation of the hip in lateral movement often escapes attention. In the type of running most used in the contact sports, such as football and basketball, lateral movement, either when the body moves away from the supporting foot or the non-weight-bearing leg moves away from the supported body to seek more lateral placement of the foot, is essential to effect a sudden change of direction or maintain equilibrium. The orthopaedist has long noted that in the treatment of postural flat feet, excessive internal rotation of the thigh occurs together with lumbar lordosis, and that such flat feet are refractory to treatment unless the forward pelvic tilt is corrected so that further external rotation can be achieved. This interrelation of pelvic tilt and thigh rotation can readily be seen by observing the internal and the external rotation of the foot in the following simple test:

Stand in the normal erect position with the weight on both feet, then lift the right foot just above the ground. Now roll the pelvis forward (clockwise as seen from the right

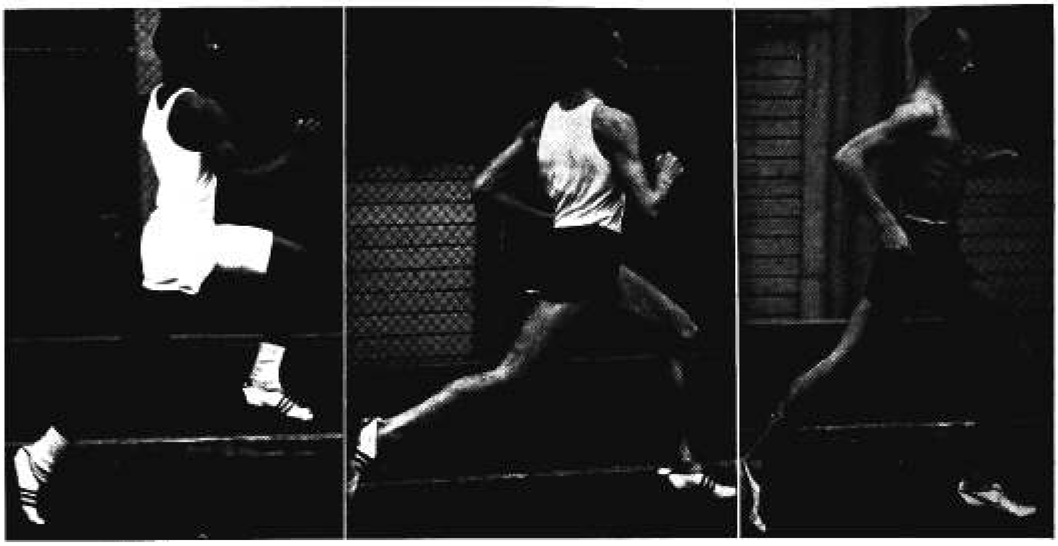

FIG. 2. The same athletes demonstrate the continued erect posture, the extension of the lumbar spine into the sway-backed position, and the counterrotation of the spine with backward movement of the pelvis and forward motion of the upper spine and shoulder as the trailing leg passes into full extension. (Slocum & Bowerman: AMA, Proceedings of the 2nd Annual Conference on the Medical Aspects of Sports, p. 53, Washington, D.C., 1960)

side), throwing the lumbar spine into the lordotic position; note the increased internal and decreased external rotation of the hip as demonstrated by the rotation of the foot. Next, roll the pelvis backward to the flat-backed position and observe that the range of external rotation is increased materially while internal rotation is decreased correspondingly.

Track embraces highly specialized types of running designed for maximal speed and endurance. The smoothness and the efficiency of the stride, which mark good running form, are the result of minimal body displacement in the vertical and the frontal planes and in the sagittal plane of maximal forward displacement of the body at takeoff and minimal deceleration by the leading leg at foot strike. The forward displacement of the body is not to be confused with forward lean.

There is little question that the less the vertical displacement of the body, the greater is the efficiency of the runner. Energy is not wasted in lifting the body upward with every step but is concentrated largely on thrusting it forward into the float phase of the stride. In the frontal plane, side-to-side sway should be kept at a minimum to lessen the burden borne by the postural muscles in maintaining equilibrium and to sustain the trunk in a position of greatest working efficiency. It should be noted that the gravitational line of weight must fall through the supporting foot, and that the upward projection of this line must divide the body weight into two equal halves if the runner is to maintain balance and not fall to one side or the other. Lateral balance is best achieved when the weight-bearing foot falls in the line of progression and the head is carried directly above this line, for in this position the least compensatory shift of the body segments is required for balance. If the supporting foot falls to either side of the line of progression, a postural shift of body weight must be made in that direction to maintain equilibrium. If the head is not kept over the line of progres-

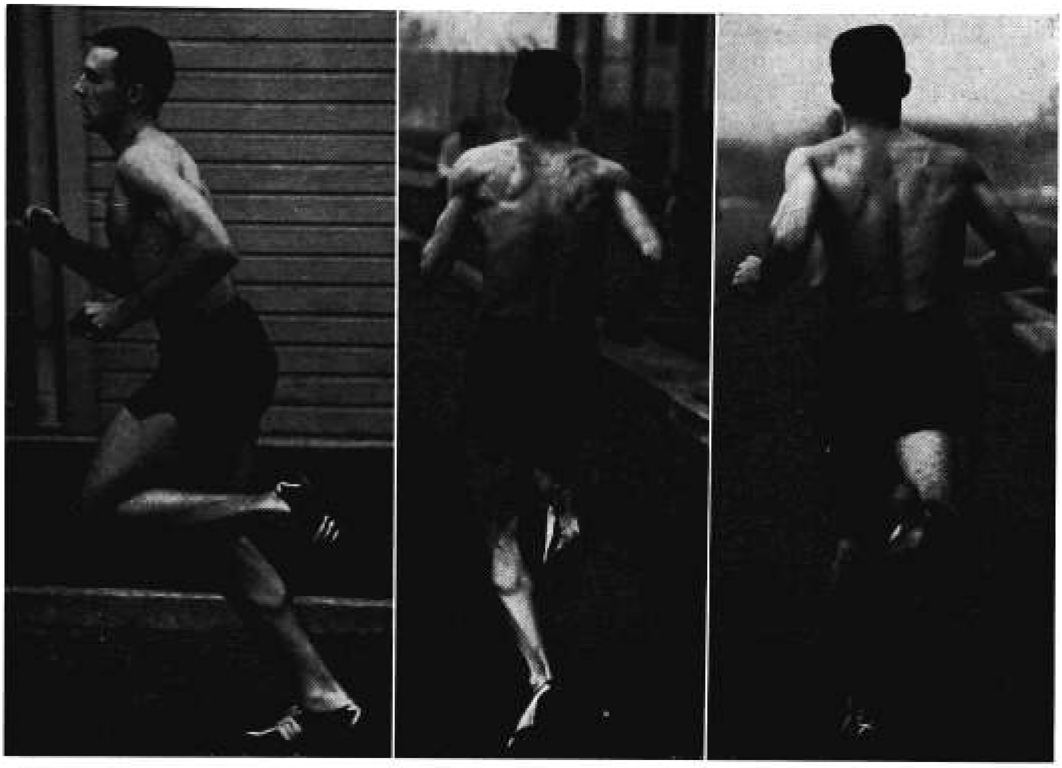

FIG. 3. Postural deviations in running. (*Left*) The forward lean prevents full use of the lumbar spine extension, decreases flexion of the hip in relation to the ground, and shifts the center of gravity forward. (*Center*) Crossing the left foot over the line of progression necessitates shift of the body weight to the right. (*Right*) Placing the left foot lateral to the line of progression causes a shift of body weight to the left to place the center of gravity over the supporting foot. Note the compensatory abduction of the right arm. (Slocum & Bowerman: AMA, Proceedings of the 2nd Annual Conference on the Medical Aspects of Sports, p. 53, Washington, D.C., 1960)

sion, body weight must be shifted. Similar adjustments must be made to counterbalance abducted leg or arm.

In the sagittal plane, i.e., looking at the runner from the side, the hip and the knee of the leading leg are in maximal flexion at the time of take-off, then go into partial extension—the degree varying with the individual runner. The entire leg must be moving strongly backward at the time of foot strike in order to lessen resistance at impact and avoid deceleration. This backward movement is imperative for two reasons. The first, of course, is obvious. If the leg were not moving backward, the forward movement of the runner would cause it to thrust against the ground as it struck. The second is a matter of having the foot more nearly under the body at the time of impact. A simple force diagram will reveal that the farther ahead of the body the foot strikes the ground, the more acute the angle of the leg with the ground and the greater the deceleration from ground resistance. Therefore, it follows that any effort to gain a slightly longer float phase by stretching out to position the foot farther ahead of the body will be of no avail, for the benefits of the longer float are negated by the increased ground resistance at foot strike. During the period of mid-support the lumbar spine, hip, knee, ankle and foot are in flexion preparatory to the synchronous burst of lower-extremity extension that occurs during take-off to project the body into the phase of float. The position of the trunk as viewed from the side should be essentially erect, for this position favors the flat-backed position of the lumbar spine in mid stance preparatory to take-off, requires less effort in maintaining postural equilibrium and provides good respiratory position and free movement of the scapula on the thoracic track.

The principal causes of forward shift of the center of gravity in the trunk are technic, fatigue and malposture. In sports other than track and in nonsports running, the load must also be considered. From the viewpoint of technic, the forward lean often is taught on the theory that the forward concentration of weight is an aid to the forceful, forward projection of the body at takeoff, and that it minimizes the vertical component of the thrust. It disregards the fact that in this position the 60 per cent of the body weight that is concentrated in head, arms and trunk must be supported rather than balanced by the postural muscles, that the full working range of the lumbar spine is not utilized to aid in extending the leg, and that flexion of the hip is relatively decreased because of the pelvic tilt that accompanies forward lean. It should also be noted that in this position weight falls more heavily on the ball of the foot at foot strike. This imposes an additional load on the calf muscles and the flexors of the foot, for now they must lower the foot to the ground so that it can support the concentration of weight. This diminishes the recovery interval between the major contractions of these muscle groups and contributes to fatigue. Since a study of some excellent runners, including three world-record holders, an American and a Canadian record holder, and three others who have been recent Olympic competitors, has demonstrated that the erect trunk posture with a flat back in mid support is consistent with good running performance, doubt could be cast on the validity of the forward-lean theory.

It is readily agreed that adaptations may be necessary when certain physical abnormalities exist. If spinal flexibility is poor and extension must be largely through hip-joint action, or if there is a flexion contracture of the hip so that the burden of extension is placed on the lumbar spine, a compensatory forward lean may be indicated.

Malposture may limit the effective use of the lumbar spine-pelvic unit. When lumbar lordosis is present, regardless of etiology, the lower and more mobile segments of the lumbar spine are held in a partially extended position. This will diminish the amount of remaining extension that may be contributed to take-off. If the lordotic position is habitual, secondary contracture of the lumbar fascia may be present and, by its checkrein action, may limit the spinal flexion to the flat-backed position that is required as a starting point for full extension of the lumbar spine. At the same time the habitual lordosis favors contracture of the soft tissues at the front of the hip that, if fixed, become a further barrier to extension. It goes without saying that such a situation will not be conducive to maximal performance, and that a corrective postural program is in order.

SUMMARY

The mechanics of running gait have been described with special emphasis on the importance of pelvic posture and lumbar spinal motion on performance.

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Le Biomechanica del Currer

Summario in Interlingua

Le mechanica corporee in su application al currer ha recipite pauc attention del parte del investigatores qui deberea esser interessate in tal questiones. In le presente articulo le autores se propone discuter certe factores que illes considera como importante in effortios de meliorar le performance del currer. Le plus importante de istos es le facto que le columna lumbar e le pelve pote esser usate pro allongar le passo, de maniera que le propulsion dynamic ad in le phase del planation (in que nulle del pedes es in contacto con le solo) es providite non solmente per le gamba (ab le coxa ad le pede) sed profita etiam del complexo articulatori del columna lumbar con su 40 grados de angulation o mobilitate. Es etiam considerate le position del corpore in relation al movimento lateral e certe factores biomechanic in le prespectiva del planos vertical, frontal, e sagittal.